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Institute of Agricultural Economics, Belgrade, (Serbia)
Академија економских наука, Букурешт (Румунија)
Academy of Economic Studies, Bucharest (Romania)
Национални институт за економска истраживања „Costin C. Kiritescu“ – Румунска академија, Букурешт (Румунија)
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Адреса уредништва / Editorial office
Београд, Волгина 15; тел/факс (+381)11/6972-848; E-mail: economicsofagriculture@ea.bg.ac.rs
Belgrade, Volgina 15; phone/fax (+381)11/6972-858; E-mail: epoljoprivrede@gmail.com

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ECONOMICS OF AGRICULTURE

CONTENT

PSYCHOGRAPHIC AND BEHAVIOURAL SEGMENTATION OF WINE CONSUMERS

Jelena Krstić[1], Milan Radojičić[2], Sonja Veljović[3]
**Corresponding author E-mail: pecic84@hotmail.com*

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A B S T R A C T

The purpose of this article is to identify specific market segments of wine consumers based on their demographic, psychographic and behavioural characteristics. The data was collected through an online survey of 269 wine consumers in Serbia. The data were analyzed by using multivariate statistical methods (factor analysis and clustering) in conjunction with descriptive and inferential statistics (Chi-square test, one-way ANOVA, independent t-test). Three consumer segments were identified by applying a TwoStep cluster analysis: Casual consumers, Recommendation responsive consumers and Wine enthusiasts. In terms of demographic characteristics, education, place of residence and household type were found to be significantly different among consumer groups. Findings can be used as a basis for the development of effective promotional campaigns targeted at specific consumer segments.

Introduction

With its pleasant flavour and aroma, wine is considered a predominantly hedonistic product with various characteristics that determine its overall quality (Veljović et al., 2021). In general, wine quality is determined only after opening the wine and tasting it, so predicting wine consumers' preferences and attitudes is highly recommended. Consequently, the need for screening wine consumers is emphasised with the aim of providing insights into the factors that determine consumption. Wine consumers'

1 Jelena Krstić, PhD, Senior Research Associate, Institute of Economic Sciences, Zmaj Jovina 12, 11000 Belgrade, Serbia, Phone: +381601129974, E-mail: jelena.krstic@ien.bg.ac.rs, ORCID ID (http://orcid.org/0000-0001-8876-8513)

2 Milan Radojičić, PhD, Assistant Professor, Faculty of Organizational Sciences, Jove Ilića 154, 11000 Belgrade, Serbia, Phone: +381698893410, E-mail: milan.radojicic@fon.bg.ac.rs, ORCID ID (http://orcid.org/0000-0002-6727-7608)

3 Sonja Veljović, PhD, Assistant Professor, University of Kragujevac, Faculty of Hotel Management and Tourism, Vojvođanska 5a, 36210 Vrnjačka Banja, Serbia, Phone: +381646398321, E-mail: pecic84@hotmail.com, ORCID ID (http://orcid.org/0000-0001-6408-9153)

preferences are not only shaped by perceptual or intrinsic wine attributes, but by the integrated influence of multiple factors related to wine consumption, such as social characteristics and influences, individual behavioural factors and interpersonal factors (e.g. culture, values) (Carollo et al., 2022).

Among the various factors that influence the quality of wine, the aging process is one of the most important for production of high-quality products (Canas et al. 2022) The common practice is that the vast majority of wine is aged in oak barrels for a long period (several months to several years), this technological process is called natural aging (Ma et al. 2022). During the aging process, the contact (e.i. time of aging) between the wood surface and the wine is crucial for developing pleasant sensory characteristics of the wine. However, among the EU's regulatory framework, Spanish wine regulations more precisely define aging requirements for different wine classifications. According to aging requirements, aged Spanish wines are classified as Young, Roble, Crianza, Reserva and Grand reserva (EC, 401/2010). In Serbian, the Wine Law («Sl. glasnik RS», 2012) defines two traditional label «mlado» and «reserve» (or «archive»). Young wine can be sold no later than March 31 of the year following the year of grape harvest. Reserve is an additional designation in the category of premium wine with controlled and guaranteed geographical origin. Although the EU countries are the most globally important producers of wine, only the Spanish regulation have a classification of wine based on aging requirements.

Nowadays, the constant decline in per capita consumption of wine (Villanueva et al., 2017) is evident in all wine-producing countries in Europe. A dramatic decline in wine consumption for one decade of around 50% is also reported for the Republic of Serbia (OIV 2025). In order to improve market presence and increase the consumption of Serbian wine, it is, therefore, necessary to gain a deeper insight into the wine market structure. Market segmentation is a valuable tool for gaining a better understanding of consumer characteristics and behaviour, which is a basis for developing effective marketing strategies for specific market segments. Consumer-related information, such as consumer profiles and perceptions, could be used by wine producers and marketers as a tool for better decision making and the development of appropriate marketing techniques (Chu et al., 2020). In this sense, the aim of this article is to identify specific market segments of wine consumers in Serbia based on their demographic, psychographic and behavioural characteristics.

Literature review

Segmentation studies serve as valuable source of information regarding different groups of people formed based on their knowledge, attitudes, sociodemographic, geographic and professional characteristics. Market segmentation studies are also common in the wine industry on a global level. There are various segmentation criteria, but the most common are demographic, psychographic and behavioural criteria. The psychographic criteria relate to lifestyle and personality traits, while behavioural segmentation is based on segmentation criteria such as consumption patterns, consumption occasions, benefits sought and the like (Geraghty & Torres, 2009). Some studies use only psychographic or behavioural segmentation approaches, while others combine the two to create more specific market segments.

Psychographic segmentation of wine consumers

Bruwer et al. (2002) developed a wine-related lifestyle (WRL) instrument for the purpose of segmenting the Australian wine market and identifying different wine-related lifestyle segments of consumers. The WRL research tool was further developed and improved by Johnson and Brewer (2003), Bruwer and Li (2007) and Bruwer and Li (2017) and used for the purpose of consumer segmentation based on a wine-related lifestyle approach. Geraghty and Torres (2009) conducted a segmentation study of the Irish wine market using a lifestyle segmentation approach that included lifestyle values, product attributes, and purchasing and consumption patterns. One of the most recent market segmentation studies, also conducted in China by Yabin and Lee (2020), combined the demographic criteria with the wine-related lifestyle (WRL) approach, resulting in five different market segments. One of the most recent studies, conducted by Bekar and Benzergil (2025) used the Values and Lifestyles Attitudes Scales to reach specific psychographic types of wine consumers in Turkey.

Koksal (2021) conducted a segmentation study on Lebanese wine customers using consumers' level of engagement with wine as the main criterion for segmentation, as well as socio-demographic characteristics and wine-related behaviour. The segmentation study conducted by Brunner and Siegrist (2011) on a sample of Swiss consumers used the criteria of consumer involvement, lifestyle and motivation. Wiedmann et al. (2014) found that consumers in Germany belonging to different age groups have different values, involvement and wine consumption. A survey of Spanish consumers aimed at identifying the most important attributes considered when choosing wine found that these attributes differ between segments with different demographics (Bernabéu et al., 2012). Pomarici et al. (2017) analysed a sample of American consumers with the aim of segmenting them based on their preferences for different wine attributes and their psychographic characteristics.

Johnson and Bastian (2007) identified different segments of Australian consumers based on purchasing characteristics and consumer knowledge. Using subjective knowledge as the main criterion for segmentation, a survey of young, urban wine consumers in the Republic of North Macedonia identified three distinct consumer segments, which also differed significantly in terms of wine consumption behaviour and information-seeking habits (Hristov & Kuhar, 2015). Bo Liu et al. (2014) conducted a study in China in which they used product preferences and preferred sources of information as the main criteria for segmentation. Cicia et al. (2013) conducted a study in the Russian wine market based on consumers' wine preferences and their requirements for wine quality. A study conducted on a sample of wine consumers on the Croatian mainland, using purchasing power and brand sensitivity as the main criteria, identified specific segments of wine consumers with different characteristics in terms of wine purchase and consumption (Kalazić et al., 2010).

A study conducted in Spain indicated four segments of wine tourists which tend to Spanish wineries (Molina et al., 2015). Cruces-Montes et al. (2023) developed an attitudinal scale of the consumer outlook toward wine consumption, on the basis of their study on Spanish consumers and pointed out three dimensions - health consumption, social consumption and wine experience. Lameiras et al. (2026) conducted a segmentation of wine tourists in Portugal and identified four clusters based on motivation and psychographic characteristics. Santos et al. (2020) conducted wine consumer profiling in Portugal on the basis of on their wine product involvement and identified three clusters: high, medium, and low involvement.

Behavioural segmentation of wine consumers

A study based on behavioural segmentation was conducted with a sample of consumers from New Zealand and revealed three distinct buying groups (Thomas & Pickering, 2003). Johnson and Bastian (2015) developed and used an instrument to assess the purchasing and consumption behaviour of wine consumers in Australia (FWI). In a large-scale survey in Hungary, different segments of wine consumers were identified based on their preferences, consumption and purchasing habits (Hlédik & Harsányi, 2019). Bo Liu et al. (2014) segmented the Chinese wine market into three wine consumer clusters based on a behavioural (utility) criterion.

In the study conducted in Germany, the sales channels were used as the most important segmentation criteria together with the average purchase value (Szolnoki & Hoffmann, 2014). A study conducted by Berni et al. (2005) in Denmark was based on occasion-related criteria in connection with wine consumption. Another study aimed to identify consumer segments in the Italian wine market by using the hedonic price model as a segmentation criterion (Caracciolo & Furno, 2020).

By examining the frequency of wine consumption, preferred type of wine, and reasons for disliking wine, Thach and Olsen (2006) segmented a sample of consumers in Northern California. In their later study, these authors examined the characteristics and behaviours of frequent wine consumers in the US and distinguished between high, moderate and low spenders by using price segmentation (Thach & Olsen, 2015). Cho et al. (2014) conducted a large-scale study on a sample of wine buyers in the United States to examine the impact of wine tourism restrictions on consumers' preferences and behavioural intentions when visiting wine-growing regions and found groups with significantly different preferences and intentions. A study conducted in British Columbia, Canada, examined the total number of market segments for California red and white wines based on price dispersion (Carew et al., 2017).

Materials and methods

The study was conducted using an online survey of a convenience sample of wine consumers in Serbia and took place from May to September 2022. As a recruitment method, the researchers' professional networks were used to overcome the low response rates associated with surveys in general, including online surveys (Bo Liu et al., 2014). The only inclusion criterion for participation was previous consumption of wine. Participation in the survey was anonymous and no sensitive personal data was collected.

The core of the study was a questionnaire comprising 48 questions. The questionnaire contained three main sections. The section on psychographic characteristics contained questions on wine knowledge, wine preferences, preferred origin of wine, wine preferences, reasons for wine consumption, desired outcomes of wine consumption and wine-related characteristics. The section on behavioural characteristics included questions on wine consumption habits and wine purchasing. The final section of the questionnaire included demographic variables. A 7-point Likert scale was used for the questions on psychographic characteristics, i.e. respondents were asked to indicate the extent to which they agreed with the statements on the various elements of the questionnaire.

The analyses were carried out using the statistical software package IBM SPSS 23. The data were analysed using multivariate statistical methods in conjunction with descriptive and inferential statistics. A TwoStep cluster was used with the aim of identifying segments of wine consumers. This approach was also used by other authors investigating similar topics, such as Szolnoki (2018) and Hlédik and Harsányi (2019). The relationship between the clusters and the demographic variables was analysed using a chi-square test for independence.

Results

The total sample comprised 269 respondents. The sample was predominantly female, as it comprised 188 female and 81 male respondents. The average age of the respondents was 38.97 years. The majority of respondents came from Belgrade (48.7%) and smaller cities (24.2%). In terms of household structure, the majority of respondents are married with children (39.4%). Purchasing power is mainly in line with the national average (65.1%), while it is 25.3% above the average. The average amount spent monthly on the purchase of wine is €32.27 (Std. Deviation 41.059).

Reducing the number of variables

The first step of the analysis was to reduce the number of elements and obtain a set of factors that could then be used for segmentation. Separate factor analyses were conducted for the segments relating to psychographic and behavioural variables. An appropriate number of factors were identified by applying parallel analysis (Horn 1965) as recommended by various researchers (Knekta et al., 2019; Lim & Jahng, 2019). The suitability of the data for factor analysis was tested using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of Sphericity.

A factor analysis was conducted with 16 items related to self-reported knowledge and interest in wine and yielded a factor explaining 59.21% of the total variance (KMO = .946; Bartlett's test = 3739.71, $p < 0.001$). The items were originally defined by

Johnson and Bastian (2007) and Brunner and Siegrist (2011). This factor was labelled as originally named, "subjective knowledge about wine". The second factor analysis was applied to six items relating to attendance at wine events. The items were originally defined by Brunner and Siegrist (2011) and Bruwer and Lin (2016). The analysis resulted in a factor that explained 72.66% of the total variance and was named „wine events" (KMO = 0.848, Bartlett's test = 1430.50, p < 0.001).

For six items related to selectivity, the importance of geographical origin and the importance of countries of wine production, originally defined by Johnson and Bastian (2015), a factor analysis revealed a factor explaining 60.96% of the total variance, labelled „constituency related to wine" (KMO = 0.854; Bartlett's test = 738.37, p < 0.001). The factor analysis for the 51 items related to the reasons for wine consumption defined by Brunner and Siegrist (2011) revealed five factors that explained 58.15% of the total variance (KMO = 0.920; Bartlett's test = 10395.11, p < 0.001). Based on the item factor loadings, these five factors were assigned the following labels: "hedonism»," "social acceptance and showing off»," "health aspects of wine drinking", "mood" and "habit".

The group of items related to consumption loaded on two factors that explained 62.84% of the total variance (KMO = 0.869; Bartlett's test = 1723.03, p < 0.001). One of these was called "consumption on special occasions" and the second factor from this group was entitled "consumption at home and in restaurants". The next step in the analysis related to the attributes that respondents look for when buying wine. For 39 items from this group, the factor analysis revealed five factors that explained 70.44% of the total variance (KMO = 0.931; Bartlett's test = 10456.38, p < 0.001): "wine origin", "labelling information", "appearance", "recommendations", "positioning". Finally, factor analysis was applied to six items related to the purchase of specific wine brands and from specific wineries, five of which were developed by Pomarici et al. (2017) and one of which was added by the authors. One factor was found to explain 65.05% of the total variance, which was labelled "loyalty" (KMO = 0.872; Bartlett's test = 960.28, p < 0.001).

In order to test the reliability and internal consistency of the factors determined, a reliability analysis was carried out using Cronbach's alpha. Cronbach's alpha was between 0.878 and 0.967, indicating a high degree of reliability (Shelby 2011). The 16 constraint factors identified using the factor analysis were used as classification variables in the further analysis.

Clusters development

In the subsequent phase of the analysis, a cluster analysis was carried out using the 16 factors identified, with the aim of identifying specific segments of wine consumers. TwoStep cluster was used for the classification (Bacher et al., 2004). Classification using TwoStep cluster is a relatively novel approach to segment wine consumers (Hlédik & Harsányi, 2019; Szolonoki, 2018). This data-driven approach to determine the number of clusters using Schwarz's Bayesian Information Criterion (BIC) is suitable for working with a large sample.

The analysis resulted in three clusters. The Silhouette measure of cohesion and separation was 0.2, which according to Kaufman and Rousseeuw (2009) represents sufficient cluster quality. The first cluster (Casual consumers - CC) comprised 68 respondents, the second (Recommendation responsive consumers - RR) 116 respondents and the third (Wine enthusiasts - WE) 85 respondents. The characteristics of the three consumer segments are presented in the following sections.

The final cluster centres and the importance of the predictors for 16 variables for three clusters are shown in *Table 1*. In addition, a one-way ANOVA was conducted to compare the means of the factors in these three clusters (Cho et al., 2014). The results were significant for all factors except loyalty ($F = 0.325$, $p = 0.723$).

Table 1. Final cluster centres and predictor importance of variables

Factors	**Cluster centres**			**Predictor importance**
	Cluster 1	**Cluster 2**	**Cluster 3**	
Subjective knowledge about wine	-.78	-.34	1.09	1.00
Wine events	-.67	-.40	1.07	.91
Label information	-1.12	.25	.55	.68
Pickiness in terms of wine	-.74	-.25	.93	.67
Consumption in special occasions	-.97	.07	.68	.57
Wine origin	-1.02	.23	.5	.53
Hedonism	-.89	.03	.68	.49
Habit	-.44	-.33	.8	.41
Recommendations	-.88	.22	.41	.36
Consumption at home and at restaurants	-.72	.01	.57	.31
Positioning	-.69	.15	.34	.21
Social acceptance and showing off	.05	-.33	.41	.12
Appearance	-.43	.01	.32	.10
Health aspects of drinking wine	-.34	-.08	.39	.10
Mood	.33	-.20	.02	.05
Loyalty	-.06	-.01	.07	.00

Source: Authors

As cluster 3 scored highest on all factors except ‘mood’ and as consumers from this cluster appeared to have a greater knowledge of wines, attended wine events, chose wines of particular origin and consumed wines on many occasions, it was labeled as Wine enthusiasts (WE). The first cluster had the lowest scores on all factors except ‘mood’, where it scored highest, and was therefore labelled as Casual consumers (CC). The second group had neither the highest nor the lowest score on any of the factors, but due to the second highest score on “recommendations”, “wine origin” and “labelling information”, they were labelled as Recommendation responsive consumers (RR).

Description of segments

Chi-Square tests of independence were used to analyse the differences between the clusters in terms of socio-demographic characteristics and wine consumption preferences (Cho et al., 2014; Hlédik & Harsányi, 2019; Szolonoki, 2018). The demographic characteristics of the three clusters and the results of the chi-square tests are shown in *Table 2*. Among the demographic characteristics, education ($\chi2$ = 21.343, p = 0.002), place of residence ($\chi2$ = 15.092, p = 0.020) and household type ($\chi2$ = 19.160, p = 0.038) were found to be significantly different when comparing the consumer clusters. Although consumers with higher education dominated in all three clusters, significant differences were found. While most (44.1%) of Casual wine consumers had a university degree, slightly less than one-fifth had a secondary school degree, which was significantly higher than in the other two groups. In the group of Wine enthusiasts, there was a high percentage of respondents with a university degree and respondents with master's and doctorate degrees (40.4%, 29.4% and 27.1% respectively). In addition to respondents with a university education (34.5%), the group of consumers responding to recommendations had the highest percentage of respondents with a doctorate (30.2%), followed by respondents with a master's degree (24.1%).

Table 2. Descriptive statistics of the clusters (Chi-Square Test)

	CC (%)	RR (%)	WE (%)	$\chi2$
Gender				5.313
Female	77.9%	71.6%	61.2%	
Male	22.1%	28.4%	38.8%	
Age				6.988
19-29	16.2%	10.3%	16.5%	
30-39	41.2%	52.6%	38.8%	
40-49	23.5%	23.3%	31.8%	
50-59	14.7%	10.3%	10.6%	
60+	4.4%	3.4%	2.4%	
Education				21.343**
Secondary	23.5%	11.2%	3.5%	
College/university	44.1%	34.5%	40.0%	
Master	20.6%	24.1%	29.4%	
Doctorate	11.8%	30.2%	27.1%	
Place of residence				15.092*
Capital city	51.5%	44.8%	51.8%	
Larger city	10.3%	15.5%	25.9%	
Smaller city	27.9%	25.8%	20.0%	
Settlement	10.3%	14.7%	2.4%	
Employment status				2.380

	CC (%)	RR (%)	WE (%)	χ2
Employed	82.4%	87.9%	90.6%	
Unemployed	17.6%	12.1%	9.4%	
Household type				19.160*
Single	20.6%	16.4%	7.1%	
Couple without children	10.3%	12.9%	27.1%	
Living with parents/siblings	23.5%	18.1%	15.3%	
Single parent with child/children	7.4%	2.6%	5.9%	
Couple with child/children	32.4%	44.8%	37.6%	
Other	5.9%	5.2%	7.1%	
Purchasing power				6.026
Below average	8.8%	9.5%	10.6%	
Average	76.5%	62.1%	60.0%	
Above average	14.7%	28.4%	29.4%	

* p<0.05; ** p < 0.01 *Source: Authors*

The majority of respondents in all three clusters lived in the capital. In groups CC and RR, respondents from smaller cities were represented in second place (27.9% and 25.8%), while respondents from larger cities were represented in second place (25.9%) in the group of WE. In terms of household type, CC were mainly couples with child(ren) (32.4%) and people living with parents/siblings (23.5%). Among WE, the largest proportion of respondents were couples with one or more children (37.6%) or without children (27.1%). Recommendation responsive consumers were mainly couples with child(ren) (44.8%) or living in households with parents/siblings (18.1%). Similarly, comparisons of clusters were made based on the preferred wine type, the origin of the wine and the preferred wine type by ageing criteria (*Table 3*).

Table 3. Comparison of clusters based on preferred wine type/origin (Chi-Square Test)

	CC (%)	RR (%)	WE (%)	χ2
Preferred type of wine				
White	36.8%	37.9%	31.8%	17.372*
Rose	5.9%	8.6%	4.7%	
Red	30.9%	36.2%	27.1%	
White and red equally	14.7%	12.9%	31.8%	
Other	11.8%	4.3%	4.7%	
Wine origin				

	CC (%)	RR (%)	WE (%)	χ2
Domestic wine	55.9%	53.4%	57.6%	
Wine from the region	10.3%	15.5%	20.0%	
Wine from traditional producing countries	4.4%	11.2%	7.1%	11.576
Wine from nontraditional producing countries	0.0%	0.0%	1.2%	
Not important	29.4%	19.8%	14.1%	
Preferred type of wine according to ageing criteria[4]				
Young wine	8.8%	6.0%	14.1%	
Roble	2.9%	11.2%	7.1%	
Crianza	13.2%	15.5%	24.7%	20.821*
Reserva	8.8%	18.1%	14.1%	
Grand reserva	5.9%	3.4%	7.1%	
Not important	60.3%	45.7%	32.9%	

* $p<0.05$; ** $p < 0.01$ *Source: Authors*

Statistically different results were obtained regarding the preferred type of wine across clusters. The results indicated that the greater number of CC (36.8%) expressed preferences for white wine, although the percentage of those preferring red wine was not much lesser (30.9%). In cluster of WE, equal percentage of respondents (31.8%) preferred white and equally red and white wine, whereas the preference for red wine expressed 27.1% of them. Almost equal percentage of respondents belonging to RR group preferred solely white (37.9%) or red wine (36.9%). In general, respondents expressed low preference for rose or other types of wines. As regarding wine origin, no significant differences were obtained. Regarding preferred type of wine according to ageing criteria, there were statistically significant results obtained. For majority of CC respondents (60.3%), ageing was not an important factor. The second frequent choice was “crianza” which was selected by 13.2%. WE expressed the highest preference (24.7%) for crianza wines among all three segments, even though the percentage of those who did not consider wine age as important was slightly higher (32.9%). Slightly less than a half of RR respondents did not pay attention to wine age, while the second most often option was “reserva” (18.1%).

In addition, comparisons were made of clusters based on behavioural patterns, such as: frequency of wine consumption, number of glasses per consumption, average price paid per bottle, consumption patterns (weekly), consumption occasions, satisfaction with wine selection and wine prices in the domestic market, and the maximum price one would pay for a bottle of barrique wine (*Table 4.*).

4 Young wines are typically released within a year and have minimal or no oak aging. Roble wines require at least 12 monthes of aging, with a minimum of 6 months in oak. Crianza wines require a minimum of 24 months of aging, with a minimum of 6 months in oak barrels. Reserva wines - a minimum of 36 months of aging with a minimum of 12 months in oak barrels. Gran Reserva requires 60 months of aging, with a minimum of 18 months in oak.

Table 4. Comparison of clusters based on behavioural patterns (Chi-Square Test)

	CC (%)	RR (%)	WE (%)	χ2
Frequency of wine consumption				103.263**
Every day/almost every day	2.9%	0.9%	12.9%	
Often (3-4 times per week)	4.4%	12.9%	35.3%	
Frequent (once a week or less)	14.7%	38.8%	38.8%	
Occasionally (once a month or less)	36.8%	37.1%	11.8%	
Rarely (at least once every 6 months)	20.6%	6.9%	0.0%	
Extremely rare (once a year or less)	20.6%	3.4%	1.2%	
Number of glasses per consumption				
1-2 glasses	82.4%	81.9%	72.9%	2.942
≥3 glasses	17.6%	18.1%	27.1%	
Average price paid per bottle				36.579**
Less than 5 EUR	30.9%	9.5%	2.4%	
Between 5 and 10 EUR	48.5%	44.8%	45.9%	
Between 10 and 20 EUR	14.7%	37.9%	41.2%	
More than 20 EUR	5.9%	7.8%	10.6%	
Consumption pattern (weekly)				24.707**
Mainly weekends	64.7%	43.1%	24.7%	
Combination weekends and workdays	35.3%	56.9%	75.3%	
Purchasing occasions				
Immediate consumption at home	20.6%	20.7%	18.8%	48.483**
Stocks for future consumption	1.5%	12.9%	24.7%	
Special occasions (celebrations)	27.9%	27.6%	22.4%	
Gift giving	39.7%	20.7%	3.5%	
No special occasions	10.3%	18.1%	30.6%	
Satisfaction with wine selection				
Satisfied	82.4%	75.9%	65.9%	6.066
Having trouble finding desired wine	5.9%	10.3%	15.3%	
Needs greater diversity	11.8%	13.8%	18.8%	
Satisfaction with wine prices				
Satisfied	85.3%	83.6%	77.6%	1.805
Having trouble finding wine at reasonable prices	14.7%	16.4%	22.4%	
The maximum price would pay for a bottle of **wine aged in barrique barrels**				47.382**
Less than 10 EUR	36.8%	12.1%	3.5%	
Between 10 and 20 EUR	41.2%	46.6%	34.1%	
Between 20 and 30 EUR	19.1%	23.3%	36.5%	
More than 30 EUR	2.9%	18.1%	25.9%	

* $p<0.05$; ** $p < 0.01$ *Source: Authors*

With regard to the frequency of wine consumption, there were significant differences between the clusters. The majority of CC reported consuming wine occasionally (once a month or less) (36.8%), followed by those who rarely and extremely rarely consume wine (20.6%). WE differed in this respect, as they appeared to be mainly frequent (once a week or less) consumers (38.8%), as well as frequent (3-4 times a week) (35.3%). The majority of respondents who were recommendation recipients stated that they drank wine frequently (38.8%) and occasionally (37.1%).

Statistically significant results were obtained with regard to the average price per bottle paid by respondents. CC mainly paid between 5 and 10 EUR (48.5%) and less than five EUR (30.9%). As expected, WE tended to pay higher prices for wine, 45.9% of them between 5 and 10 EUR and 41.2% of them between 10 and 20 EUR, while they bought almost no wines from the cheapest category. The majority of RR consumers (44.8%) chose the option between 5 and 10 EUR, while 37.9% chose the option of more expensive wines, between 10 and 20 EUR.

In terms of weekly consumption patterns, CC consumed wine mainly at weekends (64.7%). WE tended to consume wine on both weekdays and weekends (75.3%), more than the other two groups, although this was also the case for the majority of RR consumers (56.9%). The differences between the clusters were statistically significant. The differences in purchase occasions were also significant. CC tended to buy wine mainly as a gift (39.7%) and for special occasions such as celebrations (27.9%). They were less likely to buy wine to stock up for future consumption. As might be expected, wine lovers buy wine for different occasions - for immediate consumption, for consumption at home, for stockpiling for future consumption and for special occasions (around a fifth each) or for no occasion at all (30.6%). Respondents who responded to recommendations were most likely to buy wine for special occasions (27.6%).

The majority of respondents stated that they were satisfied with the wine selection and wine prices on the domestic market and no significant differences were found between the clusters. Significant differences were found between the groups in terms of the maximum price respondents would be willing to pay for a bottle of barrique wine. WE would be most willing to pay between EUR 10 and 20 (34.1%) and EUR 20 and 30 (36.5%), which is significantly higher than in the other two clusters.

Discussions

As wine is a highly complex product, gaining a deeper understanding of the key drivers of wine consumer preferences, attitudes and behaviour is a major challenge in the field of wine marketing (Wiedmann et al., 2014). In order to improve consumption in the Serbian market, it is necessary to recognise specific consumer segments with particular characteristics and develop specific marketing strategies to reach them. This study presents the results of the segmentation of wine consumers based on their knowledge, attitudes and behaviour towards wine.

The group of WE is characterised by the fact that it has the highest subjective knowledge of wine and tends to attend wine events. They are more selective about wine and consume wine on special occasions and at home. These consumers were mainly more educated, lived in the capital and in larger cities and lived mainly in couples with or without children. They had above-average purchasing power and mostly favoured white wine or both red and white wine. In addition to local wines, Wine enthusiasts also appreciated wine from countries in the region (e.g. Croatia, Macedonia). They were frequent wine consumers, consuming wine both on weekdays and weekends, and were more likely to drink a higher number of glasses per consumption than the other two groups. They were likely to pay higher prices for wine and did not buy wines from the cheapest category. They bought wine for different occasions, with or without an occasion, and were willing to pay higher prices for a bottle of barrique wine than the other two groups. At EUR 50.65 per month, they spent significantly more on wine than the other two groups. Many other studies have identified consumer segments with similar characteristics. In the study by Kalazić et al. (2010), there were two segments with similar characteristics: prestige consumers with high purchasing power and a willingness to pay higher prices, and expert consumers who, in addition to high purchasing power, also frequently consumed wine, believed that drinking wine was healthy and enjoyed consumption. Similarly, the segment of affluent wine experts found by Hlédik and Harsányi (2019), as these consumers spent the highest amounts on a bottle of wine, enjoyed visiting wineries and attending wine events. Research conducted in China by Yabin and Lee (2020) discovered a segment of wine lovers whose members had a long history of wine drinking and considered wine to be a very important lifestyle segment. A segment in Geraghty and Thores' (2009) research entitled Wine Traditionalist, which includes consumers who value wine variety, classification and vintage and spend a significant average monthly amount on wine purchases, also exhibits similar characteristics to a certain extent. Hristov and Kuhar (2015) identified a cluster with high subjective knowledge of wine, which includes consumers with the longest experience of wine drinking, weekly consumption, who value vintage and wine variety more than other segments, and front and back label information. A similar segment was found by Brunner and Siegrist (2011) to be dedicated, knowledgeable wine consumers who had the highest income and were willing to pay more for the bottle than other segments, who saw wine as very important and as their hobby and therefore spent a lot of time learning about wine and attending wine seminars. In some ways, the segment of wine enthusiasts in this study resembles the segment of ritual-orientated, conspicuous wine lovers of Bruwer et al. (2002), who valued wine as a very important part of their lives, drank almost daily and on various occasions, exhibited «connoisseur» characteristics and paid the highest average prices per bottle. In addition, the group of conservative, knowledgeable wine drinkers (Bruwer & Li 2007; Bruwer & Li 2017) is a very similar group, characterised by frequent wine drinking, connoisseur characteristics and spending more money on a bottle of wine per month. Some characteristics are also similar to the mature, time-conscious wine drinker segment, who have a history of wine consumption, enjoy acquiring knowledge about wines, have connoisseur tendencies and tend to store wine at home for future use (Bruwer & Li 2007; Bruwer & Li 2017).

The group of consumers who respond to recommendations (RR) is in the middle of the field for all factors. These consumers attach importance to recommendations from others, the origin of the wine and information on the labels. These consumers were mainly highly educated, lived in the capital and in smaller towns, were predominantly couples with child(ren) and had average purchasing power. They mostly favoured exclusively white or red wine from local production. Although they generally did not pay attention to the age of the wine, they chose “Reserva» more often than the other two groups. They consumed wine frequently and occasionally, on weekends and weekdays, one to two glasses per consumption. They mainly bought wines in the medium or higher price segment and mainly for special occasions. They spent EUR 26.46 per month on the purchase of wine. A similar consumer group called ordinary wine consumers was identified by Hlédik and Harsányi (2019), who represent the largest segment and spend an average amount on wine purchases. Although the group of consumers with low subjective knowledge about wine found in the study by Hristov and Kuhar (2015) shows certain differences (lowest knowledge, lowest frequency of consumption of all groups) and thus also resembles the group of casual consumers, it is similar to the group of recommendation-happy consumers in that it strongly favours personal sources of information and values expert recommendations as well as recommendations from family members and friends. Brunner and Siegrist (2011) distinguished the pleasure-oriented, sociable wine consumer, who sees wine as something to do with a nice atmosphere and socialising. However, as they are uncertain about their decisions, this consumer is the most likely of all segments to use recommendations and reviews when making a purchase. The survey results of Bo Liu et al. (2014) show a “traditional word-of-mouth» segment of Chinese wine consumers who most frequently sought product reviews and recommendations when purchasing.

The group of Casual wine consumers (CC) had the lowest values for all factors except “mood”, where they had the highest value. This means that the consumers belonging to this group have neither a high level of knowledge nor preferences regarding wine, but merely associate drinking wine with a certain mood. The group of modest consumers who were willing to pay the lowest price for a bottle of wine has some similarities with the segment of modest consumers of Kalazić et al. (2010). For them, the most common reasons for wine consumption were escape from problems, relaxation and feeling “cool”. In addition to consumers with higher education, the group of CC contained the highest percentage of consumers with secondary education. The consumers lived in the capital and in smaller towns, were predominantly couples with child(ren) or still lived with their parents/siblings and had average purchasing power. They expressed a higher preference for white wine and paid less attention to the origin and ageing of the wine. They consume wine mainly occasionally or rarely, at weekends and one to two glasses per consumption. They mainly buy wines from the cheapest categories and mainly as gifts or for special occasions such as celebrations. On average, they spent EUR 19.84 per month. In terms of the lowest expenditure on wine, this segment is similar to the segment of undemanding wine consumers in the study by Hlédik and Harsányi (2019). The Casual wine consumer of Geraghty and Thores (2009) was characterised by choosing wine according to less significant rather than more specific wine attributes and a more casual approach to wine consumption. Brunner and Siegrist (2011) identified the indifferent wine consumer who does not have a strong preference for wine and does not really want to drink wine frequently unless they feel in the mood to drink it with a meal. Bruwer et al. (2002) identified pleasure-orientated, sociable wine drinkers who not only enjoy drinking wine on social occasions at the weekend, but also concentrate on consuming wine privately at home and relaxing in the process.

Given the fact that their wine-related preferences and behaviour differ significantly, all three groups require different communication strategies from wine producers and sellers to cater to their preferences and needs. As for the wine enthusiasts segment, the marketing strategy should include a multi-channel approach based on emphasising outstanding wine attributes. As these consumers like to drink wine on different occasions, the availability of wine through HoReCa channels, speciality shops and wine cellars is particularly important. The organisation of various wine events (fairs, seminars, wine tours and tastings) is also considered to be very effective. The availability of various information and promotional materials such as wine books, brochures and newsletters is also important, considering the knowledge about wine that these consumers want to acquire. Labels should contain information about the wine variety, wine style and vintage and be used as a communication channel. Personalised communication via e-mail, messageing and social media should also be included in the communication mix. The content of the communication should focus on the wine variety, traditional production and quality, while prices should not take centre stage.

In addition to communication through the media and advertising at the point of sale and consumption, which should also be included in the communication strategy for consumers ready to recommend, word of mouth and marketing should be the main means of reaching these consumers. Wine producers should invest in building online communities and monitor and respond to consumer comments. They should also invest in promoting positive reviews and better positioning on review portals. In advertising, they should engage spokespeople who are relevant to this target group, have credibility and are seen as suitable to make recommendations.

As for CC who do not particularly like wine and do not consider it important to their lifestyle, and who could be described as mood-dependent wine drinkers, emphasising emotions, special atmosphere and relaxation rather than wine characteristics seems to be the most effective strategy. As this consumer group is not willing to pay high prices for wine and has the lowest consumption, the frequent use of special offers and discounts could be effective in persuading these consumers to buy.

Conclusions

Considering that the wine sector in Serbia is in transition, market screening and identification of consumer profiles are crucial to set an appropriate direction for its improvement. This study provides valuable insights into the wine-related behaviour of Serbian consumers and the results could help in planning and developing appropriate marketing strategies and effective communication with different consumer segments.

This study has several limitations that should be considered. First, the use of a convenience sample recruited through professional networks may limit the representativeness of the findings, as the sample might not fully capture the diversity of Serbian wine consumers. Second, the reliance on self-reported data raises the possibility of social desirability or recall bias, especially regarding wine consumption and purchasing behavior. Third, the cross-sectional design provides only a snapshot in time, making it difficult to capture changes in consumer attitudes or behaviors. Finally, the study was conducted in one national context, which restricts the generalizability of the results to other wine-producing or wine-consuming countries.

Future studies could address these limitations by employing probability sampling techniques or larger, more diverse samples to enhance representativeness. A longitudinal design would allow for the examination of how psychographic and behavioral characteristics of wine consumers evolve over time. In addition, cross-cultural or comparative studies could provide valuable insights into similarities and differences in wine consumer segmentation across traditional and emerging wine markets.

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Conflict of interests

The authors declare no conflict of interest.

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A MULTIDIMENSIONAL FRAMEWORK FOR UNDERSTANDING INSTITUTIONAL SUPPORT IN RURAL ENTREPRENEURSHIP

Mirjana Milovanović[1], Svetlana Dušanić Gačić[2], Dunja Demirović Bajrami[3], Tamara Gajić[4]

**Corresponding author E-mail: d.demirovic@gi.sanu.ac.rs*

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A B S T R A C T

This study investigates institutional perspectives on rural entrepreneurship in Bosnia and Herzegovina, addressing a significant gap in research on meso-level actors in post-socialist contexts. Using a structured survey of 43 institutional representatives, including ministries, municipalities, educational institutions, and development agencies, the study identifies key enablers and barriers to rural entrepreneurship. Descriptive and multivariate statistical analyses (factor and cluster analysis) reveal heterogeneous institutional priorities, highlighting human capital, infrastructure, and product quality as critical drivers. Virtual training is seen as a viable tool for capacity building, especially in sustainable agriculture, tourism, and infrastructure. Results suggest that institutions differ in strategic orientation, ranging from holistic to pragmatic mindsets. These findings advance understanding of institutional logic in rural entrepreneurship and inform targeted policy design, digital training development, and ecosystem-level interventions aligned with community needs.

1 Mirjana Milovanović, PhD, Associate Professor, Banja Luka College, Miloša Obilića 30, Banja Luka, Republic of Srpska, Bosnia and Herzegovina, Phone: +38765644135, E-mail: mirjana.milovanovic@blc.edu.ba, ORCID ID (https://orcid.org/0000-0003-3746-5517)

2 Svetlana Dušanić Gačić, PhD, Full Professor, Banja Luka College, Miloša Obilića 30, Banja Luka, Republic of Srpska, Bosnia and Herzegovina, Phone: +38765997834, E-mail: svetlanadg@blc.edu.ba, ORCID ID (https://orcid.org/0000-0001-6173-7442)

3 Dunja Demirović Bajrami, PhD, Senior Research Associate, Geographical Institute "Jovan Cvijić" Serbian Academy of Sciences and Arts, Djure Jakšića 9, 11000 Belgrade, Serbia, Phone: +381 112636594, E-mail: d.demirovic@gi.sanu.ac.rs, ORCID ID (https://orcid.org/0000-0001-5140-1515)

4 Tamara Gajić, PhD, Senior Research Associate, Geographical Institute "Jovan Cvijić" Serbian Academy of Sciences and Arts, Djure Jakšića 9, 11000 Belgrade, and University Business Academy in Novi Sad, Faculty of Organizational Studies "Eduka", Majke Jevrosime 15, 11000 Belgrade, Serbia, Phone: +381 112636594, E-mail: t.gajic@gi.sanu.ac.rs, ORCID ID (https://orcid.org/0000-0003-3016-8368)

Introduction

Rural entrepreneurship is increasingly recognized as a key driver of economic revitalization and contributes to the diversification of rural economies, helps counteract depopulation trends, and reinforces community resilience, especially in regions undergoing structural economic transitions (Fortunato, 2014; Kania et al., 2021; Masoomi, Rezaei-Maghaddam, 2024). Despite its transformative potential, rural entrepreneurship faces persistent barriers, including limited access to finance, skills, infrastructure, and institutional support mechanisms (Zaheri et al., 2025). Within this context, institutions (government bodies, local authorities, educational organizations, and development agencies) play a central role in shaping rural entrepreneurial environments. They influence regulatory frameworks, funding opportunities, knowledge transfer processes, and community engagement mechanisms (Urbano et al., 2025). The effectiveness of rural development policies largely depends on the alignment between institutional strategies and local needs (Esposti, Sotte, 2013; Aubert et al., 2025), as well as on institutions' ability to recognize and mobilize place-based assets such as cultural heritage and local identity (Vasta et al., 2019). However, existing evidence from the Western Balkans suggests that institutional responses to entrepreneurship are often fragmented, overly bureaucratic, and insufficiently aligned with the needs of rural communities (Williams, Gashi, 2022; Lica, 2024). This indicates that institutions are not merely supportive structures, but actors whose perceptions and priorities significantly shape entrepreneurial outcomes.

Bosnia and Herzegovina represents a particularly relevant empirical setting for this study due to its complex post-socialist trajectory and highly fragmented governance structure. The country operates under a multi-level administrative system characterized by overlapping competencies between state, entity, cantonal, and municipal levels, which often results in limited coordination and inconsistencies in policy implementation. In such a context, institutional actors play a disproportionately important role in shaping rural entrepreneurial ecosystems, as support mechanisms, funding opportunities, and development strategies are frequently decentralized and unevenly applied (Bubalo Živković et al., 2025). Moreover, rural areas in Bosnia and Herzegovina face persistent structural challenges, including depopulation, limited infrastructure, and constrained access to markets, further amplifying the importance of effective institutional support. These characteristics make the country a critical case for examining how institutional perceptions, priorities, and capacities influence the development of rural entrepreneurship. At the same time, Bosnia and Herzegovina reflects broader patterns observed across the Western Balkans, where post-socialist legacies, governance fragmentation, and policy-practice gaps continue to shape rural development trajectories.

For the purpose of this study, several key concepts are defined. Institutional actors refer to formal organizations involved in shaping and supporting rural entrepreneurship, including government bodies, local self-government units, educational institutions, and development agencies. These actors operate at different administrative levels and perform roles related to policy design, implementation, funding allocation, knowledge transfer, and capacity building. Support mechanisms are the set of instruments, resources, and interventions through which institutions influence entrepreneurial development. In this study, they include financial support (e.g., grants, subsidies), educational and training initiatives (formal and non-formal learning), infrastructural conditions, regulatory and policy frameworks, and socio-cultural factors. Finally, virtual training refers to digitally delivered educational and capacity-building activities aimed at enhancing entrepreneurial knowledge and skills. This includes online courses, workshops, and training programs covering areas such as agriculture, tourism, digital services, and rural development.

While prior research has identified a broad range of enablers of rural entrepreneurship, including human capital, market access, infrastructure, and local resources (Wiggins, Proctor, 2002; Kujala et al., 2021; Mondal et al., 2024; Rudnicki et al., 2023), less attention has been paid to how these factors are interpreted and prioritized by institutional actors themselves. This represents a critical gap, as institutions act as intermediaries between policy design and local implementation, particularly in contexts characterized by governance complexity and resource constraints. Moreover, contemporary research highlights the increasing importance of place-based and sustainability-oriented approaches, where entrepreneurship is embedded in local identity and environmental stewardship (McLeod et al., 2024; Utami et al., 2023), further underscoring the need to understand how institutions conceptualize and support these processes. Further, education and training are widely acknowledged as essential components of entrepreneurial capacity building (Rawat et al., 2015; Almeida, Morais, 2025). In addition, the COVID-19 pandemic has accelerated the adoption of digital tools in entrepreneurship (Santos et al., 2023). Virtual platforms have been identified as a means to bridge geographic and institutional gaps in rural areas when tailored to local needs (Sindakis, Showkat, 2024). However, there is still limited empirical understanding of how institutional actors evaluate these educational and digital mechanisms, particularly in terms of their relevance for rural entrepreneurship development. At the same time, the existing literature has predominantly focused on the characteristics, motivations, and behaviors of rural entrepreneurs (Durrah et al., 2024; Heredia-Carroza et al., 2024; Mansingh et al., 2025), while the perspectives of institutions as key ecosystem actors remain underexplored. This gap is particularly evident in the Western Balkans, where only a limited number of studies have examined institutional roles in shaping entrepreneurial environments (Lica, 2024; Martinovska Stojcheska et al., 2024; Imangulov et al., 2024). Even less attention has been given to how institutions perceive non-formal education, experiential learning, and virtual training as instruments for rural development, despite their growing relevance in the context of digital transformation (Salemink et al., 2025).

To address these gaps, this study adopts an institutional perspective to examine how different actors perceive and prioritize support mechanisms for rural entrepreneurship in Bosnia and Herzegovina. The research is guided by the following questions:

• Which forms of support do institutional actors consider most relevant for developing rural entrepreneurship?

• How do perceptions of entrepreneurial support differ among various types of institutions (e.g., ministries, municipalities, educational institutions, development agencies)?

• To what extent do institutions value virtual training and education as tools for rural entrepreneurship development, and which topics are considered most important?

This study is theoretically grounded in institutional theory, which emphasizes the role of formal and informal structures in shaping economic behavior and organizational outcomes. Within this perspective, institutions are not merely background conditions but active agents that influence entrepreneurial activity through regulatory frameworks, normative expectations, and cognitive structures. This approach is particularly relevant in post-socialist and transitional contexts, where institutional arrangements are often characterized by fragmentation, path dependency, and evolving governance systems. In addition, the study draws on the entrepreneurial ecosystem perspective, which conceptualizes entrepreneurship as embedded within a system of interdependent actors, resources, and support mechanisms. Within this framework, institutions represent a core component that enables or constrains entrepreneurial dynamics through policy design, funding structures, and capacity-building initiatives. Finally, insights from governance theory are incorporated to account for the multi-level and often fragmented nature of institutional arrangements in Bosnia and Herzegovina. This perspective highlights issues of coordination, policy alignment, and institutional capacity, which are particularly relevant for understanding variations in how different actors perceive and prioritize support mechanisms. By integrating these complementary perspectives, the study adopts a multi-level analytical lens that allows for a more nuanced interpretation of institutional heterogeneity and its implications for rural entrepreneurship development.

Based on a survey of 43 institutional representatives, the study employs a multidimensional analytical approach combining descriptive statistics, factor analysis, group comparisons, and cluster segmentation. This approach enables understanding of institutional heterogeneity, revealing distinct strategic orientations, and implications for policy alignment. By repositioning institutions as active and differentiated agents rather than passive background structures, this research contributes to a more comprehensive understanding of rural entrepreneurial ecosystems. It advances theoretical insights into institutional logic in rural development while providing practical guidance for policymakers, NGOs, and training providers to better align support mechanisms with institutional capacities and local needs.

Materials and methods

Data collection and sample

A purposive sampling strategy was employed, targeting institutions directly involved in rural entrepreneurship support. The data for this study were collected through a structured questionnaire distributed electronically, via emails to key stakeholders, including representatives of government ministries, development agencies, local municipalities, business support organizations, and educational institutions in Bosnia and Herzegovina. The data were collected in March and April 2024. A total of 43 institutional representatives participated in the study. Although the sample size is relatively modest, it reflects a specialized population of institutional actors that is inherently limited and difficult to access within a single national context. The sample included respondents from various sectors: government bodies (40%), local self-government units (25%), development agencies (20%), and academic or educational institutions (15%). The sample included 20 male and 23 female participants. In terms of age distribution, the majority (23 out of 43) were in the 36–55 age group. Regarding educational background, the majority (24 out of 43) held higher education degrees (faculty level).

Instrument design

The structure of the questionnaire was informed by existing literature on rural entrepreneurship and institutional support (e.g., Kujala et al., 2021; Mondal et al., 2024), ensuring content validity. The internal consistency of the instrument was assessed using Cronbach's alpha, with values exceeding the acceptable threshold of 0.70. The questionnaire was designed to capture both demographic information and evaluative responses across multiple thematic domains relevant to entrepreneurial development in rural areas. The first section of the instrument collected basic demographic information. The core of the questionnaire consisted of a series of grouped items organized into nine thematic categories, each reflecting a different dimension of entrepreneurial support or challenge. Respondents were asked to evaluate the relative importance of each factor on a five-point Likert-type scale (from 1 = least influential to 5 = most influential). The thematic categories included:

- *Education-related factors*, such as studying entrepreneurship in formal education, informal learning, and internships.
- *Financial support mechanisms*, including grants, guarantee funds, tax incentives, and subsidized loans.
- *Institutional cooperation and partnerships*, such as collaboration with suppliers, customers, state institutions, and professional associations.
- *Public policies and regulatory conditions*, including ease of business registration, corruption, property rights, and tax relief.
- *Market strategy and product quality*, including workforce qualifications, product standards, marketing, and market awareness.
- *Socio-cultural barriers*, such as gender and age biases, environmental concerns, and rural quality of life.

- *Natural, cultural, and infrastructural resources*, including local traditions, tourist potential, and infrastructure availability.
- *Personal attributes of entrepreneurs*, such as resilience, prior experience, family support, and risk tolerance.
- *Training needs and virtual education topics*, which assessed respondents' perceptions of priority areas for capacity-building.

Data analysis

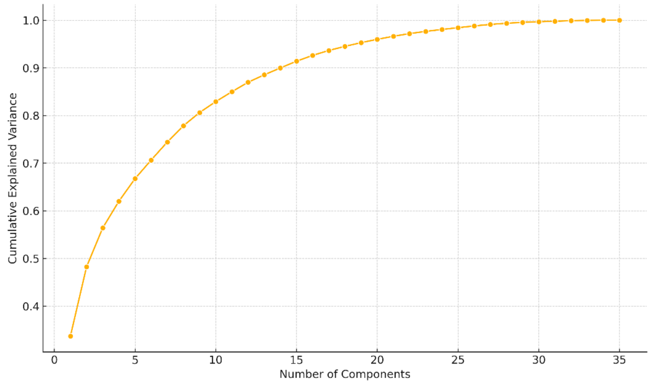
The collected data were analyzed using a combination of descriptive and inferential statistical techniques, aimed at uncovering patterns in institutional perceptions of rural entrepreneurship. All data were first screened for completeness and consistency. After the cleaning process, the responses were coded and entered into statistical software for analysis (SPSS Statistics software). Descriptive statistics were used to summarize the overall importance of various barriers and enablers, allowing for the identification of the most and least influential factors as perceived by the institutional respondents. Given the exploratory nature of the study and the absence of a predefined factor structure, exploratory factor analysis (EFA) was considered more appropriate than confirmatory techniques. The aim was to identify underlying patterns in institutional perceptions rather than to test an established theoretical model. Factor retention was guided by multiple criteria, including eigenvalues greater than 1, inspection of the scree plot, and interpretability of the factor solution. Only variables with factor loadings of $\geq |0.40|$ were retained for interpretation. Factor extraction was performed using principal component analysis with varimax rotation. To examine whether perceptions differed across institutional types, analysis of variance (ANOVA) was applied for normally distributed data, while Kruskal-Wallis tests were used as non-parametric alternatives when normality assumptions were not met. Finally, cluster analysis was employed to segment respondents into homogeneous groups based on their response patterns. This allowed for the identification of typologies among institutional stakeholders and provided insight into shared perceptions and strategic orientations.

Results

The descriptive analysis revealed that institutional representatives place the greatest importance on personal competencies, product quality, and basic infrastructure as key enablers of rural entrepreneurship. Among all rated factors, the highest mean score was attributed to personal attributes of entrepreneurs, such as persistence, goal orientation, and willingness to work hard (mean=4.51, SD=0.80). This was followed by product and service quality (mean=4.44, SD=0.73), production of healthy food (mean=4.35, SD=0.90), and communal infrastructure as a prerequisite for rural development (mean=4.30, SD=1.06). In contrast, lower average scores were typically observed for factors such as intangible cultural values and promotional activities, indicating that while these are recognized as relevant, they are perceived as less central in shaping rural entrepreneurial ecosystems.

To identify underlying dimensions in institutional perceptions of rural entrepreneurship, an exploratory factor analysis (EFA) was conducted using principal component analysis with standardization. Prior to extraction, the dataset was screened for completeness, and only numerical responses were included. The results indicated that the first several components explained a substantial portion of the variance. As shown in *Figure 1*, the first five to seven components accounted for a significant cumulative variance before the curve plateaued, suggesting this range captures the most meaningful factor structure. Based on these results, the next analytical steps focused on interpreting these retained components by examining factor loadings and grouping conceptually related items. This allowed the identification of key latent dimensions.

Figure 1. Cumulative explained variance by principal components



Source: Authors

To explore the structure of institutional perceptions, five latent components were extracted (*Table 1*). The first factor was characterized by high negative loadings from items related to entrepreneurial education and knowledge transfer, suggesting that Factor 1 represents an *Entrepreneurial Skills and Training* dimension, reflecting the perceived importance of education-related enablers. The second factor reflects a *Skepticism Toward Non-Formal Education*, capturing reservations about the effectiveness or presence of such training formats in the rural context. Factor 3 *Limited Role of Cultural Assets* reflects a perception among some institutional actors that while cultural heritage may enrich rural identity, it is not seen as a core driver of entrepreneurship. Factor 4 *Preference for Practical Learning* contrasts negative views toward formal entrepreneurship education with more favorable attitudes toward practical learning opportunities, such as internships or volunteering. Factor 5 *Limited Trust in R&D Support* reflects ambivalence or limited confidence in institutional mechanisms for translating innovation into rural entrepreneurship support.

To investigate whether institutional affiliation influences the perceived importance of different factors in rural entrepreneurship, a series of Kruskal–Wallis tests were conducted. The sample was segmented into four institutional types: government bodies, local self-government units, development agencies, and educational institutions. The analysis identified two statistically significant differences in perceptions (*Figure 2* and *3*).

Table 1. Summary of retained factors from exploratory analysis

Factor	Label	Key items	Interpretation
Factor 1	Entrepreneurial Skills and Training	Studying entrepreneurship, practical experience, knowledge transfer, business incubators	Highlights the importance of education, applied learning, and infrastructure for skills development.
Factor 2	Skepticism Toward Non-Formal Education	Informal education, studying entrepreneurship	Reflects critical views on the effectiveness or accessibility of non-formal learning.
Factor 3	Limited Role of Cultural Assets	Intangible tourist values (traditions, customs, hospitality)	Suggests skepticism about the role of cultural heritage in fostering entrepreneurship.
Factor 4	Preference for Practical Learning	Practical training, formal education (negative), volunteering	Emphasizes hands-on learning over classroom-based approaches.
Factor 5	Limited Trust in R&D Support	Knowledge transfer from R&D	Indicates modest belief in the value of research-based support mechanisms.

Source: Authors

There was a notable divergence in how institutions assessed the value of intangible tourist resources, such as local traditions, hospitality, cultural customs, and folklore (H=13.20, p=0.004). Educational institutions and development agencies tended to rate these cultural elements as more influential in fostering rural entrepreneurship, likely due to their closer engagement with community-level narratives and place-based identity. In contrast, representatives from ministries and local governments rated these factors as less impactful. This suggests that cultural assets, while less emphasized in national policy frameworks, are seen by some actors as important vehicles for tourism-related entrepreneurship and local branding. Second, significant differences emerged in perceptions of financial benefits, specifically *fiscal incentives such as reduced taxes and levies* (H=7.93, p=0.048). Government institutions tended to view these incentives as highly relevant policy tools for encouraging entrepreneurial activity, while respondents from educational institutions and agencies placed slightly less emphasis on their direct impact. This may reflect a difference in institutional proximity to policy implementation.

To identify underlying patterns in how institutional stakeholders perceive the enablers and barriers of rural entrepreneurship, a cluster analysis was conducted using the K-means algorithm. The aim was to segment respondents into groups based on similar response patterns, offering deeper insight into shared institutional mindsets. A silhouette analysis was performed to determine the optimal number of clusters. The analysis indicated that a solution with two or three clusters provided the best structure, with the highest silhouette values observed at these points.

Figure 2. Perception of intangible tourist values

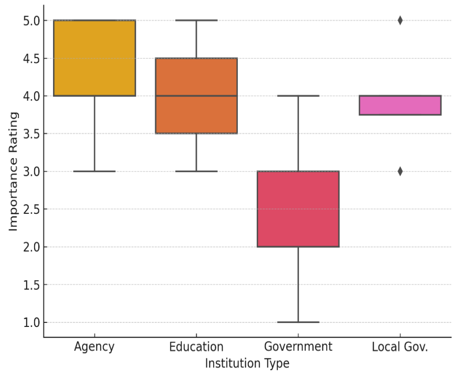
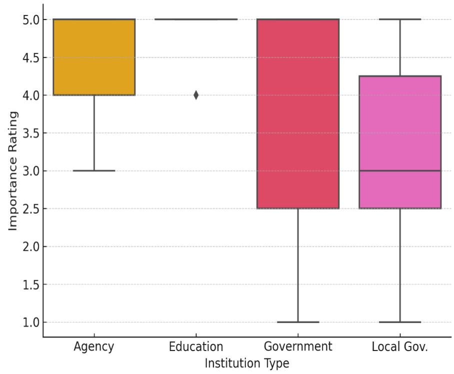


Figure 3. Perception of financial incentives



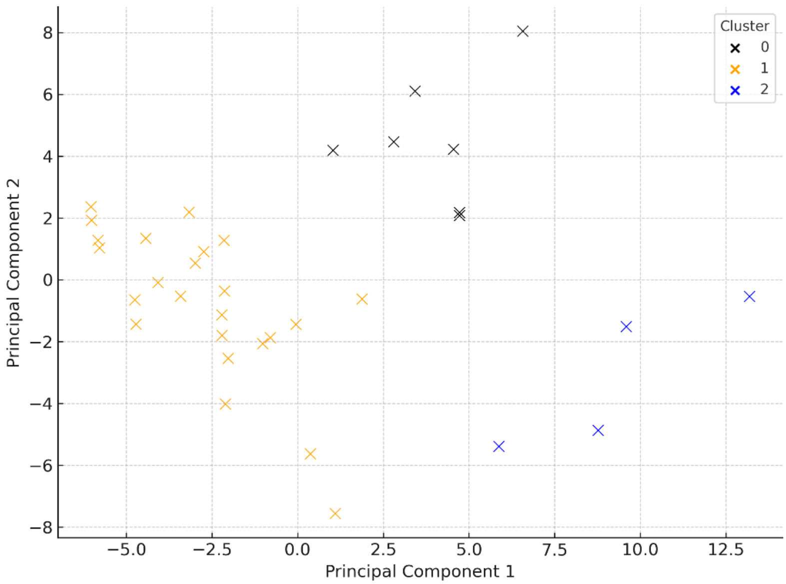
Source: Authors

Based on these results, a three-cluster solution was selected for further interpretation. Preliminary profiling of the clusters revealed meaningful distinctions in perception patterns (*Figure 4*):

- Cluster 1 stands out as the most engaged and supportive group, consistently assigning high importance to a wide range of entrepreneurship enablers. These institutions strongly value both formal education (mean=*4.12*) and informal learning opportunities (*4.04*), indicating a belief that structured training plays a central role in preparing rural entrepreneurs. They also place exceptional emphasis on practical experience through internships and volunteering (*4.62*). Furthermore, they rate highly the importance of knowledge transfer from research and development institutions (*4.25*), pointing to a systemic, infrastructure-based view of support. This cluster represents institutions that adopt a comprehensive, long-term perspective on entrepreneurship, embracing both human capital development and structural support mechanisms.
- Institutions in Cluster 2 adopt a more moderate and selective stance. While they acknowledge the relevance of formal education (*3.50*) and informal training (*3.25*), their support is tempered, suggesting a view that these inputs are useful but not transformative on their own. Notably, they show a lower emphasis on experiential learning (*2.75*) and knowledge transfer from R&D (*2.50*), possibly due to concerns about accessibility, quality, or local applicability of such resources. Cluster 2 likely represents institutions that operate under resource constraints or policy limitations, and therefore prioritize more immediate, tangible forms of support over broader structural interventions.
- Cluster 0 is characterized by a pragmatic yet somewhat skeptical approach to entrepreneurship development. These institutions rate experiential learning relatively high (*3.71*), suggesting they recognize the value of hands-on experience. Their scores for formal education (*2.43*) and informal learning

(*2.71*) are among the lowest, hinting at doubts about the effectiveness or relevance of existing educational models in rural settings. This cluster may include local government actors or smaller agencies.

Figure 4. Clustered institutional perceptions of entrepreneurship enablers (PCA projection)



Source: Authors

In addition to evaluating structural and institutional enablers of rural entrepreneurship, the questionnaire asked institutional representatives to assess the relevance of various training topics for virtual delivery. The results reveal strong institutional support for training focused on sustainable and practical topics. The highest-rated area was *Production of healthy food* (*4.35*), underscoring the alignment between rural entrepreneurship and the growing demand for health-conscious, locally produced goods. This was followed closely by *Communal infrastructure as a prerequisite for rural development* (*4.30*), indicating the importance of educating stakeholders about foundational services and facilities that support entrepreneurial growth. These responses point to a clear institutional preference for training programs that are not only relevant to rural economies but also actionable and directly linked to place-based identity and tourism potential.

Discussions

Consistent with previous research (Khlystova et al., 2022; Radosavljević et al., 2022), this study confirms the foundational importance of human capital, particularly the role of personal entrepreneurial attributes such as resilience, goal orientation, and willingness to work hard. These qualities received the highest overall rating (mean=4.51), underscoring their perceived universality in fostering successful entrepreneurial ventures in rural settings. Unlike studies conducted in more urbanized or economically diverse rural areas (Li et al., 2019; Dziekański, Prus, 2020), this research reveals a slightly different prioritization. While access to finance was rated highly, themes closely aligned with place-based development and local identity, as seen in studies on sustainable rural entrepreneurship (Soleymani et al., 2021; Shao et al., 2024; Rajsinghot et al., 2024). These results may reflect Bosnia and Herzegovina's transitional economic environment.

A particularly noteworthy contrast with broader European findings is the relatively low prioritization of intangible cultural values, such as local traditions and hospitality (Knapik, Król, 2023; Shakya, Vagnarelli, 2024). This finding can be interpreted through several complementary perspectives. First, it may reflect a policy gap, whereby cultural assets are insufficiently integrated into formal rural development and entrepreneurship strategies. In such contexts, institutional frameworks tend to prioritize measurable economic outputs, such as employment, infrastructure, and financial incentives, while the potential of cultural heritage as a driver of entrepreneurship, particularly in tourism, is underutilized. Second, the relatively low valuation of cultural assets may be linked to measurement challenges. Intangible elements such as traditions, customs, and local identity are inherently difficult to quantify and evaluate in terms of immediate economic returns, which may lead institutional actors to perceive them as less impactful compared to more tangible resources. Third, this pattern may reflect an institutional bias toward structural and policy-driven mechanisms. Actors operating within administrative and governance systems often emphasize formal instruments, such as regulations, funding schemes, and infrastructure, over softer, place-based assets that require more integrated and long-term approaches. This aligns with institutional theory, which suggests that organizational priorities are shaped by dominant norms, performance metrics, and accountability structures. These findings directly support the study's first expectation, which anticipated that institutional actors would differ in how they prioritize support mechanisms based on their roles and organizational mandates.

The exploratory factor analysis supported the multidimensional nature of institutional perceptions, revealing latent structures such as Entrepreneurial Skills and Training, Limited Role of Cultural Assets, and Limited Trust in R&D Support. The emergence of a factor reflecting skepticism toward non-formal education and cultural heritage deviates from findings in Western European contexts, where lifelong learning and cultural branding are often emphasized (Bosworth et al., 2016). This divergence may be attributed to lower systemic support for non-formal education, or a gap between policy discourse and implementation at the local level. On the other hand, ministries and municipal representatives placed higher importance on financial incentives, possibly reflecting their operational focus on policy instruments and regulatory levers. The observed differences between institutional types support the expectation that governmental and non-governmental actors emphasize different forms of support, reflecting their distinct mandates and operational frameworks.

The cluster analysis deepened this understanding, revealing three dominant institutional mindsets: (1) a holistic and development-oriented cluster valuing education and applied learning; (2) a policy-driven cluster prioritizing financial tools and governance; and (3) a pragmatic, cautious cluster that supports experiential knowledge but remains reserved about broader educational or structural enablers. These findings echo prior segmentation in rural policy perception studies (Brida et al., 2010; Korsgaard et al., 2015), reinforcing the need for tailored policy approaches that acknowledge institutional diversity. In line with the study's expectations, perceptions of virtual training were not uniform across institutions, suggesting differences in capacity and strategic orientation toward digital tools. These findings support the study's third expectation, which anticipated variation in how institutions perceive virtual training. The results indicate that while virtual training is broadly recognized as relevant, its perceived importance varies depending on institutional capacity, orientation, and engagement with digital tools. These align with recent findings by Lounge et al. (2025) and Tang et al. (2022), who emphasize the growing institutional recognition of e-learning as a tool for rural entrepreneurial empowerment in the post-pandemic landscape.

Conclusions

This study offers an in-depth examination of institutional perceptions regarding the drivers and constraints of rural entrepreneurship in Bosnia and Herzegovina, with particular attention to the tourism and agricultural sectors. By engaging a diverse sample of institutional actors, the research captured the multi-dimensional nature of entrepreneurial ecosystems in rural environments. The results underscore the central role of individual competencies, such as persistence and work ethic, alongside systemic enablers like communal infrastructure, product quality, and educational support. Factor and cluster analyses revealed nuanced typologies in how institutions conceptualize entrepreneurial support, distinguishing between development-oriented, policy-driven, and pragmatic mindsets. Moreover, the analysis of preferences for virtual training highlighted a growing institutional appetite for applied, digitally delivered education focused on practical skills and local development strategies.

Theoretical and Practical Implications

Theoretically, this study enriches the literature on rural entrepreneurship by validating the significance of institutional heterogeneity in shaping support mechanisms and policy emphasis. While prior research has often highlighted entrepreneurs themselves, this work shifts the focus to meso-level actors. The identification of distinct factor structures, such as *Entrepreneurial Skills and Training* and *Limited Role of Cultural Assets* provides conceptual clarity on how institutions prioritize different domains of rural entrepreneurial activity. The cluster analysis also supports emerging frameworks that call for segmentation-based rural policy, recognizing that institutional actors do not operate with a unified logic but are influenced by their organizational mandates, resource capacities, and proximity to local communities.

From a practical standpoint, the findings of this study provide valuable guidance for a wide range of stakeholders. First, the results can inform the design of targeted training and education programs. Institutions clearly prioritized virtual training topics related to food production, infrastructure, and craft registration. This suggests that training providers and NGOs should invest in developing modular, low-barrier e-learning platforms that offer pragmatic, locally tailored knowledge. Second, the study highlights the need for institution-specific policy communication and engagement strategies. Government institutions demonstrated a stronger preference for fiscal instruments and institutional frameworks, while educational bodies and development agencies emphasized community-based, cultural, and human capital dimensions. Third, development initiatives often fail when assuming homogeneity among institutional actors. Instead, collaboration frameworks should explicitly recognize and accommodate diverse operational logics. For example, holistic institutions (Cluster 1) may be ideal partners for pilot projects that integrate education, tourism, and community involvement, while policy-driven institutions (Cluster 2) may better support initiatives requiring regulatory backing or financing schemes.

Limitations and Directions for Future Research

While this study provides valuable insights, several limitations should be acknowledged. First, the sample is geographically restricted to Bosnia and Herzegovina, which may limit the generalizability of the findings to other national contexts with differing institutional maturity or rural entrepreneurship traditions. Second, the study relies on self-reported perceptions, which can introduce bias or inconsistencies depending on individual respondent knowledge or engagement. Future research could address these limitations in several ways. Comparative studies across countries or regions could reveal how institutional roles and priorities shift across governance systems. Longitudinal research could track how institutional perceptions evolve in response to interventions or external shocks, such as digital transitions or climate events. Additionally, triangulating institutional data with perspectives from rural entrepreneurs themselves could provide a fuller picture of alignment or disconnect between policy intent and lived entrepreneurial experience. Finally, this study relates to the relatively small sample size (N=43), which may constrain the robustness and generalizability of the findings. While these methods were employed to explore underlying patterns in institutional perceptions, the results should be interpreted with caution, as smaller samples may affect the stability of factor structures and cluster solutions. However, it is important to note that the study focuses on institutional stakeholders, a specific and relatively limited population that is difficult to access, especially within a single national context. In this regard, the sample provides valuable exploratory insights into institutional heterogeneity, even if it does not allow for broad generalization.

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Conflict of interests

The authors declare no conflict of interest.

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THE ROLE OF CORPORATE SOCIAL RESPONSIBILITY AND TECHNOLOGICAL INNOVATIONS IN THE TRANSFORMATION OF AGRICULTURAL PRODUCTION

Dragana Trifunović[1], Milena Knežević[2], Milan Milunović[3]
**Corresponding author E-mail: dragana.trifunovic@fdn.edu.rs*

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ABSTRACT

This paper examines the role of corporate social responsibility and technological innovation in the transformation of agricultural production in Serbia. The study is based on quantitative empirical research conducted on a sample of one hundred agricultural holdings and agri-food companies. The results indicate a positive relationship between socially responsible practices and production performance, as well as increasing investments in innovative technologies during the observed period. The synergy between corporate social responsibility and technological innovation is identified as an important factor in improving efficiency, environmental sustainability, and competitiveness in agricultural production. However, broader implementation is limited by financial constraints, insufficient knowledge, and moderate levels of digital adoption. The findings emphasize the importance of targeted education, institutional support, and accelerated digital transformation for the sustainable development and long-term competitiveness of the agricultural sector.

Introduction

Agriculture faces challenges arising from climate change, global population growth and the need for sustainable food production. Increasing pressure on natural resources, changing weather conditions and the need to preserve biodiversity further complicate the

1 Dragana Trifunović, PhD, Full Professor, Faculty of Social Sciences, Belgrade, Bulevar Umetnosti 2A, 11070 New Belgrade, Serbia, Phone: 0652101106, E-mail: dragana.trifunovic@fdn.edu.rs, ORCID ID (https://orcid.org/0000-0002-8051-1454)

2 Milena Knežević, PhD, associate professor, Military Academy, University of Defense in Belgrade, Republic of Serbia, Veljko Lukića Kurjaka 33, Belgrade, Serbia, Phone: 0641016596, E-mail: milena.knezevic@mod.gov.rs, ORCID ID: (https://orcid.org/0000-0003-2814-7453)

3 Milan Milunović, PhD, associate professor, Military Academy, University of Defense in Belgrade, Republic of Serbia, Veljko Lukića Kurjaka 33, Belgrade Serbia, Phone: 0641668186, E-mail: 0208luna@luna.edu.rs, ORCID ID: (https://orcid.org/0000-0002-9685-9877)

functioning of modern agricultural systems. In this context, the role of corporate social responsibility (CSR) and technological innovation becomes crucial for the transformation of agricultural production. (Gyamfi et al. 2024) In this study, CSR was measured through selected social and environmental practices, while technological innovation was assessed through the adoption of modern digital and production technologies.

CSR in agriculture implies responsible business that takes into account ecological, social and economic aspects, and contributes to the development of local communities and the preservation of natural resources. By including sustainable practices in the value chain - from cultivation, processing, distribution, to relations with consumers - CSR can become a driver of long-term stability and competitiveness in the agricultural sector (Berber et al., 2021; Aleksić et al., 2024).

Technological innovations, on the other hand, enable more efficient and precise management of agricultural production. In Serbia, the adoption of modern technologies such as drones, soil sensors, satellite monitoring and automated irrigation systems contributes to increasing productivity and reducing the negative impact on the environment (Dimitrijević, 2023; Kovačević et al., 2022; Đorđević, et al, 2020). However, despite clear advantages, their implementation is often slowed down due to limited financial resources, lack of technical knowledge and low level of digital literacy among farmers (Kljajić, Paraušić, & Stanković, 2024).

It is precisely in the synergy between CSR practices and technological innovations that the potential for a sustainable transformation of agricultural production lies. From the perspective of stakeholder theory and the Agri-4.0 concept, responsible business practices align the interests of key stakeholders, while digital technologies enable more efficient and sustainable resource management, thereby creating positive synergies in agricultural production.By integrating these approaches, it is possible to improve the efficiency of production, reduce the negative environmental impact and improve the competitiveness of Serbian agriculture on the domestic and international markets (Rajnović, Vujić, & Vujić, 2023).

Accordingly, this paper examines how corporate social responsibility (CSR) and technological innovations affect the transformation of agricultural production in Serbia.

The aim of this paper is to investigate how corporate social responsibility and technological innovation affect the transformation of agricultural production in Serbia, based on an empirical research approach. The study combines theoretical analysis with empirical evidence for the period 2020–2025, providing an updated overview of the current situation in Serbian agriculture.

The paper consists of two parts, theoretical and empirical. Special attention is given to identifying challenges in the implementation of CSR and technological innovations and to evaluating their synergistic effects on agricultural performance, with the aim of formulating practical recommendations for improving agricultural practice and policy in this area.

Literature review

The literature on corporate social responsibility and technological innovation in agriculture emphasizes their increasing importance for sustainability and competitiveness. However, existing studies often analyze these concepts separately, with limited empirical evidence on their combined effects, particularly in transition economies such as Serbia.

Corporate social responsibility (CSR) refers to a business approach in which companies, beyond profit generation, assume responsibility for their social and environmental impacts, guided by principles of ethical conduct, sustainability, transparency, and stakeholder engagement (Aguinis & Glavas, 2019; Jamali et al., 2020). In the agricultural context, CSR is most commonly reflected through practices related to working conditions, community support, environmental management, and product safety (Carroll & Shabana, 2018; Schaltegger et al., 2019).

In the agricultural sector, corporate social responsibility encompasses practices aimed at environmental sustainability and social welfare, including soil conservation, rational use of natural resources, reduction of chemical inputs, and improvement of working conditions for agricultural workers (Martínez-Fernández et al., 2021; López-Gamero et al., 2020; Fernández-Fernández et al., 2022). CSR initiatives also contribute to rural development through investments in local communities, thereby supporting long-term agricultural sustainability and stakeholder trust.

In the agro-industry, CSR has gained particular importance under conditions of climate change and growing food demand, where sustainable resource management becomes essential. Firms increasingly integrate environmental innovations such as renewable energy use, precision agriculture, and sustainable waste management in order to reduce emissions, improve efficiency, and enhance ecosystem resilience (García-Lopera et al., 2021; Tseng et al., 2019; Savić & Marjanović, 2025).

In addition, sustainable and transparent supply chains, covering all stages from the cultivation of raw materials to the distribution of finished products, are becoming key elements of CSR strategies in large food companies. These chains enable better control over environmental and social standards, reducing the risk of unethical practices and fostering consumer confidence (Nguyen et al., 2022; Chen et al., 2020). The integration of digital technologies for supply chain tracking and transparency further contributes to business efficiency and sustainability (Kumar et al., 2021).

In rural areas, corporate social responsibility contributes to social cohesion, local employment, and knowledge diffusion through investments in education, training, and community development, thereby indirectly supporting agricultural productivity and sustainability (Meyer et al., 2022). CSR initiatives aimed at social inclusion, including support for women and youth, as well as partnerships with local institutions and non-governmental organizations, further enhance the resilience and long-term development of agricultural communities (Jain & Jamali, 2016; Gavurová & Csizmadia, 2020; Panić et al., 2025).

In Serbia, the application of corporate social responsibility in agriculture and agro-industry is still in the development phase, but there are significant positive examples that indicate the potential for further progress. Certain family farms actively integrate socially responsible practices, particularly through soil conservation, collaboration with local educational institutions and donations to communities. These practices not only contribute to environmental sustainability, but also strengthen the connection between agriculture and local communities, which is crucial for the development of rural areas. (Rajnović et al., 2023)

CSR in the Serbian food industry most often focuses on environmental aspects of business, such as improving energy efficiency, using renewable energy sources and responsible management of packaging waste. (Berber et al., 2021; Bučalina Matić et al., 2024; Žikić et al., 2024). Such initiatives not only reduce the negative impact of industry on the environment, but also improve the reputation of companies with consumers and investors.

In addition, larger organizations in Serbia, especially those operating on the international market, are increasingly integrating CSR policies that include both social and environmental dimensions, aligning with global sustainability standards. These initiatives contribute to better competitiveness of the Serbian agricultural sector and the creation of long-term values for all interested parties. (Aleksić, et al., 2024)

Although previous studies provide valuable insights into CSR practices and technological innovations in agriculture, there is a lack of recent empirical research that jointly examines their synergistic effects on agricultural performance, especially in the Serbian context. Most existing research focuses either on large agribusinesses or on technological adoption in isolation, without sufficiently addressing how responsible business practices and digitalization interact at the farm and company level. This study seeks to fill this gap by providing an updated empirical analysis for the period 2020–2025 and by evaluating the combined impact of CSR and technological innovation on the transformation of agricultural production in Serbia.

Materials and methods

This study is based on quantitative empirical research, supported by a descriptive and analytical approach. The research was conducted in the Republic of Serbia during the period January–March 2025. Data were collected using a structured questionnaire, specifically designed to examine the level of implementation of corporate social responsibility (CSR) practices and technological innovations in agricultural production. The sample consisted of 100 respondents, including owners of agricultural holdings and managers of agri-food companies of different sizes. These respondents were selected due to their direct involvement in decision-making processes and their knowledge of business performance, CSR activities, and technological investments.

The observed time horizon covered the period 2020–2025, enabling an analysis of trends in CSR implementation and technological innovation adoption.

CSR was measured through indicators related to innovation and product safety, support to local communities, investment in working conditions, and environmental management. Technological innovation was assessed through investments in digital technologies, automation, precision agriculture, and modern production systems. All variables were measured using categorical and percentage-based indicators, based on respondents' self-reported data.

The collected data were processed using descriptive statistical methods, including frequency analysis and percentage distribution. In order to examine the relationship between CSR practices and agricultural performance, as well as between technological innovation and production efficiency, correlation analysis was applied. The strength and direction of relationships between variables were assessed using linear correlation coefficients. To ensure data reliability, the questionnaire was pre-tested, applied consistently across all respondents, and the collected data were checked for completeness and logical consistency prior to analysis. All statistical analyses and graphical presentations were performed using Microsoft Excel and SPSS statistical software.

It is important to emphasize that the research has certain limitations. Primarily, the results depend on the honesty and accuracy of the respondents' answers, and there is a possibility that some answers are biased or incomplete due to subjective experience or the desire to present themselves in a more positive light.

Despite these limitations, the collected data provide significant insights into the current state and challenges related to the implementation of CSR and technological innovation in agriculture, which contributes to a better understanding of the factors influencing the transformation of the sector.

Research hypotheses:

H1: There is a positive relationship between the application of corporate social responsibility and success in agricultural production.

H2: Technological innovations have a positive effect on the efficiency of agricultural production.

H3: The combination of CSR and technological innovation contributes to a greater transformation of agriculture than their individual application.

H4: There are obstacles that affect the implementation of CSR and technological innovations in agriculture.

Results with Discussion

The research was followed by data processing, which was presented through tabular and graphic displays. The first table shows the representation of corporate social responsibility in farms and agri-food companies in the last five years, in the period from 2020 to 2025. What percentage of surveyed farms and agri-food companies answered YES according to various parameters of CSR in the past five years can be seen in the tabular presentation, and after that, in the graphic presentation.

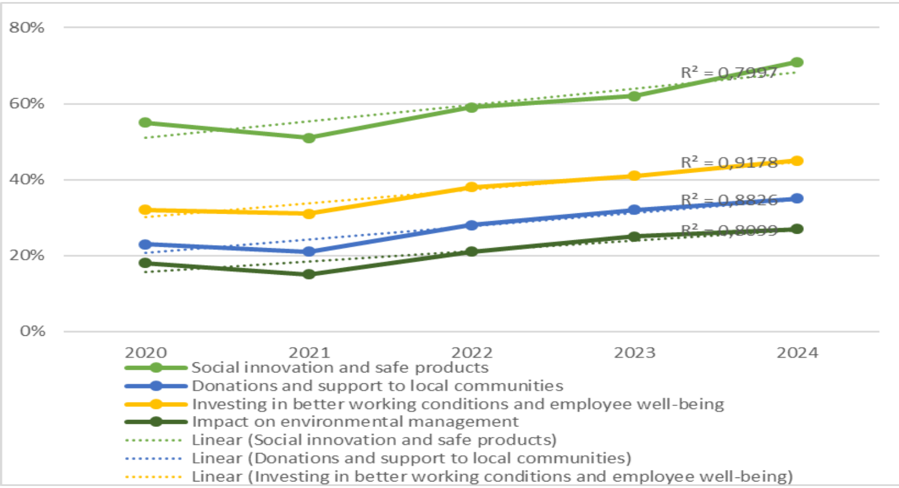
Table 1. Presentation of corporate social responsibility in farms and agri-food companies from 2020-2025

Year	Innovation and safe products	Donations and support to local communities	Investment in better working conditions and the welfare of workers	Impact on environmental management
2020	58%	21%	32%	15%
2021	51%	25%	35%	18%
2022	59%	28%	38%	21%
2023	62%	32%	41%	25%
2024	71%	35%	45%	27%

Source: author's own account

We can see that a large number of surveyed farms and agri-food companies increase innovation and work on safe products year after year, from 58% who answered yes for 2020, to 71% who answered yes for 2024. Giving donations and supporting local communities is increasing year by year, although these are not high percentages and go up to 35% of respondents who answered affirmatively for the year 2024. There is also a noticeable trend of increasing investment in better working conditions for workers, up to 45% of respondents answered affirmatively for the year 2024, as well as an increasing concern for the environment from year to year, which goes up to 27% of affirmative answers for the year 2024. These findings are consistent with previous studies indicating that the gradual adoption of CSR practices in agriculture is primarily driven by innovation-related activities, while social and environmental dimensions develop more slowly (Berber et al., 2021; Aleksić et al., 2024). Similar trends have been observed in other transition economies, where CSR implementation is often incremental and constrained by limited financial and human resources.

Figure 1. Graphic representation of CSR in farms and agro-food companies in the last five years from 2020-2025

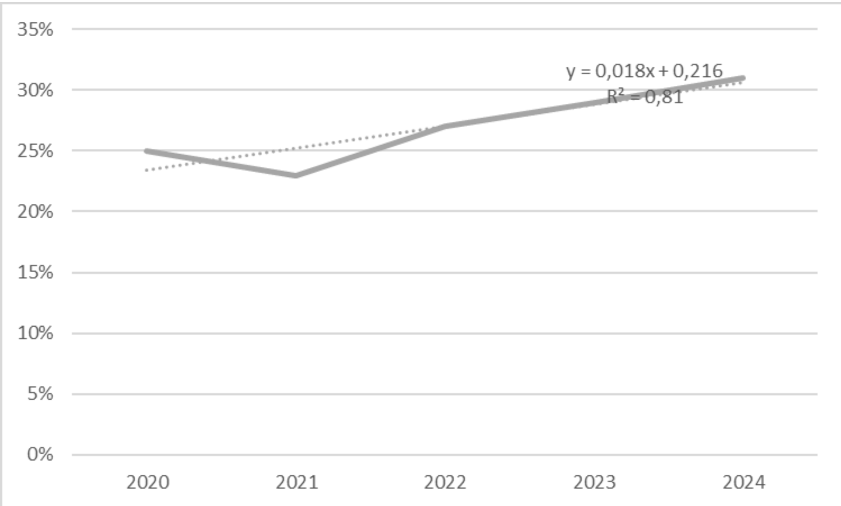


Source: author's own account

In Figure 1, we see that a high coefficient in the range from 0.7997 to 0.9178 indicates a very strong positive linear connection between various parameters of corporate social responsibility (CSR) and their implementation in Serbian agriculture during the period from 2020 to 2025.

Although there is growing awareness among farmers and agro-food companies in Serbia of the importance of implementing the principles of corporate social responsibility (CSR), there are significant obstacles in their implementation. The key factors that slow down the wider implementation of CSR practices are limited resources and lack of education. Although there is evident progress in understanding the importance of CSR, many farmers and companies face challenges in integrating sustainable practices due to a lack of capacity and professional knowledge. (Kljajić, et al., 2024; Žikić et al., 2022; Dašić et al., 2024)

Figure 2. Investments in technological innovations



Source: author's own account

Figure 2 shows a linear representation of investment in technological innovation over the last five years, from 2020 to 2025. It can be seen that the percentage of farms and agri-food companies that invest in technological innovations is increasing year by year. In 2024, 31% of respondents answered that they invested in technological innovations, it is not a large percentage compared to the total number of respondents, but it is a good indicator that it is increasing from year to year. The share of companies investing in technological innovation is continuously growing (except for a slight decline in 2021), which indicates increasing awareness and capacity for modernization in the sector. The increasing investment in technological innovation supports earlier findings that digitalization is gradually becoming a key driver of productivity and sustainability in agriculture, although adoption rates remain moderate (Kljajić et al., 2024; Gyamfi et al., 2024). Compared to studies conducted in more developed agricultural systems, the observed level of investment in Serbia remains relatively low, highlighting structural and financial constraints.

Technological innovation, digital transformation, including technologies such as IT, artificial intelligence (AI), Internet of Things (IoT) and big data analytics are key to advancing green innovation within corporate social responsibility (CSR) strategies. An empirical study conducted in China showed that digitalization directly increases the ability for green innovation, with CSR functioning as a catalyst for that process (Zhang, Liu & Cao, 2023). Technologies such as artificial intelligence, cloud computing and big data analytics enable the reorganization of business models and process paradigms towards green and low-carbon development (Zhang et al., 2023).

In the agricultural sphere, the concept of "Agriculture 4.0" integrates technologies such as precision agriculture, IoT sensors, drones and big data analytics to optimize the use of resources and increase sustainability (Gyamfi et al., 2024; Rejeb et al., 2023).

Sensor data and real-time analytics enable micro-level interventions: precise distribution of water and fertilizers according to actual soil needs, early detection of pests and plant conditions before damage occurs (Cihan, 2023; Malešević et al., 2024)

Table 2. Comparative analysis of CSR in Serbia

Element	**Farms**	**Agri-food companies**
Formal CSR	They are practically non-existent: no strategy, no reports, no certificates	Clearly structured: strategic programs, reporting
Education and digital support	Using the e-Agrar system	They provide training through foundations, partnerships with PSSS
Sustainable practices	Indirect (saving water and inputs), motivated by profit, not publicly declared	Active ecological initiatives, regenerative agriculture, certificates
Community projects/ humanitarian work	Rare, informal donor gestures - mostly individual	Regular donations (food, equipment), children's playgrounds, contribution during the pandemic
Transparency and recognition	Without public transparency and evaluation	Participation in the CSR index, awards ("Sustainability Champion"), public recognition

Source: author's own account

Table 2 shows a comparison between farms and agri-food companies by various elements based on the conducted research.

Conclusions

This paper confirms that the synergy between corporate social responsibility (CSR) and technological innovation represents a critical strategy for the transformation of agricultural production. The empirical results indicate a strong positive relationship between CSR activities and production performance, as well as a growing level of investment in technological innovation, suggesting an increasing orientation of the agricultural sector toward digitalization and environmental sustainability.

Digital technologies such as sensors, drones, IoT systems, and digital platforms enable more precise resource management, environmental monitoring, and transparency in agricultural production. In this way, technological innovation operationalizes CSR principles by transforming responsible business practices into measurable and evidence-based outcomes related to efficiency, environmental protection, and productivity. However, despite positive trends, the overall level of technological adoption remains moderate, indicating the presence of structural, financial, and knowledge-related barriers.

The results further show significant differences between agri-food companies and agricultural holdings in the implementation of CSR practices. Agri-food companies tend to adopt a more structured, transparent, and strategic approach to CSR, with greater emphasis on education, environmental initiatives, donations, and public recognition. In contrast, agricultural holdings more frequently apply informal and less visible CSR practices, primarily oriented toward short-term operational and profit-related benefits. These differences highlight the need for targeted education, advisory support, and institutional assistance for smaller farms, as well as the importance of strengthening partnerships between farms and agri-food companies to facilitate knowledge transfer and broader CSR adoption.

From a practical and policy perspective, the findings suggest that agricultural development strategies should place stronger emphasis on integrated CSR–technology programs. Financial incentives, training initiatives, and advisory services aimed at improving digital skills and access to innovative technologies—particularly for small and medium-sized farms—are essential. Institutional support mechanisms, including national subsidy schemes and rural development programs, could play a key role in reducing adoption barriers and promoting sustainable and competitive agricultural production.

This study has certain limitations. The findings rely on respondents' self-assessment, which may introduce subjective bias, while the relatively small sample size and the focus on Serbian agriculture limit the generalizability of the results. Future research should include larger and more diverse samples, apply longitudinal research designs, and use more advanced statistical methods to further examine causal relationships between CSR, technological innovation, and agricultural performance, as well as to assess the long-term effects of their combined implementation.

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Conflict of interests

The authors declare no conflict of interest.

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EXTENDING THE BUSINESS MODEL CANVAS FOR SUSTAINABLE SMALLHOLDER COFFEE FARMING: INTEGRATING DIGITAL MARKETING, GREEN FINANCE, AND CIRCULAR ECONOMY

Masyadi[1], Mukhlis Abbas[2], Andi Zulfayani[3]
**Corresponding author E-mail: masyadi@unipol.ac.id*

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A B S T R A C T

This study develops and validates an Extended Business Model Canvas (BMC) integrated with the Triple Bottom Line (TBL) principles, focusing on digital marketing, green finance, and circular economy practices for smallholder coffee farming in Soppeng Regency, Indonesia. Using a mixed-methods explanatory sequential design, the study combined exploratory fieldwork, participatory model development, and pilot testing with 100 farmers. The results showed a 44% increase in gross monthly income, a 26% increase in sales volume, a 14% rise in average selling prices, and significant environmental benefits such as 47% waste recycling and 32% reduced chemical fertilizer use. Regression analysis indicated that digital readiness, cooperative networks, and institutional support were key drivers of adoption, while limited capital and poor infrastructure remained persistent barriers. This study highlights integrated approaches to smallholder farming that promote positive social, environmental, and economic impacts, contributing to the achievement of sustainable development goals and advancing Sustainable Business Model Innovation (SBMI) literature.

Introduction

Smallholders continue to be indispensable to agricultural production in developing nations. Rural farmers continue to encounter obstacles such as inadequate infrastructure, low capital, reduced negotiating leverage, and susceptibility to climate shocks (Ma'wah et al., 2023).

1 Masyadi, Lector, Lamappapoleonro University, Soppeng, Sulawesi, Indonesia, Phone: +6282314084446, E-mail: masyadi@unpol.ac.id, ORCID ID (https://orcid.org/0000-0001-8299-099X)

2 Muchlis Abbas, Associate Professor, Lamappapoleonro University, Soppeng, Sulawesi, Indonesia, Phone: +6281241945719, E-mail: muchlisabs@gmail.com, ID ORCID (https://orcid.org/0009-0007-0004-6518)

3 Andi Zulfayani, Lektor, Universitas Lamappapoleonro, Soppeng, Sulawesi, Indonesia, Phone: +6285299639457, E-mail: andi.zulfayani@unipol.ac.id, ORCID ID (https://orcid.org/0009-0009-9045-7947)

Coffee is a very important product and a big source of wealth in Indonesia, especially in places like Soppeng. But there are still problems with the environment, restricted market links, and different manufacturing systems (Jacobi et al., 2024)(Guambi et al., 2024). These circumstances underscore the pressing necessity for sustainable business methods that enhance environmental conservation and the economic resilience of smallholders.

The circular economy and zero-waste practices have been suggested as strategies to enhance soil fertility and resource efficiency (Barbhuiya et al., 2024)(Bocken et al., 2019), green finance to reduce production costs and promote eco-innovation (Bachmann et al., 2025)(Eshbayev et al., 2024), and digital marketing to increase market penetration (Yang et al., 2024)(Uçar et al., 2020). The majority of these research concentrate on a singular aspect of the systemic challenges confronting smallholder agriculture, leading to disjointed strategies for addressing these challenges (Lorinkova & Perry, 2019) (Rossi & Srai, 2024). At this time, there isn't a comprehensive framework for smallholder agriculture that brings together the notions of digital marketing, green finance, and the circular economy.

Bringing these things together is especially important in two areas: sustainable agriculture and the global development agenda. To meet the United Nations' Sustainable Development Goals (SDGs), especially Goals 2, 12, 13, and 15, it is necessary to put into action agroecology, diversification, and soil-health programs (Himshikha et al., 2024); (Philip & G., 2024). Even though organic and integrated farming methods make better use of resources (Philip & G., 2024) (SHEN et al., 2020), they are still not widely used because of problems with technology, governance, and social and economic factors (Duarte et al., 2021)(da Silva et al., 2023). Policy-supported strategies from Spain, Kenya, India, and Africa illustrate the implementation of solutions that simultaneously increase soil production, alleviate poverty, and improve climate resilience.

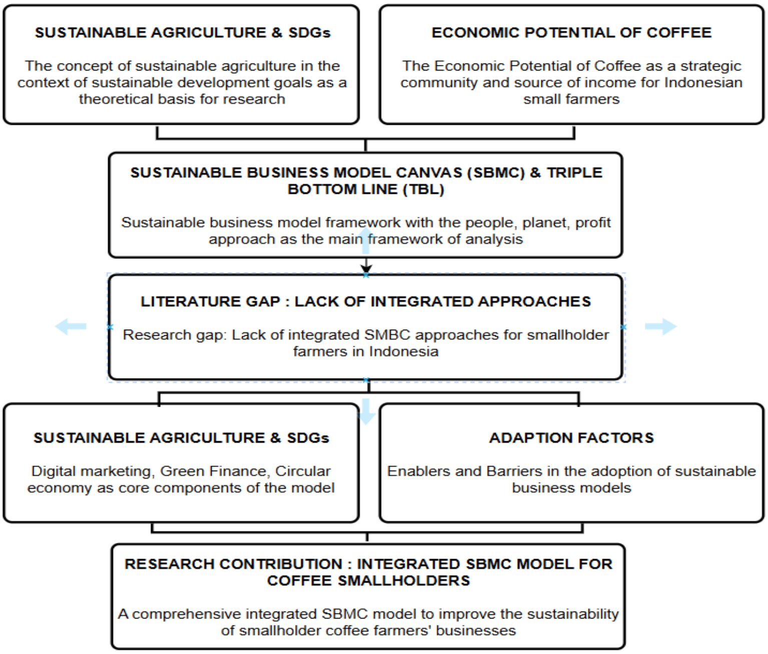
Coffee shows how smallholder systems may be both profitable and weak. Businesses in Rwanda and Indonesia show that Gayo Arabica is a key export that brings in money from other countries and helps people in rural areas (Ma'wah et al., 2023). Coffee is the principal source of income for millions of smallholder farmers in Latin America, Africa, and Asia. Speciality coffee markets in Bolivia, Ecuador, and Colombia are opening up new markets (Jacobi et al., 2024)(Guambi et al., 2024). But illnesses, pests, changes in the weather, and structural financial shortages still threaten sustainability (Smith et al., 2022) (Ma'wah et al., 2023). Integrated value chains and collaborative breeding are two new yet promising technologies (Ngure & Watanabe, 2024)(Smith et al., 2022).

To address these concerns, the Sustainable Business Model Canvas (SBMC) was developed by integrating the Triple Bottom Line (TBL) components of economic, social, and environmental value creation into the Business Model Canvas (BMC) (Duarte et al., 2021) (da Silva et al., 2023) (Zybareva et al., 2022). The SBMC's programs can assist agribusinesses find a balance between making money and doing good for people and the environment. Governance instruments like B Corps encourage stakeholder involvement and responsibility, but cooperatives and extension services have been used in smallholder settings to solve environmental problems and problems with getting to markets (Muafi & Hadi, 2023) (Zybareva et al., 2022). But SBMC is still not widely used in developing nations since there isn't enough money, the implementation isn't well-organised, and people don't know how to use digital tools.

Digital marketing, green finance, and the circular economy together offer smallholder coffee systems revolutionary potential that empirical study has not yet proved. Digital platforms enhance visibility and marketing avenues (Yang et al., 2024)(Uçar et al., 2020) (Trajkovska Petkoska et al., 2025), while green finance instruments such as bonds and sustainability-linked loans reduce the cost of capital for environmentally friendly innovation (Castrillón et al., 2021)(Lv et al., 2023). However, adoption frequently necessitates institutional and cooperative endorsement. Composting, trash reduction, and nutrient cycling are examples of circular economy activities that enhance resource productivity but are underutilised in the absence of financing and enabling laws (Islam et al., 2024) (Srisathan et al., 2025).

In conclusion, research on smallholder coffee systems underscores the advantages and disadvantages of sustainable development. However, an integrated model with empirical support is still required (Pretty et al., 2020) (Khan & Mahajan, 2025). This research fills this knowledge void by formulating and validating an enhanced SBMC framework that integrates digital marketing, green financing, and circular economy concepts. This research implements the TBL strategy in rural coffee growing in Indonesia, enhancing alignment with the SDGs, fostering socioeconomic transformation, and bolstering smallholder (da Silva et al., 2023) (Ma'wah et al., 2023).

Figure 1. Literature Review Framework



Source: Author's modification based on Osterwalder & and field data

Materials and methods

This study utilized a mixed-method approach, weaving quantitative and qualitative data in an explanatory sequential manner in order to understand the nuanced complexities of sustainable agribusiness in smallholder coffee farms and develop, implement and assess a novel integrated business model harnessing socio-economic resilience through digital marketing, green finance, and circular economy in Soppeng Regency, South Sulawesi, Indonesia.

Research included five steps: first, an exploratory phase to evaluate the model barriers and opportunities, which commenced with the Business Model Canvas (BMC) and geometrically expanded to include the Triple Bottom Line (TBL) principles to formulate the model, the integration of the model with farmer organizations, value chain assessment and iterative refinement of the model assessment and iterative refinement of the policy model with recommendations.

The study disenfranchised smallholder coffee farmers since Soppeng Regency was an advantageous highland with a long-standing tradition of cultivating coffee and possessing active farmer cooperatives. For the qualitative phase, purposive sampling targeted and selected fifteen farmers, cooperative heads, and government bureaucrats as key informants. Additionally, two focus group discussions (FGDs) were conducted with cohorts of 8-10 participants. In the quantitative phase and the pilot stage, the population was aligned stratified purposively with 50 farmers, expanded in the evaluation phase to 100 farmers. Respondents with land, education, cooperative membership, and age diversity were included.

The data collection procedures were comprised of both qualitative and quantitative methods. Qualitative information was obtained via semi-structured interviews and focus group discussions (FGDs), participant observation and engagement, and ongoing interaction. Quantitative data was collected through structured pre-and post-surveys measuring variables of income, market access, digital financial access, financial literacy and waste management, and perceived well-being. The survey instruments were adapted from peer-reviewed sustainability studies, with contextual purchase, to ensure reliability and congruence to local settings.

The independent variables were adoption of digital marketing, access to green finance and zero waste practices, and dependent variables were farmer income, market access, and cost as well as environmental efficiency. Control variables were age, level of education, size of land, and membership to a cooperative.

Data were analyzed qualitatively using grounded theory through open, axial, and selective coding, using NVivo 12 software. Credibility was established through triangulation and member checking. Quantitative data was analyzed and processed using SPSS v28, and employed descriptive statistics and multiple linear regression with t-tests and Wilcoxon tests for non-parametric data. Instrument validity and reliability tests were conducted and all Cronbach's alpha results exceeding 0.7, regression assumptions were tested and confirmed including normality, homoscedasticity, and absence of multicollinearity.

The local government, as well as farmer cooperatives, have provided their ethical approval. No one was forced and all participants signed statements of consent. Identification of respondents and private details was omitted, and the information was only used for scholarly purposes, thus, anonymity and confidentiality was protected.

Soppeng Regency was selected for the location of the study because of it's reputation as a highland producing coffee as well as socio-ecological problems like market dependence, poor finances, and environmental issues. The active involvement of cooperatives in the area made it an ideal area for implementing and improving the tested sustainable business model.

Results

The preliminary stage of research detected three key obstacles to smallholder coffee farming in Soppeng Regency. First, 86% of farmers in Soppeng Regency, considered to be digital illiterate, have never used e-commerce and have no experience employing it. Farmers predominantly market to and sell their coffee to middlemen. Second, 74% of smallholder farmers did not have access to appropriate finance, through no fault of their own. Sustainable finance was mostly inaccessible because the farmers could not meet the collateral stipulations set for formal loans. Third, 90% of the coffee by-products, namely, pulp and grounds, were not treated, and proper waste management was inefficient by default

Table 1. Barriers to Coffee Farming in Soppeng

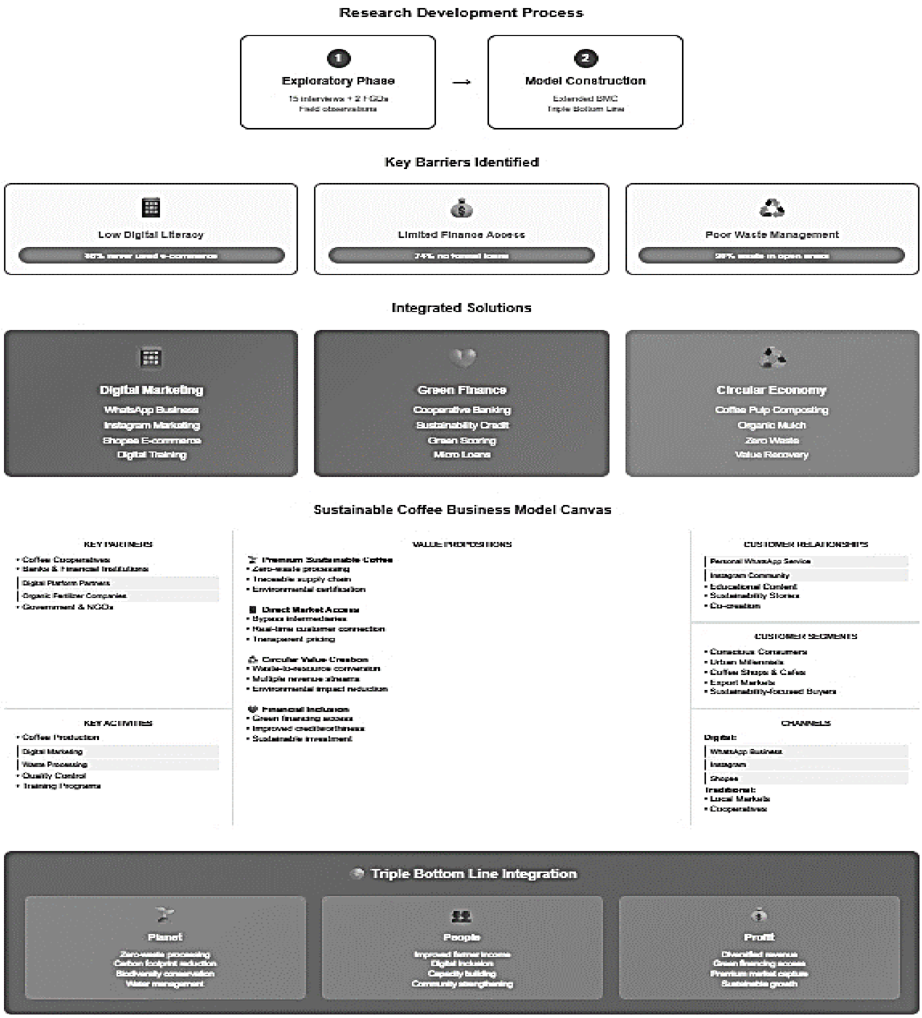
Identified Barriers	Description	Evidence from the Field
Low Digital Literacy	Farmers rely heavily on traditional intermediaries and have limited knowledge of online marketing platforms.	86% of respondents reported never using e-commerce for sales.
Limited Access to Sustainable Finance	Absence of financing schemes linked to sustainable practices; high collateral requirements from banks.	74% of respondents stated they had no access to formal loans.
Inefficient Waste Management	Coffee pulp and spent coffee grounds are discarded without processing, contributing to environmental degradation.	Observations confirmed 90% of the waste was disposed of in open areas.

Source: Field Survey

The findings attest to structural deficits that, in comparative terms, are no different than those exhibited in Latin America and Africa where smallholders have defined and deeply-rooted challenges in the adoption of market-based technologies (Dibbern et al. 2025, Bashiru et al. 2024).

With the adoption of participatory workshops, the Extended Business Model Canvas (BMC) was created incorporating TBL principles. The Extended BMC did promote economic, social and environmental sustainability through the marketing of digital platforms, composting coffee waste, and the production of organic coffee at premium prices. The proposed framework is shown in Figure 1 and the TBL impacts are detailed in Table 2.

Figure 2 Extended Business Model Canvas for Coffee Farmers



Source : Adapted from Osterwalder & Pigneur

Table 2. Triple Bottom Line Impacts of the Proposed Model

BMC Block	Proposed Strategy	Triple Bottom Line Impact
Customer Segments	Specialty coffee buyers, eco-conscious consumers, domestic and export markets.	**Economic**: Premium price. **Social**: Stronger community branding. **Environmental**: Support for eco-certified products.
Value Proposition	High-quality organic coffee; transparent sourcing; zero-waste processing.	E: Increased income. S: Farmer empowerment. Env: Waste reduction.
Channels	Digital platforms (WhatsApp Business, Instagram, Shopee), local coffee shops, and cooperatives.	E: Wider market access. S: Inclusion of youth & women. Env: Reduced carbon footprint via direct sales.

BMC Block	Proposed Strategy	Triple Bottom Line Impact
Customer Relationships	Direct buyer engagement via storytelling, traceability labels, and community tours.	E: Loyalty. S: Cultural preservation. Env: Awareness building.
Revenue Streams	Coffee sales, compost sales, eco-tourism packages.	E: Income diversification. S: Local job creation. Env: Circular income loop.
Key Resources	Coffee farms, composting facilities, trained farmer groups, digital tools.	E: Sustainable productivity. S: Capacity building. Env: Organic inputs.
Key Activities	Training in digital marketing, composting, and green finance literacy.	E: Skills enhancement. S: Social capital. Env: Regenerative farming.
Key Partnerships	Cooperatives, local government, microfinance institutions, NGOs.	E: Financing channels. S: Institutional trust. Env: Policy support.
Cost Structure	Digital tools, training programs, waste processing equipment.	E: Efficient resource allocation. S: Inclusive budgeting. Env: Investment in sustainability.

Source: Author's Calculations

Pilot testing involved 50 farmers belonging to three farmer clusters. The adoption rates were favorable: 78% of the farmers on Instagram and WhatsApp Business utilized them for direct sales, 71% of the farmers engaged in composting and mulching, and 62% of farmers were able to access sustainability-linked cooperative loans. These results suggested the possibility of integrating digital, financial, and circular economy practices within smallholder systems.

Sales in the 6 months after the intervention had grown quite significantly. There was an increase of 145kg to 183kg worth 26% of sales in one month and the kg was significantly worth 0.001. Selling prices worth 0.001 also had an increase of 14% from IDR 42,000 to 47,800. The gross monthly income also had an increase which was about 6.09 million to 8.75 million which is worth 44% and is significant of 0.001. The Entrepreneurs had an increase in confidence which was 1.07 points and there was an engagement from the younger people and women in marketing digitally. There was an increase in the reuse of organic waste which was 47% from 21% to 68%. There was an increase in the organic matter soil which was 0.6% and the chemical use of fertilizers decreased 32% and all of these were statistically significant.

Table 3. Pre- and Post-Implementation Scores of Key Indicators

Model Component / Indicator	Adoption Rate (%)	Pre-Test Mean	Post-Test Mean	Mean Difference	t-value	p-value	Interpreta-tion	Evidence Source
Digital Marketing	78%	Monthly Sales Volume: 145 kg	183 kg	+38	-9.72	<0.001	Significant increase	WhatsApp & Instagram analytics
		Average Selling Price: IDR 42,000	IDR 47,800	+5,800	-8.41	<0.001	Significant increase	
		Gross Monthly Income: IDR 6,090,000	IDR 8,747,400	+2,657,400	-11.56	<0.001	Significant increase	

Model Component / Indicator	Adoption Rate (%)	Pre-Test Mean	Post-Test Mean	Mean Difference	t-value	p-value	Interpreta-tion	Evidence Source
		Market Access Score (1–5): 2.84	4.09	+1.25	-14.22	<0.001	Significant improvement	
		Entrepreneurial Confidence (1–5): 3.05	4.12	+1.07	-13.85	<0.001	Significant improvement	
Green Finance Access	62%	Input Cost Burden	↓ 18%	—	—	<0.001	Substantial decrease	Cooperative loan records
Zero-Waste Practices	71%	Organic Waste Recycling Rate: 21%	68%	+47%	-15.44	<0.001	Significant improvement	Field soil tests
		Reduction in Chemical Fertilizer Use	—	32% decrease	—	—	<0.001	Substantial decrease
		Soil Organic Matter: 2.1%	2.7%	+0.6	-7.83	<0.001	Significant improvement	
Cross-Component Impact	—	—	—	—	—	—	Enhanced negotiation confidence and business planning	Post-intervention interviews

Source: Author's Calculations

Adoption of new techniques was explained in beta value of recordable change of 0.64 as in Table 4.

Table 4. Regression Results for Factors Affecting Model Adoption

Predictor Variable	Coefficient (B)	Std. Error	t-value	p-value	Interpretation
Strong Cooperative Networks	0.214	0.062	3.45	0.001	Positive, significant
Government & NGO Support	0.198	0.059	3.36	0.001	Positive, significant
Digital Marketing Readiness	0.254	0.071	3.58	<0.001	Strongest positive driver
Cultural Alignment	0.127	0.055	2.31	0.023	Positive, moderate effect
Demonstrated Income Increase	0.183	0.066	2.77	0.007	Positive, significant
Limited Upfront Capital	-0.219	0.058	-3.78	<0.001	Negative, significant
Resistance to Change	-0.141	0.061	-2.31	0.023	Negative, moderate effect
Infrastructure Gaps	-0.176	0.057	-3.09	0.003	Negative, significant
Knowledge Gaps in Green Finance	-0.133	0.056	-2.38	0.019	Negative, moderate effect
Seasonal Production Variability	-0.095	0.052	-1.83	0.070	Negative, marginal significance

Source: Author's Calculations

Most positively driving adoptions were digital readiness ($\beta = 0.254$, $p < 0.001$), cooperative networks ($\beta = 0.214$, $p = 0.001$), and support from government or donor organization ($\beta = 0.198$, $p = 0.001$) in addition to demonstrated income increases. The negative hindrances to change adoption were, however, limited available capital ($\beta = -0.219$, $p < 0.001$), infrastructural gaps ($\beta = -0.176$, $p = 0.003$), and lack of knowledge of green financing ($\beta = -0.133$, $p = 0.019$). Old farmers' mentalities, change resistance, and variability in seasonal production were also barriers, but these had weak or marginal effects.

As a whole, these findings reveal that the addition of digital marketing, financing, and green circular economy integrated with developing of a BMC framework previously resulted in improved economic, social, and environmental benefits for smallholder coffee farmers in Soppeng Regency.

Discussions

The integration of digital marketing together with green finance and zero-waste practices enhanced smallholder coffee systems economically and ecologically more than any measures taken individually. This is contrary to previous works that examined these factors in isolation. For instance, in Vietnam, (Nguyen & Vo, 2021) found that digital platforms enhanced market access, but ignored the financing gaps while in Brazil (da Silva et al., 2023) found that the financial advantages of composting were unaccounted for. By integrating these factors, the pairs create further evidence of a more bounded and viable pathway in smallholder agriculture through an integrated Business Model Canvas based on the Triple Bottom Line framework.

This research also enhances the emerging literature on Sustainable Business Model Innovation (SBMI) by demonstrating that, contrary to the previous works that focused on certification, market access, and ecological practices in a siloed approach, the variables of profit, social inclusion, and environmental inclusion can all be achieved together. The cooperative interrelations and local integration became central factors to the more beneficial model, supporting the evidence that sustainable business models anchored on trust and cooperative action (Schiavon et al., 2022)(Bemelmans & Maertens, 2025) work best.The effects cross numerous domains. To begin with, the farmers made capital gains while reducing chemical dependencies and embracing composting because digital channels enabled them to sell their goods virtually. Selling online enabled the participation of women and the youth. This indicates generational renewal and gender inclusivity. Cooperatives reinforced their institutional trust by providing the farmers and other stakeholders with training on peer-to-peer learning, indirectly becoming financial intermediaries. This also showed the trust policymakers and financing institutions place on them. These conclusions point to the policymakers and financing institutions digital rural infrastructure, green finance, and digital circular economy enforcement policies strategy gaps.

The model's social and environmental dimensions add on to the previously mentioned economic gains. Cultural practices such as gotong royong fostered community cohesion, traditionally revitalized, alongside improved soil quality and reduced soil erosion because the zero-waste practices and the olden community. These insights align with emerging literature that argues on the enhanced focus of sustainable development and transition on social and cultural wellbeing beyond the economy (Ayeyemi et al., 2023)(Zhu & Wang, 2024).

More focus should be paid to the other literature though. Especially the literature that focuses on the challenges of the model. Reluctance from older farmers, lack of funding, and poor infrastructure are the most significant gaps, next to the slim range of the sample and short duration the pilot was conducted.

Hence, future research should utilize longitudinal designs to assess the permanence of recorded results, investigate the technologies of mobile banking and blockchain to broaden the availability of green finance, and assess the transferability of the augmented model to additional crops and areas. Integrating on-farm innovations with worldwide value chains and consumer demand would enhance the relevance and effectiveness of smallholder agriculture sustainable business models.

Conclusions

Indeed, the practice of digital marketing, green finance, and zero-waste within the encapsulating framework of the extended Business Model Canvas, abiding by the principles of the Triple Bottom Line, also showed clinically proven enhancement of the resilience and sustainable practice of smallholder coffee farming in Soppeng, Indonesia. The Pilot confirmed substantial economic, social, and environmental benefits, which also verified increased revenue, enhanced market penetration, and improved soil and waste management.

This approach also contributes to literature as sustainable business model innovation within smallholder agriculture has yet to be explored in such vast detail. The extended framework demonstrates that, in contrast to previous, siloed attempts at reaching balance, profit, inclusivity, and ecological protection can be targeted at the same time.

The results of the study also indicate that in order to achieve scaling, there has to be digital infrastructure in place, cooperative-driven finance, and local farming curricular which emphasize the principles of a circular economy. Capacity building, particularly focused on women and youth, is also necessary to achieve greater resistance through intergenerational adoption.

Further research should take other commodities and other regions into account to cross study the model as well as apply a longitudinal approach to more accurately gauge the resilience and scalability of the results across different farming systems.

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Conflict of interests

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AGRI-ENVIRONMENTAL INDICATORS IN THE EU: MEASURING DISCREPANCIES ACROSS MEMBER STATES

Danijela Pantović[1], Nemanja Pantić[2], Milica Luković[3], Branislav Dudić[4]
**Corresponding author E-mail: milica.petrovic@kg.ac.rs*

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ABSTRACT

The paper analyzes agri-environmental indicators of EU countries from 2017 to 2023 to assess progress toward sustainable agriculture. Using descriptive statistics, principal component analysis (PCA), and a composite index, it identifies key sustainability dimensions and ranks EU countries by performance. Results indicate reduced agricultural greenhouse gas emissions, growth in renewable energy production, and expansion of organic farming areas. However, pesticide sales and related environmental risks remain high, highlighting ongoing dependence on chemical inputs. PCA reveals two main components: the first reflects energy and agricultural sustainability, while the second captures ecological risks linked to pesticide use and emissions. The composite index shows clear disparities among EU countries—some have advanced, while others lag behind the EU average. Findings suggest that EU agricultural policy should intensify pesticide reduction efforts while continuing to promote renewable energy and organic farming initiatives.

1 Danijela Pantović, PhD, Associate Professor, University of Kragujevac, Faculty of Hotel Management and Tourism Vrnjacka Banja, Vojvodjanska Street No. 5A, 36210 Vrnjacka Banja, Serbia, Phone: +381365150024, E-mail: danijela.durkalic@kg.ac.rs, ORCID ID (https://orcid.org/0000-0001-8605-8614)

2 Nemanja Pantić, PhD, Associate Professor, Universitiy of Kragujevac, Faculty of Hotel management and Tourism in Vrnjačka Banja, Vojvođanska 5A, 36210 Vrnjačka Banja, Republic of Serbia, Phone: +381 60 20 58 758, E-mail: nemanja.pantic@kg.ac.rs, ORCID ID (http://orcid.org/0000-0003-0030-6950)

3 Milica Luković, PhD, Associate Professor, University in Kragujevac, Faculty of Hotel Management and Tourism, Vojvodjanska 5A, 36210 Vrnjačka Banja, Serbia, Phone: +38162245630, E- mail: milica.petrovic@kg.ac.rs, ORCID ID (https://orcid.org/0000-0002-7102-0178)

4 Branislav Dudić, PhD, Scientific Researcher, Comenius University Bratislava, Faculty of Management, Odbojárov 10, P.O.BOX 95 82018 Bratislava 218, Slovak Republic, Phone: +421250117403, E- mail: branislav.dudic@fm.uniba.sk, ORCID ID (https://orcid.org/0000-0002-4647-6026)

Introduction

Agriculture in the European Union (EU) plays a key role in achieving the goals of sustainable development, but at the same time represents a significant source of pressure on the environment through greenhouse gas emissions, energy consumption, soil degradation and intensive use of pesticides (Eurostat, 2023). That is why specific agri-environmental indicators (AEIs) were developed as an instrument for monitoring the relationship between agriculture and the environment, and which enable the assessment of progress towards sustainable production patterns (OECD, 2025; European Commission, 2025).

The development and implementation of AEIs has a dual significance. On the one hand, they enable the adoption of informed policies within the Common Agricultural Policy (CAP), while on the other they provide a basis for international comparisons and the identification of disparities among member states (Rega et al., 2020). Previous research has shown that despite progress in increasing the share of renewable energy sources and the expansion of areas under organic agriculture, the EU still records a high level of dependence on pesticides and a relatively slow reduction of greenhouse gas emissions from agriculture (European Environment Agency, 2023).

It is especially important to observe the temporal dynamics and compare different EU countries, because there are pronounced differences in the intensity of agriculture, the degree of implementation of sustainable practices and national environmental protection policies (Latruffe et al., 2016; Mihajlović et al., 2025; Dimitrijević, 2025). Analytical approaches such as Principal Component Analysis (PCA) and the calculation of composite indices are increasingly used in the scientific literature in order to turn the unified indicators into measurable dimensions and to perform the ranking of countries, which provides clearer insights into the structure and dynamics of the observed parameters (Angilella et al., 2018).

Starting from these assumptions, the goal of this work is to, using a set of agri-environmental indicators, perform a comparative analysis of EU member states for 2017 and 2023, with a focus on identifying the main dimensions of environmental indicators in agriculture. This approach enables a better understanding of the extent to which member states have progressed in the transition to sustainable agriculture and where the key challenges for future development lie. The main goal of this work is to carry out a comprehensive analysis of agri-environmental indicators in the countries of the European Union in 2017 vs. 2023, with an emphasis on the identification of disparities among member states and the ranking of countries according to overall performance.

Literature review

Agriculture is increasingly viewed as a sector that, in addition to its economic role in food supply, must also contribute to the preservation of the ecosystem and the reduction of the ecological footprint. Numerous studies indicate that sustainable practices, such as organic production and the reduction of pesticide use, are of crucial importance for the preservation of natural resources and the long-term stability of rural communities (Pretty, 2008; Smith et al., 2019). In this sense, measuring the sustainability of agriculture through a set of indicators becomes necessary in order to systematically identify positive and negative trends.

Monitoring the integration of environmental problems of agriculture in the European Union is based on the system of agri-environmental indicators (AEI), developed by Eurostat and the European Environment Agency (European Environment Agency, 2023; Eurostat, 2023). These indicators include various aspects of agricultural practice - from greenhouse gas emissions and energy consumption, through the use of pesticides and environmental risks, to the spread of organic production (Dimitrijević, 2025). Their comparability and standardization make them a suitable tool for evaluating and shaping agricultural policies at the EU level. However, a large number of indicators and their mutual dependence make interpretation difficult, so multivariate dimensionality reduction methods, such as principal component analysis (PCA), are increasingly used in the analysis.

Due to the large number of indicators and their interdependence, researchers often use multivariate statistical methods such as principal component analysis (PCA) and factor analysis. Dabkiene et al., (2021) developed the concept of "agri-environmental footprint" using PCA and multi-criteria analysis to reduce complexity and build a unique index. A similar methodological approach was proposed by Gómez-Limón et al., (2020), who point out that PCA can be used not only for dimensionality reduction, but also for the objective determination of weights when constructing composite indicators.

The literature review also indicates the growing use of composite indicators in the agricultural sector. Magrini & Giambona, (2022) provide a systematic review of methodologies, highlighting the advantages and limitations of different approaches, including PCA-weights, equal weighted indices and expertly determined weights. Their findings suggest that the use of PCA is particularly useful in situations where there are a large number of highly correlated indicators, as is the case with AEI.

Empirical research conducted at the level of the European Union additionally confirms the importance of the application of multicriteria and multivariate methods in the analysis of agricultural sustainability. Belinska, et al., (2020) analyzed regional differences within the EU using a set of indicators that reflect the ecological context of development, pointing to pronounced geographical and structural disparities between the countries of Central, Western and Southern Europe. Their findings confirm that variations in sustainability performance are closely related to economic development, agricultural structure, and environmental policies. In a more recent work, Marković et al., (2024) the authors conducted an analysis of the performance of agri-ecological sustainability in EU countries using the multi-criteria method and principal component analysis (PCA). The results of their study indicated the existence of significant differences between member states, with Western and Northern European countries achieving better results thanks to a higher share of organic production, more efficient use of energy and less use of pesticides. The authors point out that combining AEI indicators and PCA enables a more comprehensive insight into real differences in sustainability and contributes to the development of more precise instruments for creating agricultural policies.

Materials and methods

Dataset Description

The dataset uses Eurostat data on Agri-environmental Indicators (AEIs) for 2017 and 2023 to assess the relationship between agriculture and the environment and the integration of environmental goals into the EU's Common Agricultural Policy (CAP). It originally included 28 indicators grouped into six themes: (1) Agricultural Land Use, (2) Input Use, (3) Emissions and Climate Change, (4) Biodiversity, (5) Soil and Water, and (6) Socio-economic Factors. Due to missing data, Luxembourg and Malta were excluded, resulting in a final dataset of 25 EU countries and 9 selected indicators. Only indicators with complete data for both years and countries were used in the analysis. The data set is shown in Table 1.

Table 1. List of used indicators

<table>
<tr><th>Agri-environmental indicator</th><th>Sub indicator</th><th>Unit of measure:</th><th>Code</th></tr>
<tr><td>Climate</td><td>Greenhouse gas emissions from agriculture (Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent)Percentage</td><td>percentage</td><td>GHG</td></tr>
<tr><td rowspan="3">Environment: Energy</td><td>Energy use: Gross available energy</td><td rowspan="3">Thousand tonnes of oil equivalent</td><td>EUGAE</td></tr>
<tr><td>Production of renewable energy - Complete energy balances: Primary production</td><td>REPP</td></tr>
<tr><td>Production of renewable energy - Complete energy balances: Recovered and recycled products</td><td>RERRP</td></tr>
<tr><td rowspan="4">Societal demand on food and health</td><td>Area under organic farming</td><td>Percentage of total utilised agricultural area</td><td>OF</td></tr>
<tr><td>Pesticide sales: Fungicides and bactericides</td><td rowspan="3">kilogram</td><td>PSFB</td></tr>
<tr><td>Pesticide sales:Herbicides, haulm destructors and moss killers</td><td>PSHDMK</td></tr>
<tr><td>Pesticide sales:Insecticides and acaricides</td><td>PSIA</td></tr>
<tr><td></td><td>Pesticide risk: Harmonised risk indicator 1 for pesticides by categorisation of active substances</td><td>Index, 2011-2013 average =100</td><td>PSI</td></tr>
</table>

Source: Authors' calculations based on Eurostat data.

Statistical Tools and Techniques

For the purposes of this research, the Principal Component Analysis (PCA) method will be used, which is one of the most commonly applied multivariate techniques for data dimensionality reduction. PCA enables the identification of latent structures in a data set by correcting the intercorrelations between variables and reducing a large number of initial indicators to a smaller number of components that retain most of the variance. In this way, factors are obtained that are orthogonal to each other and that facilitate further interpretation and interpretation of the underlying patterns in the data. As part of the preliminary adequacy check, the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity will be used to determine whether the data meet the conditions for applying PCA. Based on the obtained PCA results, the main factors that explain the largest part of the variance will be extracted and will be used in further analysis.

The generalized forms of the estimated principal components in the linear combination of the indicators can be expressed as follows, after Manly's (1994) suggestion:

$$Z_1 = a_{11}x_1 + a_{12}x_2 + \ldots\ldots + a_{1n}x_n$$

$$Z_2 = a_{21}x_1 + a_{22}x_2 + \ldots\ldots + a_{2n}x_n$$

$$Z_s = a_{n1}x_1 + a_{n2}x_2 + \ldots\ldots + a_{nn}x_n$$

Where,

The number of retrieved extracted components is represented by the variables z_1, z_2 and z_s; the factor loadings linked to the x_{ij} indicators on a specific main component are denoted by a_{ij}; the value of the indicator for the specific case or sample is denoted by x. The total number of indicators used to create a specific composite index is denoted by n.

Results

In this research, principal component analysis (PCA) was conducted to reduce the dimensionality of the data and extract the main factors. After checking the level of adequacy of application using the KMO method and Bartlett's test, PCA was applied to the standardized values of the variables (Linting et al., 2007). The number of factors was determined based on the Kaiser criterion (eigenvalue > 1) and scree diagram, and then rotation was performed for a clearer interpretation of the obtained factor structure.

Table 2. KMO and Bartlett's Test

Year		**2017**	**2023**
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.528	0.544
Bartlett's Test of Sphericity	Approx. Chi-Square	271.943	224.980
	df	45	36
	Sig.	0.000	0.000

Source: Authors' calculations

When checking the adequacy of the data for factor analysis, the Kaiser-Meyer-Olkin (KMO) index and Bartlett's test of sphericity were calculated (Table 2). The obtained value of the KMO test is 0.528/0.544, which according to Kaiser (1974) and Hair et al. (2019) is in the "weak but acceptable" category. Thus, although the value of the KMO index is not high, it exceeds the minimum threshold of 0.50, which means that factor analysis can be conducted, but the results should be interpreted with some caution (Field, 2013; Hutcheson & Sofroniou, 1999). Bartlett's test of sphericity (χ^2 = 271.943/224.980; df = 45/36; p < 0.001) shows that there are enough significant correlations between the variables, which further confirms the justification of applying factor analysis.

The analysis of descriptive indicators for EU countries in the period 2017 vs. 2023 (Table 3.) indicates two parallel trends. On the one hand, there is a reduction in greenhouse gas emissions, a significant increase in the production and availability of energy from renewable sources, which confirms progress in the direction of climate and energy sustainability. On the other hand, there is a strong increase in the use of pesticides and chemical agents, while the growth of organic agriculture is relatively slow, which indicates the continued dependence of agriculture on intensive inputs and challenges in the transition to more sustainable practices.

Table 3. Descriptive Statistics results

Indicator	N (2017, 2023)	Minimum (2017)	Minimum (2023)	Maximum (2017)	Maximum (2023)	Mean (2017)	Mean (2023)	Std. Deviation (2017)	Std. Deviation (2023)
PSI	25	5.30	24.00	33.10	96.00	11.9760	47.0400	6.72175	21.76097
GHG	25	2826.81	6.00	324280.63	36.20	61085.5048	13.7400	81275.54001	7.00643
EUGAE	25	144.70	2844.68	131768.04	257206.48	25627.2179	53295.7108	33428.24452	67873.28629
REPP	25	0.00	268.37	484.85	122122.79	66.0990	22111.7928	136.06476	28308.49975
RERRP	25	1.66	0.00	23.37	664.31	8.9264	64.8714	5.80481	145.85369
OF	25	117032.00	2.95	37982029.00	23.37	6255205.4000	11.5968	10713497.93412	6.05267
PSFB	25	138932.00	117659.00	30252649.00	26115431.00	4769842.3200	4620759.6400	7123997.73356	7851533.25904
PSHDMK	25	24998.00	119470.00	14548167.00	29905629.00	1539690.5600	4344480.1200	3106822.17974	6656276.77906
PSIA	25	41.00	4880.00	163.00	15948944.00	93.2000	1759429.8800	25.99840	3749854.19886

Source: Authors' calculations

When we talk about the indicators individually, the PSI (pesticide risk indicator) recorded an increase in the average value from 11.98 (2017) to 47.04 (2023), with increased variability (Std. dev. 6.72 → 21.76), which indicates the growth of risks associated with the use of pesticides in agriculture. GHG emissions from agriculture decreased on average (from 61,085.5 to 13,740), which suggests progress in reducing emissions, although in 2017 there were extremely high values in certain countries (maximum over 324,000), while in 2023 the distribution was more uniform (Std. dev. significantly lower). EUGAE (gross available energy) shows a significant growth of the average (from 25,627 to 53,296), which indicates increased available energy in the

EU. REPP (primary renewable energy production) also recorded significant growth (from 66.9 to 22,111), which confirms the trend of strengthening renewable energy sources. RERRP (recovered and recycled products) increased on average (from 5.9 to 64.9), which indicates progress in the circular economy and better utilization of waste. Indicator OF (organic farming) recorded stagnation and a slight increase in the average value (from 10,734 to 11,968), which indicates that the share of areas under organic production is growing slowly compared to energy indicators. PSFB, PSHDMK and PSIA recording very high average values in 2023 compared to 2017 (e.g. fungicides and bactericides from 1,074,387 to 11,596,800; herbicides from 310,682 to 6,652,676; insecticides from 25.99 to 3,749,284), indicating strong growth in pesticide use and chemical agents in EU agriculture.

Table 4 shows the results of the principal component analysis (PCA) for 2017 and 2023, where two components are separated that group the indicators depending on their connection.

Table 4. Summary statistics of the principal component analysis.

Year	2017		2023	
Indicator	Component		Component	
	1	2	1	2
GHG	-.188	-.622	-.196	-.044
EUGAE	.981	.065	.987	.037
REPP	.940	-.007	.933	.057
RERRP	.672	.095	.661	-.124
OF	-.199	.747	-.080	.889
PSFB	.729	-.006	.805	.120
PSHDMK	.905	-.125	.894	-.017
PSIA	.872	.097	.867	.112
PSI	-.078	.709	-.153	.809
Extraction Method: Principal Component Analysis.				
a. 2 components extracted.				

Source: Authors' calculations

The PCA results show that in both observed years the indicators are distributed in two clear clusters. In 2017, the first component is heavily loaded with indicators related to energy efficiency and renewable sources (EUGAE, REPP, RERRP), as well as organic agriculture (OF) and pesticide consumption (PSFB, PSHDMK, PSIA), while the second component mostly includes indicators of pesticide risk (PSI) and GHG emissions. In 2023, the structure partially changes - the first component still gathers energy indicators and organic agriculture, but the pesticide risk (PSI) is still clearly distinguished as a dominant indicator of the second component, which indicates its special role in the differentiation of countries. This suggests that over time EU policies have contributed to the homogenization of countries in terms of energy and agricultural indicators, while pesticides continue to be a key factor in differences between countries.

Based on the scree plot diagram, a clear "break" point can be seen after the second component, which confirms that it is justified to keep exactly two factors. This result is also consistent with Kaiser's criterion (value of latent roots above 1), which further justifies the extraction of a two-component structure. The first component explains most of the variance and is related to energy and agricultural indicators, while the second component includes primarily risks associated with pesticides and greenhouse gas emissions. Such a structure indicates that the EU countries in the analyzed period are differentiated on the basis of two basic dimensional directions - sustainability in energy and agriculture, on the one hand, and environmental risks from pesticides, on the other.

Figure 1. Scree plot of the principal component analysis, 2017

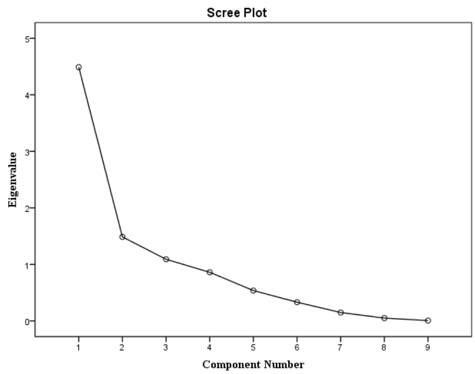
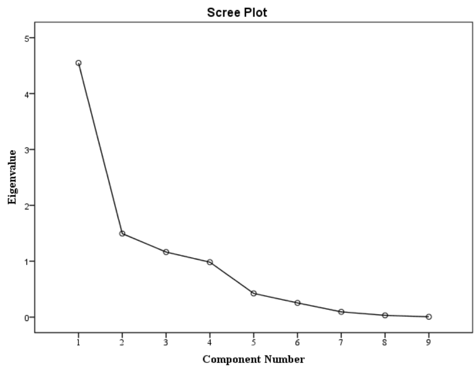


Figure 2. Scree plot of the principal component analysis, 2023



Source: Authors' calculations

Further, the Figures 1 and Figures 2 shows Scree plot diagrams for 2017 and 2023, which show the distribution of characteristic values (eigenvalues) by components. In both cases, a sharp drop in value is noticeable after the second component, which indicates the so-called "elbow point" after which the contribution of each subsequent component significantly decreases. Based on Kaiser's criterion (eigenvalue > 1) and visual assessment of the plot, two principal components were retained that together explain the largest part of the total variance of the data.

This result confirms that the structure of agri-environmental indicators in both observed years can be reduced to two dominant dimensions. The first component includes indicators related to energy efficiency and renewable energy sources, while the second component reflects the dimension of the pressure of agriculture on the environment through gas emissions and the use of pesticides. By comparing 2017 and 2023, it can be concluded that the stability of the indicator structure is high, which indicates the persistence of the basic patterns of sustainability within European agriculture.

In order to determine the position of the observed variables, a rotated component diagram was arranged (Figures 3 and 4). Based on the rotated component diagrams for 2017 and 2023, a relatively similar structure of the factor distribution of variables can be observed, with certain differences in the intensity of connection between individual indicators.

Figure 3. Component plot in Rotated Space, 2017

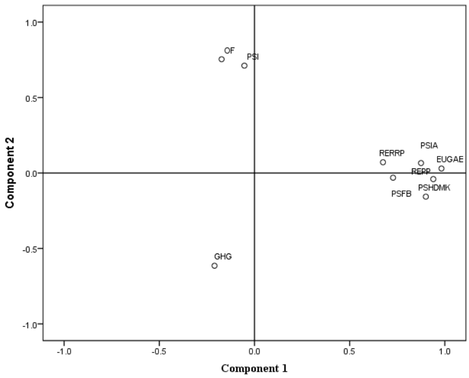
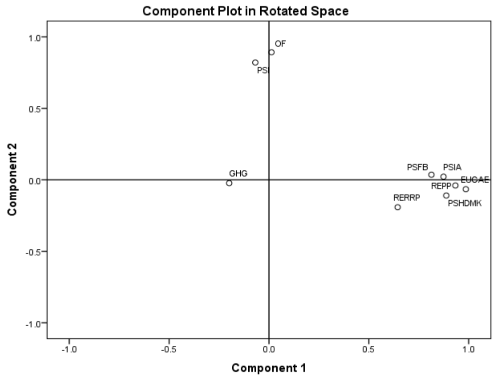


Figure 4. Component plot in Rotated Space, 2023



Source: Authors' calculations

Based on the rotated component diagrams for 2017 and 2023, a relatively similar structure of the factor distribution of variables can be observed, with certain differences in the intensity of connection between individual indicators.

In 2017, the variables related to the use of energy and pesticides (EUGAE, REPP, RERRP, PSFB, PSHDMK, PSIA) were grouped with the first component, indicating that it dominantly reflects the energy-agricultural factor related to the intensity of production. In contrast, the variables OF (organ farming) and PSI (pesticide risk indicator) are positioned next to the second component, which indicates a separate dimension related to sustainability and ecological practices in agriculture. The variable GHG (greenhouse gases) is in the opposite quadrant, suggesting a negative association with sustainability factors.

In 2023, the structure is similar, but the components are more compact and stable. Variables related to pesticides and energy use (PSFB, PSHDMK, PSIA, REPP, RERRP, EUGAE) are again grouped with the first component, confirming the existence of the same latent factor that describes the intensity of production activities. The variables OF and PSI still form a separate set connected to the second component, which still represents an ecologically sustainable approach. Changes in the distribution of variables between the two years indicate a slight strengthening of the links within the first component, which may suggest increased homogeneity of indicators related to agricultural and energy activities.

By calculating the composite index of agri-environmental performance, the comparison of EU countries and their ranking in 2017 and 2023 is enabled (Table 5). The obtained results indicate changes in the positioning of individual countries - while some have made progress through reducing greenhouse gas emissions, increasing the share of renewable energy and expanding areas under organic agriculture, other countries still record a high level of dependence on pesticides and intensive use of chemical agents.

In this analysis, the index is constructed so that more negative values (e.g. -0.62 for Cyprus, -0.54 for Croatia) indicate lower emissions, more efficient energy use and a higher share of sustainable practices — hence better agri-environmental performance. Conversely, more positive values (e.g. +1.63 for Germany or +1.59 for France) indicate higher environmental burdens, which means poorer sustainability performance. As can be seen, since negative values of the composite index indicate better agri-environmental performance, countries with the lowest indices (e.g. Cyprus, Croatia, Greece) occupy the top positions in the ranking, while more positive values (e.g. Germany and France) reflect poorer performance and are positioned at the bottom of the list. Thus, the results show that Cyprus, Croatia and Greece maintain the most favourable agri-environmental performance in both 2017 and 2023, indicating a relatively balanced relationship between agricultural activities and environmental protection. In contrast, Germany and France consistently record the highest (positive) index values, reflecting a lower level of sustainability due to intensive agricultural production and increased greenhouse gas emissions.

Comparing the two periods, a relative stability in the ranking of countries is observed, with a slight improvement in the case of Slovenia and Hungary, which record progress in the implementation of sustainable agricultural practices and energy efficiency. The reduction in differences between middle-ranking countries indicates a gradual convergence of agri-environmental performance within the European Union. These results are consistent with the findings of the PCA analysis, where the same countries showed the highest values of the first component associated with efficient resource management, renewable energy and reduced gas emissions. At the same time, countries with a higher index (such as Germany and France) have a higher load in the second component reflecting intensive production and higher energy impact.

Table 5. Composite index of agri-environmental of EU countries 2017 vs.2023

Country	Composite index 2017	Rank 2017	Country	Composite index 2023	Rank 2023
Cyprus	-0.62	1	**Cyprus**	-0.61	1
Croatia	-0.54	2	**Croatia**	-0.59	2
Greece	-0.51	3	**Slovenia**	-0.49	3
Bulgaria	-0.42	4	**Greece**	-0.49	4
Slovakia	-0.42	5	**Slovakia**	-0.44	5
Portugal	-0.4	6	**Bulgaria**	-0.41	6
Slovenia	-0.37	7	**Hungary**	-0.41	7

Country	Composite index 2017	Rank 2017	Country	Composite index 2023	Rank 2023
Denmark	-0.3	8	**Belgium**	-0.4	8
Belgium	-0.3	9	**Romania**	-0.3	9
Romania	-0.28	10	**Czechia**	-0.23	10
Hungary	-0.26	11	**Ireland**	-0.18	11
Czechia	-0.18	12	**Lithuania**	-0.11	12
Ireland	-0.15	13	**Netherlands**	-0.11	13
Sweden	-0.09	14	**Denmark**	-0.1	14
Lithuania	-0.07	15	**Portugal**	-0.1	15
Finland	-0.06	16	**Sweden**	0	16
Latvia	-0.04	17	**Finland**	0.04	17
Estonia	0.05	18	**Latvia**	0.05	18
Austria	0.1	19	**Estonia**	0.08	19
Netherlands	0.25	20	**Austria**	0.16	20
Poland	0.44	21	**Poland**	0.17	21
Italy	0.53	22	**Italy**	0.51	22
Spain	0.64	23	**Spain**	0.73	23
France	1.37	24	**Germany**	1.59	24
Germany	1.63	25	**France**	1.61	25

Source: Authors' calculations

The results obtained are in line with previous research (e.g. Eurostat, 2023; OECD, 2022; Gómez-Limón & Sanchez-Fernandez, 2010), which indicate the existence of a clear difference between Mediterranean countries that tend more towards sustainable production systems and Western European countries where a high degree of agricultural industrialization dominates. Overall, the analysis confirms that, despite moderate improvements, structural differences in agri-environmental performance among EU Member States remain present.

Conclusion

The analysis of agri-environmental indicators provides a comprehensive insight into the state and dynamics of the sustainability of agriculture in the countries of the European Union. By comparing the data for 2017 and 2023, progress can be seen in certain dimensions, especially with regard to the increase in the share of organic production and the growth of energy production from renewable sources, while greenhouse gas emissions and the use of pesticides are still a significant challenge. These results confirm that the transition towards sustainable production models is progressing, but unevenly among member states.

The application of principal component analysis (PCA) proved to be a useful method for identifying the basic dimensions of sustainability and reducing a complex set of indicators to a smaller number of representative factors. The overall findings show two contrasting trends in EU agriculture: Positive developments have been achieved in reducing GHG emissions and increasing production and availability of energy from renewable sources, with growth in recycling. Negative trends are observed through the increase in the risk and scope of pesticide use, while the participation of organic agriculture is increasing very slowly. These results suggest that the EU is simultaneously making progress in the energy and climate sectors, but still has challenges in the area of chemical dependency of agriculture and the transition to more sustainable practices.

Also, the results indicate that future EU policies should be aimed at reducing sustainability differences among member states through targeted incentives and knowledge sharing. The Common Agricultural Policy (CAP) should strengthen support for organic production, energy efficiency and reduction of pesticide use. The inclusion of composite agri-environmental indices in the CAP monitoring system can contribute to a more precise measurement of progress and more efficient implementation of the goals of the European Green Deal.

This research faces several limitations. First, the availability and consistency of data varies between countries and years, which may affect the precision of the estimate. Second, the choice of indicators was conditioned by the availability of data at the Eurostat level, so some important aspects of sustainability could not be included. Third, the methodological framework based on PCA analysis depends on correlations among indicators and does not take into account causal relationships. In this regard, future research can be conducted using more advanced methods of multi-criteria analysis (eg DEA, TOPSIS or fuzzy-MCDM) and combining quantitative and qualitative approaches.

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Conflict of interests

The authors declare no conflict of interest.

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INNOVATIVE LEADERSHIP IN AGRICULTURE: TRANSFORMING FARM RESOURCES INTO INNOVATIVE RURAL PRODUCTS – THE CASE OF TUSCANY

Aleksandar Ignjatović P[1], Aleksandra Vujko[2], Marijana Zimonjić[3]

**Corresponding author E-mail: avujko@singidunum.ac.rs*

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A B S T R A C T

Agricultural systems are increasingly shifting from production-oriented models toward diversified and market-integrated structures, requiring new approaches to value creation. The purpose of this study is to examine how leadership influences the transformation of farm resources into innovative and market-relevant outputs. The research is based on survey data collected from 488 farm owners and agricultural entrepreneurs in Tuscany, and the relationships among constructs were analyzed using a structural modeling approach. The results show that visionary leadership significantly drives resource transformation and innovation, while innovation orientation represents the strongest predictor of market integration. Resource transformation also contributes directly and indirectly to market outcomes through innovation processes. The findings indicate that value creation in agriculture follows a sequential pathway linking leadership, resources, innovation, and markets. The study concludes that leadership is a key mechanism in enhancing farm competitiveness and sustainability. It is recommended that farm managers and policymakers support leadership development, resource diversification, and innovation-oriented strategies in rural areas.

1 Aleksandar Ignjatović P., PhD, Assistant Professor, Beopolis University, Belgrade School of Engineering Management, Bulevar Vojvode Mišića 43, 11000 Belgrade, Serbia, E-mail: aleksandar.drugi@gmail.com, ORCID ID (https://orcid.org/0009-0005-4291-3494)

2 Aleksandra Vujko, PhD, Associate Professor, Singidunum University, Faculty of Tourism and Hospitality Management, Danijelova 32, Belgrade 11000, Serbia, E-mail: avujko@singidunum.ac.rs, ORCID ID (https://orcid.org/0000-0001-8684-4228)

3 Marijana Zimonjić, Ph.D., Megatrend University, Bulevar Maršala Tolbukhin no. 8, 11070 New Belgrade, Serbia, E-mail: marijanazimonjic1978@gmail.com, ORCID ID (https://orcid.org/0009-0005-6323-0393)

Introduction

Agriculture is increasingly shaped by structural transformations driven by market volatility, technological change, and the need for diversification (Knežević et al., 2025). Traditional production models are evolving toward multifunctional systems that integrate value-added products, services, and experiences, particularly through agritourism and rural entrepreneurship (Mowla et al., 2026; Popescu et al., 2023; Drăgoi et al., 2018). In this context, the ability to transform resources into market-relevant outputs has become a key determinant of competitiveness (Turčinović et al., 2025). The resource-based view (Barney, 1991) and dynamic capability theory (Teece, 2007) provide a relevant theoretical foundation; however, their application in agricultural systems remains fragmented, as prior studies predominantly examine innovation, diversification, or entrepreneurship in isolation (Hjalager, 2010; Radovanović, 2025; Wang et al., 2024; Vik & McElwee, 2011).

Innovation orientation and resource transformation are recognized as critical for value creation in rural contexts (Cvijanović et al., 2025; Vujanić et al., 2025; Korsgaard et al., 2026), while market integration determines the realization of these outputs (Marković & Mihajlović, 2006; Popescu & Andrei, 2011). Nevertheless, the relationship among these elements remains insufficiently integrated, particularly regarding the role of leadership. Although leadership is acknowledged as a driver of innovation and strategic change (Ignjatović et al., 2023), its function in initiating resource transformation and shaping subsequent innovation and market integration has not been systematically examined.

Furthermore, existing research lacks process-oriented models that capture the sequential nature of rural value creation, where resource transformation, innovation, and market integration operate as interconnected stages (Gaba et al., 2026). To address these gaps, this study develops and empirically tests a structural model linking visionary leadership, resource transformation, innovation orientation, and market integration within a unified framework. The empirical analysis is conducted in Tuscany, a region characterized by advanced integration of agriculture, heritage, and market-oriented diversification (Lombardi et al., 2021).

The study examines how visionary leadership shapes the transformation of farm resources into innovative and market-integrated outputs, focusing on both direct and indirect relationships among constructs. It advances existing research by conceptualizing agricultural competitiveness as a process-based pathway in which leadership acts as the central activating mechanism connecting resources, innovation, and market outcomes. By integrating RBV and dynamic capability perspectives, the study provides a more comprehensive explanation of how internal capabilities are translated into market performance. In addition, the analysis of mediation effects offers deeper insight into the mechanisms of value creation, with practical implications for farm management and rural development policy.

Literature Review and Hypotheses Development

Within the resource-based view (RBV), firm performance depends on the strategic mobilization and recombination of valuable resources (Barney, 1991). In agricultural contexts, resources such as land, heritage, and local knowledge often require reinterpretation, consistent with dynamic capability theory emphasizing managerial agency in resource transformation (Teece, 2007). Visionary leadership plays a central role in this process by enabling the recognition and activation of latent resource value, particularly in multifunctional rural development (Yasin & Bacsi, 2025; Pesut, 2025). In agritourism and rural entrepreneurship, leadership facilitates resource recombination across agriculture, tourism, and services (Shitile et al., 2025), with empirical evidence confirming its influence on resource valorization and diversification (Zhu, 2026). Accordingly, leadership functions as an active mechanism of resource transformation.

H1: Visionary leadership positively influences the transformation of farm resources into innovative rural products.

Innovation orientation reflects an organization's strategic openness to experimentation, creativity, and the adoption of new ideas (Hurley & Hult, 1998). In agricultural contexts characterized by strong traditional practices, leadership plays a critical role in fostering such orientation. Upper echelons theory suggests that organizational outcomes are shaped by leaders' cognitive frames and values (Hambrick & Mason, 1984), with visionary leaders more likely to promote risk-taking and challenge established production logics, particularly in path-dependent rural systems (Shao et al., 2024). Empirical research further confirms leadership as a key driver of innovation adoption and strategic change in rural enterprises (Adnan et al., 2025). Accordingly, leadership enables the emergence of new products and services through an innovation-supportive environment.

H2: Visionary leadership positively influences innovation orientation in agricultural enterprises.

Resource transformation expands the range of value-creating activities by enabling the reconfiguration of existing assets, consistent with RBV and dynamic capability perspectives (Teece, 2007). In rural contexts, innovation frequently emerges through the reinterpretation of traditional resources, such as embedding cultural identity into products or converting agricultural landscapes into experiential offerings (Turtureanu et al., 2025), reflecting territorial embeddedness (Ray, 1998). Empirical evidence indicates that diversified farms are more likely to develop innovative business models (Hjalager, 2010), suggesting that resource transformation acts as a precondition for innovation.

H3: Resource transformation capability positively influences innovation orientation in farms.

The economic relevance of transformed resources depends on their connection to markets, as value creation must be translated into market participation. In agribusiness and rural tourism, resource transformation enables access to new segments through differentiated offerings and reduced reliance on traditional production (Martinus et al., 2024). This process is reinforced by short supply chains and localized markets, which enhance visibility and competitiveness (Vujko et al., 2025).

H4: Resource transformation capability positively influences the market integration of innovative rural products.

Innovation orientation facilitates the translation of internal capabilities into market outcomes, as innovation generates value only when commercialized (Schumpeter, 1934). In rural enterprises, it supports the development of differentiated products and adaptation to evolving demand (Hjalager, 2010), with evidence linking innovation orientation to higher market performance and integration (Saharti, 2025).

H5: Innovation orientation positively influences the market integration of farm products.

In addition to indirect effects, visionary leadership directly shapes market integration by guiding strategic positioning, branding, and market engagement. Leadership enables the connection between local production and broader market networks (Vik & McElwee, 2011), aligning internal capabilities with external opportunities (Porter, 1985).

H6: Visionary leadership positively influences the market integration of innovative rural products.

Mediating Mechanisms

The model incorporates mediating effects reflecting the sequential nature of rural value creation. Resource transformation is expected to mediate the relationship between leadership and innovation, as dynamic capability theory suggests that leadership shapes outcomes through resource reconfiguration rather than direct innovation (Teece, 2007).

H7: Resource transformation mediates the relationship between visionary leadership and innovation orientation.

Innovation orientation further mediates the relationship between resource transformation and market integration, as transformed resources generate potential value that must be converted into marketable outputs through innovation.

H8: Innovation orientation mediates the relationship between resource transformation and market integration.

Materials and methods

This study employs a quantitative, cross-sectional design to test the structural relationships among visionary leadership, resource transformation, innovation orientation, and market integration. The empirical analysis was conducted in Tuscany, a region characterized by advanced agricultural development and strong integration of farming, heritage, and tourism (Mensing et al., 2025; Vollheyde & von Haaren, 2024). The target population included farm owners and agricultural entrepreneurs, as key decision-makers in innovation and strategic processes. The final sample (N = 488) reflects a predominantly male, middle-aged, and experienced population, operating mainly small to medium-sized farms with diversified activities and primarily local and regional market orientation.

Data were collected through a structured online survey administered between January and March 2026, distributed via professional platforms and agricultural networks (e.g., LinkedIn, Facebook, Agriturismo.it, Coldiretti, Confagricoltura, CIA – Agricoltori Italiani). A screening question ensured that only respondents with managerial roles participated. The sampling approach was purposive and convenience-based, with voluntary and anonymous participation. The sample size exceeds recommended thresholds for structural equation modeling (Hair et al., 2010).

The questionnaire initially included 28 items measuring four constructs: visionary leadership, resource transformation, innovation orientation, and market integration, using a five-point Likert scale. Measurement was grounded in established frameworks, including innovation orientation (Hurley & Hult, 1998), upper echelons theory (Hambrick & Mason, 1984), RBV and dynamic capabilities (Barney, 1991; Teece, 2007), rural resource transformation (Turtureanu et al., 2025), and market integration (Porter, 1985). Following exploratory factor analysis, 19 items were retained, ensuring improved reliability and validity in line with recommended procedures (Hair et al., 2010).

Data analysis was conducted using SPSS and AMOS. Descriptive statistics were followed by tests of sampling adequacy (KMO, Bartlett's test), confirmatory factor analysis, and structural equation modeling. Model fit was assessed using standard indices (CFI, TLI, RMSEA, RMR, GFI, AGFI) (Hair et al., 2010). Reliability and validity were evaluated through composite reliability, average variance extracted, the Fornell–Larcker criterion, and HTMT. Structural relationships, including mediation effects, were tested using bias-corrected bootstrapping procedures.

Results

The results presented in Table 1 indicate a very high level of sampling adequacy, as evidenced by the KMO value of 0.962, which significantly exceeds the recommended threshold of 0.60. This suggests that the dataset is highly suitable for factor analysis, with strong intercorrelations among variables. Furthermore, Bartlett's Test of Sphericity is statistically significant ($\chi^2 = 6752.678$, df = 378, $p < 0.001$), indicating that the correlation matrix is not an identity matrix and that meaningful relationships exist among the observed variables. Taken together, these results confirm that the data meet the necessary assumptions for conducting exploratory and confirmatory factor analyses, thereby supporting the validity of subsequent multivariate procedures.

Table 1. KMO and Bartlett's Test of Sphericity

Test	Value
Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy	0.962
Bartlett's Test of Sphericity	
Approx. Chi-square	6752.678
df	378
Sig.	0.000

Source: Authors' research

The results indicate four factors with eigenvalues greater than 1, supporting their retention according to the Kaiser criterion. The first factor explains the largest share of variance (39.798%), while the remaining factors contribute 6.983%, 6.534%, and 5.034%, resulting in a cumulative explained variance of 51.416%, which confirms the adequacy of the solution. The use of oblimin rotation reflects the expected correlation among factors, with interpretation based on the pattern matrix. Overall, the findings support a coherent four-factor structure suitable for further confirmatory analysis.

Table 2. Total Variance Explained

Factor	**Initial Eigenvalues (Total)**	**% of Variance**	**Cumulative %**	**Extraction Sums of Squared Loadings (Total)**	**% of Variance**	**Cumulative %**
1	11.144	39.798	39.798	10.647	38.026	38.026
2	1.955	6.983	46.781	1.452	5.186	43.213
3	1.829	6.534	53.315	1.293	4.618	47.831
4	1.409	5.034	58.349	1.004	3.585	51.416

Note: Extraction method: Maximum Likelihood. Rotation method: Oblimin with Kaiser normalization. Source: Authors' research

The results of the exploratory factor analysis (EFA), presented in Table 3, reveal a clear and well-defined four-factor structure corresponding to the theoretically proposed dimensions: *Innovation Orientation, Visionary Leadership, Resource Transformation,* and *Market Integration*.

Table 3. Pattern Matrix

	Factor			
	Innovation Orientation	**Visionary Leadership**	**Resource Transformation**	**Market Integration**
Opportunity Vision	-,012	,696	,003	,008
Strategic Thinking	,020	,726	,002	,042
Adaptive Leadership	,012	,696	,054	-,045
Value Vision	,019	,658	,002	-,006
Land Diversification	-,037	,008	-,634	-,055
Facility Adaptation	-,005	,005	-,653	-,029
Nature Utilization	-,060	,060	-,675	-,022
Knowledge Transformation	,090	,000	-,688	,090
Innovation Investment	,709	,027	-,015	-,018
Model Experimentation	,679	,043	-,074	,039
Risk Acceptance	,672	,030	-,040	-,012
Innovation Culture	,728	,013	,016	-,035
Trend Awareness	,696	,003	,004	,009
Business Collaboration	,062	,018	,028	-,752
Consumer Orientation	,066	,079	,065	-,749
Marketing Innovation	,022	-,023	-,028	-,742

	Factor			
	Innovation Orientation	**Visionary Leadership**	**Resource Transformation**	**Market Integration**
Stakeholder Partnership	-,028	,038	-,081	-,723
Digital Promotion	-,022	,012	-,014	-,770
Market Responsiveness	-,023	,001	-,033	-,776

Source: Authors' research

All four constructs exhibit strong and consistent factor loadings, confirming clear dimensional structure and internal coherence. Visionary Leadership, Resource Transformation, Innovation Orientation, and Market Integration are well defined, with no significant cross-loadings, while the direction of loadings does not affect interpretation. The results confirm convergent validity and support the adequacy of the measurement model for further analysis. The measurement model demonstrates excellent fit (CMIN/DF = 0.878; p = 0.852), with fit indices exceeding recommended thresholds (CFI = 1.000, TLI = 1.005, IFI = 1.004). Additional indicators (RMSEA = 0.000, PCLOSE = 1.000; RMR = 0.011; GFI = 0.973; AGFI = 0.965) further confirm strong model adequacy.

As shown in Table 4, no substantial cross-loadings are observed, confirming clear item–factor associations and discriminant validity. The results support the proposed four-factor structure and its suitability for further analysis. Composite reliability values exceed 0.70 for all constructs (CR = 0.769–0.903), confirming internal consistency. Convergent validity is supported for Innovation Orientation (AVE = 0.526) and Market Integration (AVE = 0.607), while slightly lower AVE values for Visionary Leadership (0.475) and Resource Transformation (0.454) remain acceptable given adequate reliability.

Table 4. Composite Reliability (CR) and Average Variance Extracted (AVE)

Construct	**CR**	**AVE**
Innovation Orientation	0.847	0.526
Visionary Leadership	0.783	0.475
Resource Transformation	0.769	0.454
Market Integration	0.903	0.607

Source: Authors' research

As shown in Tables 5 and 6, discriminant validity is confirmed, as the square roots of AVE exceed inter-construct correlations (Fornell–Larcker criterion), and all HTMT values remain below 0.85, with the highest at 0.74.

Table 5. Fornell–Larcker Criterion

Construct	Innovation Orientation	Visionary Leadership	Resource Transformation	Market Integration
Innovation Orientation	**0.725**			
Visionary Leadership	0.59	**0.689**		
Resource Transformation	0.65	0.56	**0.674**	
Market Integration	0.74	0.57	0.65	**0.779**

Source: Authors' research

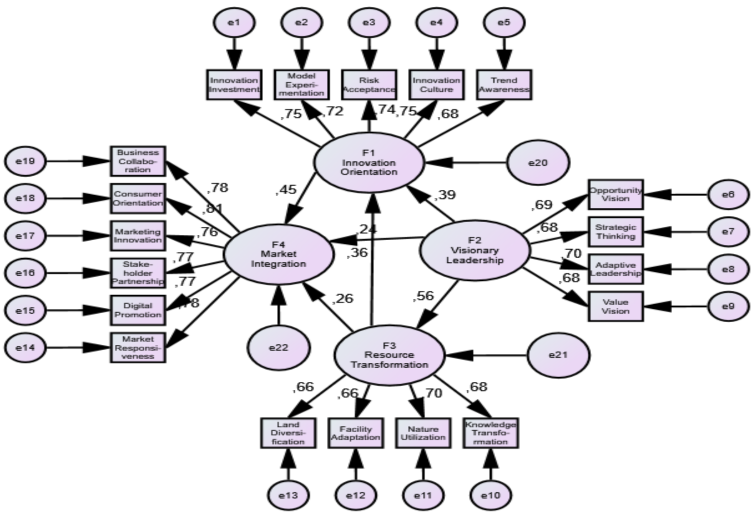
Table 6. HTMT Ratio

Construct Pair	HTMT
Innovation Orientation – Visionary Leadership	0.59
Innovation Orientation – Resource Transformation	0.65
Innovation Orientation – Market Integration	0.74
Visionary Leadership – Resource Transformation	0.56
Visionary Leadership – Market Integration	0.57
Resource Transformation – Market Integration	0.65

Source: Authors' research

The structural model shows good fit (CMIN/DF = 1.310), with fit indices above recommended thresholds (CFI = 0.989, TLI = 0.987, IFI = 0.989). Additional indicators (RMSEA = 0.025, PCLOSE = 1.000; RMR = 0.026; GFI = 0.960; AGFI = 0.948) further confirm model adequacy despite a significant chi-square (χ^2 = 192.621, p = 0.007).

Figure 1. Structural Equation Modeling (SEM)



Source: Prepared by the authors (2026).

The structural model results are presented in Table 7, which summarizes the standardized path coefficients (β), standard errors (SE), critical ratios (C.R.), and significance levels for all hypothesized relationships.

Table 7. Structural Model Results

Hypothesis	**Path**	**β (Standardized)**	**SE**	**C.R.**	**p-value**	**Supported**
H1	Visionary Leadership → Resource Transformation	0.557	0.067	8.403	***	Yes
H2	Visionary Leadership → Innovation Orientation	0.387	0.080	5.819	***	Yes
H3	Resource Transformation → Innovation Orientation	0.358	0.079	5.399	***	Yes
H4	Resource Transformation → Market Integration	0.257	0.060	4.580	***	Yes
H5	Innovation Orientation → Market Integration	0.449	0.052	7.756	***	Yes
H6	Visionary Leadership → Market Integration	0.241	0.060	4.309	***	Yes

Source: Authors' research

Table 7. Structural Model Results clearly indicates that all proposed direct relationships are statistically significant and positive, providing full empirical support for hypotheses H1–H6. The results reveal that visionary leadership exerts a strong and significant effect on resource transformation ($\beta = 0.557$, C.R. = 8.403, $p < 0.001$), supporting H1. This represents the strongest path in the model directed toward resource capabilities, suggesting that leadership plays a central role in enabling farms to reinterpret and utilize their tangible and intangible resources in innovative ways. Furthermore, visionary leadership also significantly influences innovation orientation ($\beta = 0.387$, C.R. = 5.819, $p < 0.001$), confirming H2. This finding highlights the importance of leadership in shaping an organizational climate that supports experimentation, creativity, and the development of new ideas within agricultural enterprises. The analysis also demonstrates that resource transformation capability positively affects innovation orientation ($\beta = 0.358$, C.R. = 5.399, $p < 0.001$), supporting H3. This suggests that when farms successfully reinterpret land, heritage, and knowledge, they create a foundation for further innovation processes. Regarding market outcomes, resource transformation shows a significant positive effect on market integration ($\beta = 0.257$, C.R. = 4.580, $p < 0.001$), supporting H4. Although moderate in magnitude, this relationship indicates that transformed resources contribute directly to the ability of farms to position their products within the market.

At the same time, innovation orientation has the strongest effect on market integration ($\beta = 0.449$, C.R. = 7.756, $p < 0.001$), supporting H5. This finding underscores that innovation acts as a key mechanism through which farm products achieve market relevance and competitiveness. Finally, visionary leadership also directly influences market integration ($\beta = 0.241$, C.R. = 4.309, $p < 0.001$), supporting H6. Although weaker than the indirect pathways, this result indicates that leadership contributes not only through internal capabilities but also through strategic market positioning. Overall, the structural model demonstrates a coherent pattern in which visionary leadership drives both resource transformation and innovation orientation, which in turn enhance market integration. The relative strength of the paths suggests that innovation orientation serves as the most critical direct predictor of market integration, while leadership plays a foundational role in activating the entire transformation–innovation–market chain.

The mediation results presented in Table 8 reveal that both indirect pathways in the model are not only statistically significant but also substantively meaningful for explaining how leadership-driven processes unfold within farm-based innovation systems.

Table 8. Mediation Effects (Standardized)

Hypothesis	**Path**	**Direct Effect**	**Indirect Effect**	**95% BC CI Lower**	**95% BC CI Upper**	**Mediation Type**	**Supported**
H7	Visionary Leadership → Resource Transformation → Innovation Orientation	0.415	0.222	0.170	0.280	Partial mediation	Yes
H8	Resource Transformation → Innovation Orientation → Market Integration	0.449	0.180	0.130	0.240	Partial mediation	Yes

Source: Authors' research

The findings show that resource transformation acts as a key transmission mechanism through which visionary leadership enhances innovation orientation (H7). The indirect effect ($\beta = 0.222$) is substantial relative to the direct effect ($\beta = 0.415$), indicating that a significant portion of leadership influence is channelled through the reinterpretation and recombination of farm resources. This suggests that leadership does not operate solely at the level of organizational climate, but materially restructures how resources are mobilized, thereby enabling innovation. At the same time, the persistence of a strong direct effect confirms partial mediation, implying that leadership simultaneously influences innovation both structurally (through resources) and behaviorally (through strategic orientation). This dual pathway highlights the multi-layered nature of leadership impact in rural innovation contexts. Furthermore, the results demonstrate that innovation orientation serves as a critical mechanism linking resource transformation to market integration (H8). The indirect effect ($\beta = 0.180$) indicates that transformed resources do not automatically translate into market outcomes; rather, their value is realized through innovation processes that convert resource potential into marketable products and services.

Although the direct effect of resource transformation on market integration remains strong (β = 0.449), the presence of a significant indirect pathway confirms that innovation acts as a necessary amplifying layer, enhancing the economic relevance of transformed resources. This again reflects partial mediation, suggesting that both direct commercialization and innovation-driven pathways coexist. Taken together, these findings indicate a sequential value-creation logic within the model: leadership activates resource transformation, resource transformation enables innovation, and innovation strengthens market integration. The coexistence of direct and indirect effects across both mediation paths points to a complementary rather than substitutive mechanism, where multiple pathways jointly contribute to performance outcomes. These results further support the interpretation of agricultural value creation as a staged and cumulative process, in which each subsequent phase amplifies and operationalizes the outcomes of the previous one. As shown in Table 9, the model explains a substantial proportion of variance across all endogenous constructs, confirming its strong explanatory and predictive capacity.

Table 9. Explained Variance (R^2)

Endogenous Construct	R^2	Interpretation
Resource Transformation	0.310	Moderate
Innovation Orientation	0.474	Moderate to High
Market Integration	0.552	High

Source: Authors' research

The highest explanatory power is observed for Market Integration ($R^2 = 0.552$), followed by Innovation Orientation ($R^2 = 0.474$) and Resource Transformation ($R^2 = 0.310$). This pattern reflects a sequential structure in which explanatory power increases along the transformation–innovation–market pathway.

Discussions

The findings provide a process-based explanation of value creation in agriculture, showing that competitiveness depends on the strategic reconfiguration and deployment of resources rather than their mere possession (Barney, 1991; Teece, 2007). The results confirm that visionary leadership plays a central role in activating resource transformation (H1), supporting its function as a micro-foundation of dynamic capabilities (Teece, 2007) and aligning with arguments on the reinterpretation of endogenous rural resources (Ray, 1998). Leadership also directly shapes innovation orientation (H2), consistent with upper echelons theory (Hambrick & Mason, 1984) and prior findings on innovation adoption in rural contexts (Zhao et al., 2025).

The relationship between resource transformation and innovation orientation (H3) confirms that innovation emerges through the recombination of existing resources (Barney, 1991), particularly in rural contexts where traditional assets are reinterpreted into new offerings (Turtureanu et al., 2025), extending prior work on diversification (Vujko et al., 2025). Resource transformation further contributes to market integration

(H4) by enabling differentiated outputs and access to new market segments, consistent with research on rural entrepreneurship and short supply chains (Masi et al., 2025). Innovation orientation plays a central role in converting internal capabilities into market outcomes (H5), in line with Schumpeterian theory (Schumpeter, 1934), confirming that transformed resources generate value only when embedded in innovation-driven strategies (Labella-Fernández et al., 2026).

Visionary leadership also directly influences market integration (H6), supporting strategic management perspectives on aligning internal capabilities with external opportunities (Porter, 1985) and facilitating market access in rural systems (Vik & McElwee, 2011). The mediation effects further clarify these mechanisms: resource transformation mediates the relationship between leadership and innovation (H7), consistent with dynamic capability theory (Teece, 2007), while innovation orientation mediates the link between resource transformation and market integration (H8), reflecting a sequential transformation–innovation–market pathway. These results confirm a cumulative and multi-stage process in which leadership activates resources, resources enable innovation, and innovation drives market outcomes.

The study contributes by integrating RBV and dynamic capability perspectives through a leadership-centered framework that explains how internal capabilities are translated into market performance. Empirically, the Tuscan context illustrates this process, showing how traditional resources are transformed into high-value, market-integrated offerings within advanced agritourism systems. This suggests that competitiveness in rural regions depends not on scale, but on the ability to recombine local assets and position them within differentiated market segments, offering transferable insights for other regions undergoing similar transitions.

Conclusions

This study demonstrates that agricultural competitiveness depends on the alignment of leadership, resource transformation, innovation, and market integration within a coherent value-creation system. These elements operate as an interconnected process in which leadership acts as the central mechanism activating and linking internal capabilities to market outcomes. By integrating resource transformation and innovation, the study advances fragmented approaches and shows that value creation is capability-driven rather than resource-based. The findings further indicate that competitiveness relies on the strategic recombination of local assets and innovation-oriented practices rather than scale or production intensity.

From a practical perspective, the results highlight the need to strengthen leadership capabilities and support innovation-oriented strategies through capacity building and knowledge transfer. Limitations include the cross-sectional design and restricted generalizability, suggesting future research should adopt longitudinal and comparative approaches and incorporate additional dimensions such as digital transformation and sustainability. The findings indicate that agricultural development increasingly depends on the ability to transform resources and integrate them into market systems through leadership-driven innovation.

Conflict of interests

The authors declare no conflict of interest.

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FINANCIAL LITERACY, RISK ASSESSMENT AND MARKETING OPPORTUNITIES IN THE ADOPTION OF NEW AGRICULTURAL PRODUCTS

Aleksandra Zlatić Tešić[1], *Bojana Ostojić*[2], *Miloš Nikolić* [3]

**Corresponding author E-mail: bojanaostojic85@gmail.com*

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A B S T R A C T

This paper investigates the relationship between financial literacy, financial risk perception, and marketing opportunities during adoption of new agricultural products. Based on a sample of 307 agricultural producers from Serbia, the findings highlight the central role of financial literacy in shaping both market orientation and risk awareness. Agricultural producers with stronger financial literacy were more likely to recognize the importance of marketing for new product success, while also demonstrating heightened sensitivity to financial risks. Importantly, financial literacy did not diminish perceived risks but sharpened agricultural producers' ability to critically evaluate uncertainties and investment decisions. At the same time, risk-aware producers tended to view marketing not as an additional burden but as a strategic mechanism to mitigate or balance risks. Overall, the results underscore how financial literacy and risk perception jointly foster opportunity-driven behavior in the placement of new agricultural products.

Introduction

Financial literacy encompasses understanding basic financial concepts, managing resources effectively, and applying skills such as risk management, savings, and opportunity recognition (Alshebami & Al Marri, 2022; Becić et al., 2025; Twumasi et al., 2022). It is particularly important in rural economies, where resource constraints are

1 Aleksandra Zlatić Tešić, PhD, Full professor, University Business Academy Novi Sad, Faculty of law for commerce and judicary, Cvecarska 1, 21000 Novi Sad, Serbia, E-mail: prod.aleksandra.tesic@gmail.com, ORCID ID (https://orcid.org/0000-0001-5993-3065)

2 Bojana Ostojić, PhD, Associate professor, Faculty of Project Management (PMC), Bozidara Jankovica Street 14, 11000 Belgrade, Serbia, Phone: +381693370334, E-mail: bojanaostojic85@gmail.com, ORCID ID (https://orcid.org/0000-0001-6731-431X)

3 Miloš Nikolić, PhD, Assistant professor, MB University, Faculty of Business and Law, Teodora Drajzera no. 27, 11000 Belgrade, Serbia, Phone:+381 62 168 52 08 E-mail: nikolic2206@gmail.com, ORCID ID (https://orcid.org/0000-0003-0690-8047)

common. Financial literacy is oriented to equipping individuals with the knowledge and skills to make informed financial decisions (Li & Zhang, 2025). Agricultural producers with higher financial literacy are better able to plan household finances, assess risks, and make sound investments, thereby strengthening entrepreneurial capacity (Struckell et al., 2022). Moreover, financial literacy facilitates access to formal credit channels, expands financing opportunities, and reduces constraints that hinder agricultural entrepreneurship (Hasan et al., 2024). In this way, it is both an individual capability and a driver of sustainable agricultural development (Hadjielias, Christofi, & Tarba, 2021), especially for agricultural producers in Serbia which need finances and investments for modernization of equipment and technology (Aničić et al., 2025).

For agricultural producers, financial literacy enables effective farm financial management, informed borrowing and investment decisions, and navigation of credit markets (Fahlevi et al., 2025). Agricultural producers often face challenges such as limited education, rural isolation, and resource constraints, which can reduce financial knowledge (Klapper & Lusardi, 2020). By improving financial literacy, agricultural producers can strengthen planning, budgeting, and resource allocation, thereby enhancing efficiency, reducing financial risks, and increasing access to external support such as loans or subsidies (Nikolić et al., 2025). Ultimately, higher financial literacy improves household well-being and entrepreneurial capacity, making it a cornerstone of sustainable agricultural development (Gottlieb & Hansson, 2024).

Agricultural producers face diverse risks such as production risks (droughts, excessive rainfall), market risks (price volatility), and institutional risks (policy changes), which often compound and destabilize farm operations (Komarek, De Pinto, & Smith, 2020). In rural areas, limited economic resources and insufficient human capital skills represent significant weaknesses that hinder the future development of agricultural products and tourism activities (Dejanović, Lukić Nikolić, & Ljubojević, 2024). Financial risks are particularly important, as adverse events in production or markets can quickly lead to loan repayment difficulties, reduced credit access, and financial instability. Financial risk in agriculture refers to uncertainty in meeting financial obligations due to fluctuating interest rates, lenders' willingness to provide capital, cash flow challenges, and changes in collateral value (Wolf & Karszes, 2023). Managing financial risk is therefore essential for sustaining operations, investing in improvements, and ensuring long-term resilience. Strengthening financial literacy and access to formal credit channels provides agricultural producers with the tools to mitigate these risks, stabilize income, and navigate the uncertainties inherent in agriculture (Komarek, De Pinto, & Smith, 2020).

The purpose of this paper is to investigate the extent to which financial literacy shapes agricultural producers' capacity to evaluate financial risks and recognize marketing opportunities when introducing new agricultural products. Financial literacy evaluation amongst agricultural producers is scarce, especially in emerging economies (Maji & Laha, 2023). By examining the intersection of financial knowledge, risk management, and market positioning, the research highlights how financial literacy contributes to improved decision-making, resource allocation, and entrepreneurial success in agriculture. Strengthening financial literacy is expected to enhance agricultural producers' financial resilience, reduce vulnerability to market and credit uncertainties, and increase their competitiveness in modern agricultural markets. Finally, the paper seeks to generate insights that support sustainable rural development by demonstrating the critical role of financial literacy in fostering innovation and long-term viability in agricultural enterprises.

Theoretical framework and hypotheses development

Agricultural producers with higher levels of financial literacy are more likely to recognize the strategic importance of marketing in ensuring the success of new agricultural products. Marketing, as a highly dynamic discipline, bridges businesses and consumers by creating, communicating, and delivering value in ways that foster and sustain organizational success (Kaur et al., 2022). Its evolution has been shaped by technological progress, economic fluctuations, and societal change (Cui et al., 2025). This progression is evident across the industrial revolutions: *Marketing 1.0* emphasized product quality and functional benefits through mass media; *Marketing 2.0* shifted toward customer-centric strategies with research and internet-based communication; *Marketing 3.0* recognized consumers as multidimensional beings with values and emotions, integrating ethical and social considerations; and *Marketing 4.0* leverages big data, artificial intelligence, and machine learning to personalize offerings and enhance engagement (Kaur et al., 2022). The development of innovative technologies and tools has enabled significant changes in the way individuals operate and function, driving the digitalization of processes and services across all industries and sectors (Labus & Lukić Nikolić, 2024; Životić et al., 2025; Lukić Nikolić, 2024). In agriculture, the expansion of electronic commerce has accelerated the online trade of products, intensified competition and heightened the need for differentiation (Guo et al., 2022; Uzelac, Dukić Mijatović, & Lukinović, 2022). The further rise of the internet transformed marketing into a data-driven practice, enabling organizations to gather timely insights and adapt strategies, while successful leaders and managers realized that they must integrate digital approaches in their organizations in order to remain competitive (Dobričanin & Aleksić, 2025; Dash, Kiefer & Paul, 2021). Moreover, the limited storage stability of agricultural goods presents both challenges and opportunities: unsold harvests lead to economic loss, grain depletion, and food waste, undermining sustainability goals (Li, Guo, & Huang, 2023). Effective marketing strategies are therefore essential to improve distribution efficiency, enhance demand forecasting, and foster consumer engagement aligned with sustainable behavior (Zia & Alzahrani, 2022).

Financial literacy equips producers with the ability to evaluate costs, returns, and profitability, which in turn enhances their appreciation of marketing as a tool for product differentiation and competitiveness. Prior studies emphasize that financially literate entrepreneurs are more inclined to invest in marketing activities because they understand their impact on revenue generation and long-term sustainability (Struckell et al., 2022;

Twumasi et al., 2022). Evidence from agrifood systems further shows that financial literacy improves agricultural producers' capacity to adopt marketing and distribution strategies that increase product success (FAO Investment Centre, 2025). Similarly, research on rural entrepreneurship highlights that financial knowledge strengthens opportunity recognition and resource allocation, making agricultural producers more likely to agree that marketing enhances the chances of success for new products (Gottlieb & Hansson, 2024; Hasan et al., 2024). This leads to the first hypothesis proposed in this paper:

Hypothesis 1: *Financial literacy of agricultural producers is positively associated with perceptions of marketing effectiveness in new product success.*

Financial literacy enhances agricultural producers' ability to evaluate investment options, anticipate cash flow challenges, and identify appropriate financing mechanisms, thereby reducing their perception of risk. Prior research shows that financially literate individuals are more confident in their capacity to manage uncertainty, as they possess the skills to budget effectively, diversify income sources, and access formal credit channels (Hasan et al., 2024; Klapper & Lusardi, 2020). In agricultural contexts, this knowledge enables agricultural producers to mitigate risks associated with fluctuating prices, high input costs, and uncertain demand by making informed borrowing and investment decisions (Wolf & Karszes, 2023). Consequently, financially literate agricultural producers are less likely to perceive new product introduction as highly risky, since they can rely on their financial knowledge to manage potential challenges and safeguard farm stability (Gottlieb & Hansson, 2024; Struckell et al., 2022). That leads to the second hypothesis:

Hypothesis 2: *Agricultural producers with higher levels of financial literacy will report stronger perceptions of financial risks when introducing new products.*

Elevated risk perception may lead to conservative decision-making, where agricultural producers prioritize avoiding potential losses over pursuing new opportunities (Wan et al., 2023). Research on entrepreneurial behavior suggests that when financial risks are perceived as dominant, individuals tend to limit innovation and reduce investment in marketing activities, thereby constraining opportunity recognition (Komarek, De Pinto, & Smith, 2020). In agriculture, high perceived risks, such as uncertain demand, volatile prices, or high input costs, can overshadow potential benefits of marketing strategies like branding, promotion, or collaboration with retailers (Wolf & Karszes, 2023). Consequently, agricultural producers who perceive greater financial risks may be less likely to view marketing as a viable pathway for success, since their focus shifts toward risk avoidance rather than opportunity exploitation (Gottlieb & Hansson, 2024; Hasan et al., 2024). Following the case of Chinese smallholders, agricultural producers with high-risk perception prefer immediate sales at low prices during harvest rather than storing grain for later, even though delayed sales could yield higher returns. The theoretical framework of expected utility explains this: when risk perception is high, the uncertain (but potentially more profitable) future outcome is valued less than the certain but lower immediate return (Tian & Zhao, 2024). That leads to the third hypothesis:

Hypothesis 3: *Agricultural producers with higher perceptions of financial risk will report lower perceptions of marketing opportunities in the placement of new products.*

Materials and methods

Research design. A quantitative research design was employed to examine agricultural producers' perceptions of financial literacy, financial risks, and marketing opportunities in the placement of new agricultural products. Data were collected via a structured online questionnaire distributed during March 2026. The questionnaire was disseminated using a random sampling approach and made available online, allowing broad participation from agricultural producers in Serbia. This method ensured accessibility, cost-effectiveness, and time efficiency, while also facilitating the inclusion of diverse respondents actively engaged in agricultural production.

Questionnaire. The questionnaire was structured into two main sections. The first section collected socio-demographic and farm-related data: gender, age, education, farming experience, farm size, motives for introducing new agricultural products, and dominant marketing channels used. The second section of the questionnaire assessed agricultural producers' attitudes across three domains using a five-point Likert scale (1 = strongly disagree, 5 = strongly agree): Financial Literacy (understanding financial concepts, calculating profitability, knowledge of banking products, record-keeping, use of digital tools, monitoring marketing costs), Financial Risks (perceived risks of new product introduction, lack of funds, marketing costs, insufficient financial knowledge, uncertain demand, high initial costs), and Marketing Opportunities (role of marketing, branding, social media, digital tools, and collaboration with restaurants/shops). This structure allows for both descriptive profiling of agricultural producers and analytical measurement of their financial literacy, risk perception, and marketing orientation. Pilot research encompassing 30 respondents showed that proposed scales manifest high reliability and validity with Cronbach's Alpha coefficient higher than 0.80.

Sample. The sample consisted of agricultural producers selected through a random sampling approach, who voluntarily completed the questionnaire during March 2026. The questionnaire was distributed and administered online, ensuring accessibility and broad participation among individuals actively engaged in agricultural production. In total, 307 agricultural producers responded, providing a reliable dataset for examining the relationship between financial literacy, financial risks, and marketing opportunities in the placement of new agricultural products.

Data Analysis. Data were processed using the Statistical Package for the Social Sciences (SPSS), version 21.0. To examine the proposed hypotheses, a combination of descriptive and inferential statistical techniques was employed. First, descriptive statistics were used to summarize socio-demographic characteristics and provide an overview of agricultural producers' responses across the constructs of financial literacy, financial risk perception, and marketing opportunities. Reliability analysis (Cronbach's Alpha) was conducted to ensure internal consistency of the Likert-scale items measuring each construct, as shown in Table 1. Cronbach's alpha values demonstrated high internal consistency for all scales, with coefficients well above the recommended threshold of 0.70 (DeVellis, 2003).

Table 1. Cronbach's Alpha coefficients

Scale	N	Cronbach's Alpha
Financial Literacy (FL)	6	0.899
Financial Risks (FR)	6	0.919
Marketing Opportunities (MO)	5	0.902

Further data analysis was conducted to examine the relationships among financial literacy, financial risk perception, and marketing opportunities. The analysis proceeded in two stages: correlation analysis and regression analysis. First, a Pearson correlation matrix was computed to assess the strength and direction of associations among the constructs. Next, a series of linear regression analyses were performed to test the hypotheses.

Research results

Table 2 presents the basic information about the respondents. The gender distribution is relatively balanced, with a slight predominance of male participants (53.42%). Age composition indicates that the majority of respondents fall within the younger and middle-aged categories, particularly between 21 and 40 years (52.77%), which suggests an active and potentially adaptable agricultural producers. Over two-thirds of respondents have completed college or university (68.08%). Respondents are evenly distributed across experience levels regarding agriculture, with approximately one-third in each category (less than 5 years, from 5 to 10 years, more than 10 years). Farm size is predominantly medium (47.88%), while small and large farms are less represented. Introduction of new agricultural products was driven mainly by personal initiative (27.36%), followed by subsidies (24.76%), diversification motives (24.76%), and demand for that product in the market (23.13%). Marketing channels are diverse, with social media/internet (29.32%) and direct sales (24.43%) being most frequently utilized, indicating a usage of modern and customer-oriented distribution strategies.

Table 2. Key information about respondents

	Answers	N	%
Gender	Male	164	53.42
	Female	143	46.58
Age	Up to 20	48	15.64
	From 21 to 30	85	27.69
	From 31 to 40	77	25.08
	From 41 to 50	60	19.54
	Above 50	37	12.05
Education	Primary School	19	6.19
	High School	79	25.73
	College	94	30.62
	University	115	37.46

	Answers	N	%
How long have you been engaged in agriculture?	Less than 5 years	109	35.50
	From 5 to 10 years	105	34.20
	Above 10 years	93	30.29
Farm size	Small (up to 5 ha)	87	28.34
	Medium (5–20 ha)	147	47.88
	Large (over 20 ha)	73	23.78
What was the main motive for new agricultural product?	Demand for that product in the market	71	23.13
	Subsidies / incentives	76	24.76
	Diversification of production	76	24.76
	Personal initiative	84	27.36
Which channels do you use for marketing/distributing new products?	Market (farmers' market)	54	17.59
	Agricultural cooperatives	42	13.68
	Social media / internet	90	29.32
	Direct sales to customers	75	24.43
	Collaboration with shops/restaurants	46	14.98

Source: Authors' calculations

Table 3 presents the responses to the statements in the measurement scale "Financial Literacy". The mean values (M) for all statements range between 3.40 and 3.60, indicating moderate agreement. The highest mean scores were observed for statements related to record-keeping of the farm's income and expenses (M = 3.60) and monitoring marketing costs (M = 3.60), suggesting stronger competencies in practical financial management. The proportion of respondents selecting marks 4 and 5 (indicating agreement or strong agreement) is substantial across all statements, ranging from approximately 46% to 57%. This distribution highlights that nearly half of the sample demonstrates higher levels of financial literacy. The share of mark 3 responses ranges between 25% and 31% indicating that many respondents perceive their financial literacy as adequate, but not advanced.

Table 3. Results regarding the scale "Financial Literacy"

Statements	Answer	N	%	M	SD
I understand basic financial concepts such as income, expenses, and profit.	**1**	22	7.17	3.40	1.242
	2	53	17.26		
	3	91	29.64		
	4	61	19.87		
	5	80	26.06		
I know how to calculate the profitability of production on my farm.	**1**	10	3.26	3.49	1.139
	2	54	17.59		
	3	94	30.62		
	4	73	23.78		
	5	76	24.76		

Statements	Answer	N	%	M	SD
I am aware of which banking products (loans, leasing, subsidies) can be used to finance agriculture.	1	13	4.23	3.55	1.137
	2	44	14.33		
	3	87	28.34		
	4	86	28.01		
	5	77	25.08		
I regularly keep records of the farm's income and expenses.	1	12	3.91	3.60	1.149
	2	43	14.01		
	3	88	28.66		
	4	78	25.41		
	5	86	28.01		
I use digital tools (Excel, applications) to track finances.	1	18	5.86	3.51	1.173
	2	45	14.66		
	3	79	25.73		
	4	92	29.97		
	5	73	23.78		
I monitor the costs of marketing and promoting my agricultural products.	1	19	6.19	3.60	1.176
	2	35	11.40		
	3	78	25.41		
	4	92	29.97		
	5	83	27.04		

Source: Authors' calculations

Table 4 provides insights into respondents' perceptions of financial risks associated with placement of new agricultural products. The mean values (M) across all statements range between 3.41 and 3.66 indicating moderate agreement. The highest mean scores were recorded for statements concerning uncertain market demand (M = 3.66) and high initial costs (M = 3.62), underscoring that external market conditions and upfront investments are perceived as the most significant sources of risk. The distribution of marks 4 and 5 (agreement and strong agreement) is substantial, ranging from 49% to 60% across statements, with the highest levels observed for uncertain market demand and high initial costs. Responses marked with a score of 3 range from 23% to 34%, representing a significant portion of agricultural producers who hold moderate views on financial risks.

Table 4. Results regarding the scale "Financial Risks"

Statements	Answer	N	%	M	SD
Introducing new agricultural products carries significant financial risk.	1	27	8.79	3.41	1.261
	2	51	16.61		
	3	71	23.13		
	4	84	27.36		
	5	74	24.10		
Lack of financial resources is the main obstacle to placing new agricultural products on the market.	1	14	4.56	3.52	1.127
	2	39	12.70		
	3	103	33.55		
	4	76	24.76		
	5	75	24.43		

Statements	Answer	N	%	M	SD
Marketing and promotion costs significantly increase financial risk for small agricultural producers.	1	14	4.56	3.56	1.148
	2	43	14.01		
	3	85	27.69		
	4	86	28.01		
	5	79	25.73		
Lack of financial knowledge makes it difficult to make decisions about placing new agricultural products.	1	13	4.23	3.60	1.111
	2	39	12.70		
	3	79	25.73		
	4	102	33.22		
	5	74	24.10		
Uncertain market demand represents a serious financial risk for new agricultural products.	1	17	5.54	3.66	1.164
	2	34	11.07		
	3	73	23.78		
	4	95	30.94		
	5	88	28.66		
High initial costs for seeds, seedlings, equipment, and labor increase the financial risk that investment in a new product will not pay off if buyers are not found.	1	22	7.17	3.62	1.216
	2	35	11.40		
	3	71	23.13		
	4	90	29.32		
	5	89	28.99		

Source: Authors' calculations

Table 5 presents respondents' perceptions of marketing opportunities during placement of new agricultural products. The mean values (M) range from 3.40 to 3.73, indicating moderate agreement. The highest mean score was recorded for collaboration with local restaurants and shops (M = 3.73), suggesting that respondents view partnerships with local businesses as particularly effective for product placement. Social media (M = 3.64) and digital tools (M = 3.59) also scored highly, reflecting recognition of modern channels as valuable opportunities. Marks 4 and 5 (agreement and strong agreement) are substantial across all statements, ranging from 51% to 64%. This indicates that most respondents acknowledge the importance of marketing strategies, especially those involving direct partnerships and digital promotion. Scores of 3 account for 21 to 29% of responses, highlighting a notable group of agricultural producers who express moderate attitudes toward marketing opportunities.

Table 5. Results regarding the scale "Marketing Opportunities"

Statements	**Answer**	**N**	**%**	**M**	**SD**
Marketing significantly increases the chances of success for new agricultural products.	**1**	28	9.12	3.40	1.262
	2	51	16.61		
	3	70	22.80		
	4	86	28.01		
	5	72	23.45		
Branding (packaging, labeling, name) contributes to better sales of new agricultural products.	**1**	7	2.28	3.55	1.091
	2	50	16.29		
	3	90	29.32		
	4	87	28.34		
	5	73	23.78		
Social media represents an effective channel for promoting agricultural products.	**1**	17	5.54	3.64	1.153
	2	31	10.10		
	3	85	27.69		
	4	88	28.66		
	5	86	28.01		
Digital tools (e-commerce platforms, applications) facilitate the placement of new agricultural products.	**1**	22	7.17	3.59	1.197
	2	34	11.07		
	3	74	24.10		
	4	95	30.94		
	5	82	26.71		
Collaboration with local restaurants and shops creates new opportunities for placing new agricultural products.	**1**	23	7.49	3.73	1.203
	2	24	7.82		
	3	65	21.17		
	4	97	31.60		
	5	98	31.92		

Source: Authors' calculations

The correlation matrix (Table 6) indicated strong, positive, and statistically significant associations among all three constructs. Financial literacy is highly correlated with financial risk perception ($r = 0.710$, $p < 0.01$) and marketing opportunities ($r = 0.681$, $p < 0.01$). Similarly, financial risk perception is highly correlated with marketing opportunities ($r = 0.660$, $p < 0.01$). The consistently large correlations highlight that these constructs are closely interrelated, supporting the rationale for regression analysis.

Table 6. Correlation matrix

		Financial Literacy	**Financial Risk**	**Marketing Opportunities**
Financial Literacy	Pearson Correlation	1	0.710**	0.681**
	Sig. (2-tailed)		0	0
	N	307	307	307
Financial Risk	Pearson Correlation	0.710**	1	0.660**
	Sig. (2-tailed)	0		0
	N	307	307	307

		Financial Literacy	Financial Risk	Marketing Opportunities
Marketing Opportunities	Pearson Correlation	0.681**	0.660**	1
	Sig. (2-tailed)	0	0	
	N	307	307	307
** Correlation is significant at the 0.01 level (2-tailed).				

Source: Authors' calculations

The regression analysis results presented in Table 7 demonstrated that financial literacy significantly predicted marketing opportunities, $F(1, 305) = 263.591$, $p < 0.001$. The model explained 46.4% of the variance in marketing perception ($R^2 = 0.464$). Financial literacy was a strong positive predictor (B = 0.716, β = 0.681, $p < 0.001$). This result supports H1.

Table 7. Relationship between Financial Literacy and Marketing Opportunities

Predictor	B	SE B	β	t	p	Tolerance	VIF
Constant	1.056	0.161	—	6.557	0.000	—	—
Financial Literacy	0.716	0.044	0.681	16.235	0.000	1.000	1.000
Model Summary: R = 0.681, R² =0 .464, Adjusted R² = 0.462, Std. Error = 0.735 **ANOVA**: F(1, 305) = 263.591, p < 0.001							

Source: Authors' calculations

Furthermore, the regression analysis (Table 8) revealed that financial literacy significantly predicted perceptions of financial risk, $F(1, 305) = 310.089$, $p < 0.001$. The model accounted for 50.4% of the variance in financial risk perception ($R^2 = 0.504$). Financial literacy was a strong positive predictor (B = 0.737, β = 0.710, $p < 0.001$). This result supports H2.

Table 8. Relationship between Financial Risk perception and Financial Literacy

Predictor	B	SE B	β	t	p	Tolerance	VIF
Constant	0.964	0.153	—	6.308	0.000	—	—
Financial Literacy	0.737	0.042	0.710	17.609	0.000	1.000	1.000
Model Summary: R = 0.710, R² = 0.504, Adjusted R² = 0.503, Std. Error = 0.698 **ANOVA:** F(1, 305) = 310.089, p < 0.001							

Source: Authors' calculations

Finally, the regression analysis results presented in Table 9 did not provide support for H3. The regression coefficient (B = 0.669, β = 0.660, p < 0.001) is positive and significant, meaning that higher financial risk perception is associated with greater perceptions regarding marketing opportunities during introduction of new agricultural products. Financial risk perception explains about 43.6% of the variance in marketing opportunity perception which is a substantial effect. ANOVA ($F(1,305) = 235.304$, $p < 0.001$) which means that the overall regression model is statistically significant.

Producers with strong risk perception may be strategic thinkers: they acknowledge risks but also identify opportunities in marketing as a way to mitigate or balance those risks. Although regression results show that higher financial risk perception increases agreement with marketing opportunities in the process of new product placement, this reveals a deep insight: risk-aware producers are opportunity focused. This aligns with theories in entrepreneurship and strategic management: risk perception can sharpen opportunity recognition rather than suppress it (Caputo, Nguyen, & Delladio, 2025; Yin & Wu, 2023).

Table 9. Relationship between Marketing Opportunities and Financial Risk Perception

Predictor	B	SE B	β	t	p	Tolerance	VIF
Constant	1.199	0.161	—	7.438	0.000	—	—
Financial Risk	0.669	0.044	0.660	15.340	0.000	1.000	1.000
Model Summary: $R = 0.660$, $R^2 = 0.436$, Adjusted $R^2 = 0.434$, Std. Error = 0.754 **ANOVA:** $F(1, 305) = 235.304$, $p < 0.001$							

Source: Authors' calculations

Discussion of research findings

The results of regression analyses presented in Tables 7, 8 and 9 provide strong empirical support for the hypothesized relationships between financial literacy, financial risk perception, and marketing opportunities. First, the results confirm that financial literacy is a significant and robust predictor of marketing opportunities perceptions (H1). With an explained variance of 46.4%, the findings highlight that agricultural producers with higher levels of financial literacy are more likely to perceive marketing as an important driver of success in agricultural product placement. This aligns with prior studies emphasizing the role of financial competencies in shaping strategic decision-making and market orientation. Other studies have emphasized that financial literacy must indeed be developed, but with appropriate regulation and guidance to ensure it does not merely encourage short-term profit seeking but rather supports stable and sustainable food production (Li et al., 2024). Furthermore, several studies highlight that many agricultural entrepreneurs possess limited financial literacy, which often results in weak financial management and inadequate risk-handling practices (Kaur & Dharni, 2024; Pal & Sharma, 2023). A survey conducted among 505 farmers in India revealed that only about 33% demonstrated financial discipline, with an average financial literacy score of just 1.80 (Das & Maji, 2025).

Similarly, financial literacy emerged as a strong positive predictor of financial risk perception (H2), accounting for 50.4% of the variance. This suggests that financially literate agricultural producers are more aware of potential risks, which may reflect their ability to critically evaluate investment decisions and market uncertainties (Lu, Li, & Wu, 2024). Rather than reducing perceived risk, financial literacy appears to sharpen awareness, consistent with theories of bounded rationality and informed risk assessment in entrepreneurship (Pandey & Chadha, 2026).

Unexpectedly, the results regarding H3 revealed that financial risk perception positively predicted marketing opportunity perception, explaining 43.6% of the variance. Although the hypothesis anticipated a negative relationship, the findings suggest that risk-aware producers are not deterred by financial risks; instead, they recognize marketing as a strategic tool to mitigate or balance those risks. This interpretation resonates with entrepreneurial theory, which posits that heightened risk perception can enhance opportunity recognition by encouraging proactive strategies (Caputo, Nguyen, & Delladio, 2025; Yin & Wu, 2023). Agricultural producers who acknowledge risks may therefore be more inclined to adopt innovative marketing practices, such as collaboration with local businesses or digital promotion, to secure competitive advantage.

Taken together, these findings underscore the central role of financial literacy in shaping both risk awareness and marketing orientation. Moreover, they reveal a nuanced dynamic: risk perception does not suppress opportunity recognition but rather coexists with it, fostering strategic thinking among agricultural producers.

Conclusion

This paper examined the relationships between financial literacy, financial risk perception, and marketing opportunities among agricultural producers in Serbia. The results in which participated 307 agricultural producers revealed strong, positive, and statistically significant correlations among all three constructs, confirming that they are closely interrelated. Regression analyses further demonstrated that financial literacy significantly predicted both marketing perception and financial risk perception, supporting Hypotheses 1 and 2. Interestingly, Hypothesis 3 was not supported: rather than a negative association, financial risk perception was positively related to marketing opportunities. This finding suggests that agricultural producers who are more risk-aware also tend to recognize greater marketing opportunities, highlighting the duality of risk and opportunity in their decision-making.

The results contribute to theory by demonstrating that financial literacy plays a dual role: it not only enhances perceptions of marketing effectiveness but also heightens awareness of financial risks. This supports theories that emphasize the importance of cognitive capabilities in opportunity recognition and risk assessment. Importantly, the unexpected positive relationship between financial risk perception and marketing opportunities challenges traditional assumptions that risk awareness dampens opportunity recognition. Instead, the findings align with perspectives that view risk and opportunity as interdependent, suggesting that producers who are more risk-aware may simultaneously be more opportunity-focused.

From the practical standpoint findings suggest that improving financial literacy among agricultural producers can strengthen both their ability to recognize risks and their confidence in marketing strategies for new products. The positive association between risk perception and marketing opportunities implies that risk-aware producers may be better positioned to identify market gaps and innovate in product placement.

Policymakers and industry stakeholders can leverage this by designing support mechanisms that encourage producers to treat risk as a signal for potential opportunity.

Despite these contributions, several methodological limitations must be acknowledged. First, the study employed a cross-sectional design, which captures perceptions at a single point in time (2026). Second, data were collected through self-reported online questionnaires, which may introduce response bias and exclude producers with limited internet access or digital literacy. Third, the sample was restricted to agricultural producers in only one country (Serbia), limiting the generalizability of findings to other cultural and institutional contexts.

Building on these limitations, future research should adopt longitudinal designs to track how financial literacy, risk perception, and marketing orientation evolve over time. Incorporating objective measures of financial literacy and marketing performance, alongside qualitative interviews, would reduce self-report bias and provide richer insights. Finally, comparative studies across countries or regions would enhance external validity and reveal whether the observed relationships hold across diverse agricultural systems, thereby offering a broader understanding of how financial literacy and risk perception shape opportunity recognition in agriculture.

Conflict of interests

The authors declare no conflict of interest.

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EVALUATION OF CRITERIA FOR THE DIGITALIZATION OF AGRICULTURAL MACHINERY

Miroslav Nedeljković[1], Mate Budimir[2], Bojan Branković[3]
**Corresponding author E-mail: miroslavnedeljkovic2015@gmail.com*

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A B S T R A C T

In the paper, using the multi-criteria decision-making method SiWeC, the digitization criteria were evaluated on the example of medium- and heavy-duty tractors. A fuzzy variant of the multi-criteria decision-making method was used in order to obtain as precise assessment of the given ten qualitative criteria as possible. The results show that, according to the expert evaluation, the technical criterion "Precision of operations" gained the most importance, while immediately after them in importance were the criteria related to the level of work automation and digital connectivity. The results show important implications for decision makers, technology producers and the shaping of agricultural policy. In the future, the model needs to be expanded with impact criteria, and the number of decision-makers who would give a practical contribution, as well as a base for further development of the applied research method, should be increased.

Introduction

Digitization of agricultural equipment is a important segment of the agricultural revolution. This approach includes the introduction of advanced information and communication technologies into automated processes in food production. The goal is not only to replace the human workforce, but also to achieve an improved level of efficiency, precision and sustainability (Kiktev et al., 2025; Pantović et al., 2026). Classical mechanized methods, although effective at the macro level, often result in the waste of resources such as seeds and fertilizers, with heterogeneous yield results due to the inability to adapt to spatial

1 Miroslav Nedeljković, Ph.D., Senior Research Associate, Institute of Agricultural Economics, Volgina Street no. 15, 11060 Belgrade, Serbia, Phone: +381 65 447 1201, E-mail: miroslav_n@iep.bg.ac.rs, ORCID ID (https://orcid.org/0000-0002-7393-2146)

2 Mate Budimir, Ph.D., Hunting Association of Split-Dalmatia County, Kralja Zvonimira 75, 21210 Solin, Croatia, Phone: +385 21 539 814, E-mail: budimir.split@gmail.com, ORCID ID (https://orcid.org/0009-0000-1219-4621)

3 Bojan Branković, M.A., Independent Researcher, Pančevo, Serbia, Phone: +381 60 0324233, E-mail: mrbojanbrankovic@gmail.com, ORCID ID (https://orcid.org/0009-0004-5505-4230)

variations within the plot (Wang et al., 2025; Janković & Golubović, 2025; Zhang, 2023; Luković et al., 2026). Digitization is currently emerging as a solution to these challenges, enabling a shift from standardized processing to flexible, analysis-driven application of data. Modern agriculture faces a contradiction: it is necessary to significantly improve food production in order to feed the growing global population, while at the same time reducing the harmful effects on the environment and mitigating the effects of climate change, with a constant shortage of labor in rural areas. (Padhiary et al., 2024; Vujanić et al., 2026; Wang et al., 2025) In this context, the digitization of agricultural machinery ceases to be only a technological advance, and becomes an economic and environmental necessity.

Multi-criteria decision-making methods play a major role in the evaluation of digitalization criteria. An expert assessment of pre-set criteria provides a rational insight into their weight (importance), which enables their development or eliminates negative influence. Accordingly, the subject of the research is the identification and assessment of important criteria that influence the digitization process on the example of medium-heavy and heavy tractors, with special emphasis on technological, operational and economic aspects. The analysis includes the use of the fuzzy multi-criteria decision-making method SiWeC (*Simple Weight Calculation*) in order to quantify the importance of individual criteria and clarify their influence on the decision-making process in modern agricultural systems.

The main goal of the work is the development and implementation of an integrated model for evaluating the criteria of digitization of medium-heavy and heavy tractors using the fuzzy multi-criteria decision-making method. Specific objectives include: determination of the relative weights of criteria using the fuzzy SiWeC approach, validation and comparison of results using other methods of multi-criteria analysis, analysis of model consistency and robustness using correlation, as well as identification of key factors that have the greatest impact on digital transformation in agricultural mechanization.

Accordingly, the main hypothesis in the paper would be that the application of fuzzy multi-criteria decision-making methods enables reliable determination of the relative weights of tractor digitization criteria, whereby technological criteria have a dominant influence.

Literature review

In their previous works and studies, many researchers have dealt with the application of multi-criteria decision-making methods when the subject was digitization in agriculture and agribusiness. Thus Albahri et al. (2025) in their work investigate the fusion of sensor technologies and multi-criteria decision-making methods (MCDM) in precision agriculture. The authors recognize three key application areas: sensor selection for irrigation systems, sensor selection for crop monitoring, and sensor selection for machine control. The paper contains 47 references and offers a comprehensive overview of the methods used, including AHP, ANP, TOPSIS, VIKOR and PROMETHEE method.

Nanje et al. (2024) used a multi-criteria approach to evaluate the suitability of areas for the use of potato harvesters in Kenya. The research applied the AHP method to determine the weights of the criteria (soil, climate, relief, infrastructure) and GIS for spatial analysis. Kizielewicz et al. (2025) created a comprehensive decision-making framework based on MCDM methods for the evaluation of intelligent sensors for drones (UAVs) in the field of precision agriculture. The framework integrates objective weight estimation methods (Standard Deviation, Entropy, CRITIC and MEREC) with four MCDM ranking techniques, including the new COCOCOMET (COmbined COmpromise solution with Characteristic Objects METhod) method. The survey included 11 sensor options and 9 evaluation criteria. Kenarsari et al. (2024) used the integration of AHP and GRA methods to select a sustainable combination of machinery in rice production. The research included economic (costs, operating costs, durability), social (safety, ergonomics, ease of handling) and environmental (fuel consumption, gas emissions, impact on the earth) criteria. Weight criteria were determined using the Delphi method and partial comparisons. The authors point out that hybrid methods serve as a powerful instrument for solving questions that include qualitative and quantitative criteria. El-Sayed et al. (2024) proposed a combination of AHP method with machine learning (hierarchical agglomerative clustering) to select a sustainable tractor for small farms in Egypt. The initially identified nine criteria (price, power, fuel consumption, maintenance costs, weight, working life, safety, ergonomics and environmental performance) were summarized into three basic criteria, namely: price, power and maintenance costs.

In addition to everything, many studies also confirm the successful application of the fuzzy variant of multi-criteria methods when it comes to the use of digitalization in agricultural machinery. Sarkar et al. (2024) used a fuzzy AHP approach to evaluate and select tractors for small farms in Bangladesh. The research included 5 options and 12 parameters divided into three groups: technical (engine power, working width, weight, payload), economic (price, fuel consumption, maintenance costs) and social (safety, ergonomics, ease of handling). Chauhan et al. (2023) created a coupled fuzzy AHP and fuzzy TOPSIS model for combine selection for wheat harvesting in India. The research included 6 different types of harvesters and 9 evaluation criteria: harvesting capacity, harvesting losses, fuel consumption, price, service costs, availability of spare parts, ease of operation, safety and environmental aspects. Fuzzy AHP is used to determine the weights of criteria, while fuzzy TOPSIS is used to classify alternatives. Büyüközkan et al. (2024) applied the fuzzy TOPSIS method for the selection of smart sensors in precision agriculture in Turkey.

The research included 8 sensor options and 7 criteria: accuracy, dependability, cost, ease of integration, energy efficiency, resistance to the external environment and compatibility with IoT platforms. Liu et al. (2024) created a fuzzy VIKOR model to select the best sensor-integrated irrigation system in China. The research included 5 irrigation systems and 11 criteria divided into technical, economic, ecological and social categories. Peci et al. (2025) created a hybrid phase model that relies on a combination of LOPCOW and MABAC methods to select the best tractor for the Myzeqe area in Albania. The survey included 15 tractors with different characteristics, and the evaluation was performed according to seven criteria: engine power, price, fuel consumption, weight, load capacity, durability and maintenance costs. The authors were introduced to the extension phase of both methods in order to solve the uncertainty in the estimates. Kumar et al. (2023) created an integrated SWARA (Step-wise Weight Assessment Ratio Analysis) model and WASPAS (Weighted Aggregated Sum Product Assessment) model for sensor selection in precision agriculture in India. The research covered 7 sensor options and 8 criteria: accuracy, response speed, cost, power consumption, compliance, robustness, ease of calibration and availability. Fuzzy SWARA was used to define criteria weights by comparing the importance of criteria by experts, while fuzzy WASPAS was used to rank options. Nedeljković et al. (2021) select apple picking machines using the fuzzy CRITIC and MARCOS methods based on seven predetermined criteria, while Puška et al. (2025) select the most favorable from the category of electric tractors for small farms in the Semberija region of Bosnia and Herzegovina. On this occasion, the authors use the new fuzzy SiWeC-RAWEC multi-criteria decision-making method. Also, Puška et al. (2024) evaluate tractors using the fuzzy SAW method of multi-criteria analysis.

Methodology

The analysis of interested parties recognizes agricultural farms as the main actors in the process of digitalization of agricultural equipment, because they make important investment and operational decisions. These actors function in collaboration with technical experts, technology producers and institutional frameworks, which influence the availability, choice and use of digital solutions. The results show a complex decision-making system, in which direct and indirect participants jointly shape the success of digital transformation in agriculture. This work involved seven experts from the field with extensive experience in the analyzed field. (Table 1)

Table 1. Linguistic scale

1	Very-Low (V-L)	(1. 1. 2)
2	Low (L)	(1. 2. 4)
3	Medium-Low (M-L)	(2. 4. 6)
4	Medium (M)	(3. 5. 7)
5	Medium-Good (M-G)	(5. 7. 9)
6	Good (G)	(7. 9. 10)
7	Very-Good (V-G)	(9. 10. 10)

Source: Puška et al., 2024a

Before the very beginning of the evaluation, the criteria were determined, which were once again agreed upon by the engaged experts on the basis of professional scientific literature. Their explanation and overview are given in the following table 2.

Table 2. Analyzed criteria

ID	Name of the criterion	Description of criteria
C1	Level of work automation	It measures the tractor's level of autonomy in performing operations (eg automatic steering, autopilot, autonomous operation mode).
C2	Sensor integration (IoT capacity)	Tractor capability for sensor use (soil moisture, temperature, pressure, etc.).
C3	Precision of operations	It measures the accuracy of agricultural operations (sowing, fertilizing, spraying).
C4	Digital connectivity (real-time data)	It evaluates the tractor's ability to exchange data in real time (cloud, farm management systems).
C5	System interoperability	It refers to the compatibility of tractors with different attachments and software (ISOBUS standard).
C6	Analytics and decision support systems	Assessment of the existence and quality of systems that analyze data and provide recommendations (eg when to sow, how much fertilizer to apply).
C7	Resource utilization efficiency	It measures how much the tractor optimizes use.
C8	Predictive maintenance	It refers to the system's ability to predict failures based on data (AI, sensors).
C9	Ease of use	Assessment of how intuitive the system is for the user (farmer/operator).
C10	Digitization costs	Total Cost of Ownership.

Source: Authors

It is important to point out that during the evaluation of the criteria, the fuzzy variant of the multi-criteria method is used. Fuzzy decision making in smart agriculture improves crop yield and quality. In addition, it improves the use of resources, reduces waste and increases efficiency and sustainability. (Erdoğan, 2022)

The procedure we used to evaluate the mentioned criteria is fuzzy simple calculation of weights. The applied method is the SiWeC method of multi-criteria decision-making (Simple weight calculation), and its fuzzy approach was used for the subjective evaluation of the importance of the criteria, relying on the use of linguistic expressions. The method was created by Puška et al. (2024a) and its steps include:

- Assessment of the criteria,
- Construction of fuzzy numbers,
- Normalization fuzzy numbers,

$$\tilde{n}_{ij} = \frac{x_{ij}^{l}}{max\ x_{ij}^{u}}, \frac{x_{ij}^{m}}{max\ x_{ij}^{u}}, \frac{x_{ij}^{u}}{max\ x_{ij}^{u}}$$

Where is $max\ x_{ij}^{u}$ maximum value for all criteria.

- Calculating the standard deviation ($st.dev_j$),

- Display of normalized results with standard deviation values,

$$\tilde{v}_{ij} = \tilde{n}_{ij} \times st.dev_j$$

- Calculation of total weights for specific criteria,

$$\tilde{s}_{ij} = \sum_{j=1}^{n} \tilde{v}_j$$

- Getting criteria weight.

$$\widetilde{w}_{ij} = \frac{s_{ij}^l}{\sum_{j=1}^n s_{ij}^u}, \frac{s_{ij}^m}{\sum_{j=1}^n s_{ij}^m}, \frac{s_{ij}^u}{\sum_{j=1}^n s_{ij}^l}$$

After the obtained results, the validation of the results was carried out, as well as the discussion and making of the necessary conclusions. In addition, certain recommendations were highlighted that should be kept in mind during further similar research in this area.

Results and Discussion

The experts' rating is shown in the following table 1, while the linguistic conversion of the ratings is presented in table 2.

Table 3. Expert assessment

ID	Name of the criterion	e1	e2	e3	e4	e5	e6	e7
C1	Level of work automation	6	7	6	7	6	6	7
C2	Sensor integration (IoT capacity)	4	5	3	7	6	7	7
C3	Precision of operations	7	7	7	7	6	6	7
C4	Digital connectivity (real-time data)	7	6	7	6	6	6	7
C5	System interoperability	5	4	5	5	4	6	5
C6	Analytics and decision support systems	5	4	3	4	3	4	6
C7	Resource utilization efficiency	5	6	5	5	6	6	5
C8	Predictive maintenance	4	5	6	5	6	5	5
C9	Ease of use	6	6	7	6	6	6	7
C10	Digitization costs	5	6	5	7	6	7	6

Source: Authors

Table 4. Linguistic evaluation of criteria

Criteria	e1	e2	e3	e4	e5	e6	e7
C1	G	V-G	G	V-G	G	G	V-G
C2	M	M-G	M-L	V-G	G	V-G	V-G
C3	V-G	V-G	V-G	V-G	G	G	V-G
C4	V-G	G	V-G	G	G	G	V-G
C5	M-G	M	M-G	M-G	M	G	M-G
C6	M-G	M	M-L	M	M-L	M	V-G
C7	M-G	G	M-G	M-G	G	G	M-G

Criteria	e1	e2	e3	e4	e5	e6	e7
C8	M	M-G	G	M-G	G	M-G	M-G
C9	G	G	V-G	G	G	G	V-G
C10	M-G	G	M-G	V-G	G	V-G	G

Source: Authors

By applying all the steps of the used method, the final ratings of the analyzed criteria in tractor digitalization were obtained, and their final ranking is given in the following table 3. From it, we can see that the technical criterion "precision of operations" is the best rated, that is, it has the highest weight (0.118). The criteria "Level of work automation" and "Digital connectivity" follow immediately after, while the criterion "Analytics and decision support systems" has the least weight according to expert evaluation.

Table 5. Rang alternative

Rank	ID	Criteria	$\widetilde{w}_{ij}$
1	C3	Precision of operations	**0.118**
2	C1	Level of work automation	**0.114**
2	C4	Digital connectivity (real-time data)	**0.114**
4	C9	Ease of use	**0.112**
5	C10	Digitization costs	**0.105**
6	C7	Resource utilization efficiency	**0.097**
7	C2	Sensor integration (IoT capacity)	**0.096**
8	C8	Predictive maintenance	**0.090**
9	C5	System interoperability	**0.083**
10	C6	Analytics and decision support systems	**0.071**

Source: Authors

By comparing with other subjective fuzzy variants of decision-making methods, we get a final overview of the given criteria (table 4). We notice that by applying the other methods we get a very similar final ranking. With the other methods, the criterion "*Precision of operations*" was rated the best, and "*Analytics and decision support systems*" the lowest.

Table 6. Ranking of alternatives using different MCDM methods

Rank	Criteria	ID	FAHP	FBWM	FSWARA
1	Precision of operations	C3	**0.135**	**0.140**	**0.128**
2	Level of work automation	C1	0.128	0.125	0.130
2	Digital connectivity (real-time data)	C4	0.132	0.130	0.125
4	Ease of use	C9	0.125	0.120	0.120
5	Digitization costs	C10	0.122	0.118	0.118
6	Resource utilization efficiency	C7	0.090	0.095	0.092
7	Sensor integration (IoT capacity)	C2	0.085	0.090	0.095
8	Predictive maintenance	C8	0.083	0.085	0.085
9	System interoperability	C5	0.060	0.060	0.065
10	Analytics and decision support systems	C6	**0.040**	**0.037**	**0.042**

Source: Authors

In the last stage, before drawing conclusions in the work, we validated the obtained results in such a way that the ranked results obtained by the FSiWeC method were compared with the ranked results of other methods (fuzzy AHP, fuzzy BWM and fuzzy SWARA) using the Spearman correlation coefficient using the following expression (Božanić et al., 2022):

$$SCC = 1 + \frac{6\sum_{i=1}^{n} D_i^2}{n(n^2 - 1)}$$

In this equation, Di is the difference between the rank of an item in the vector w and the rank of the corresponding item in the reference vector, and n is the number of ranked items. (Božanić et al., 2022). A SCC value of 0 means that there is no relationship between the variables. (Katranci et al., 2025)

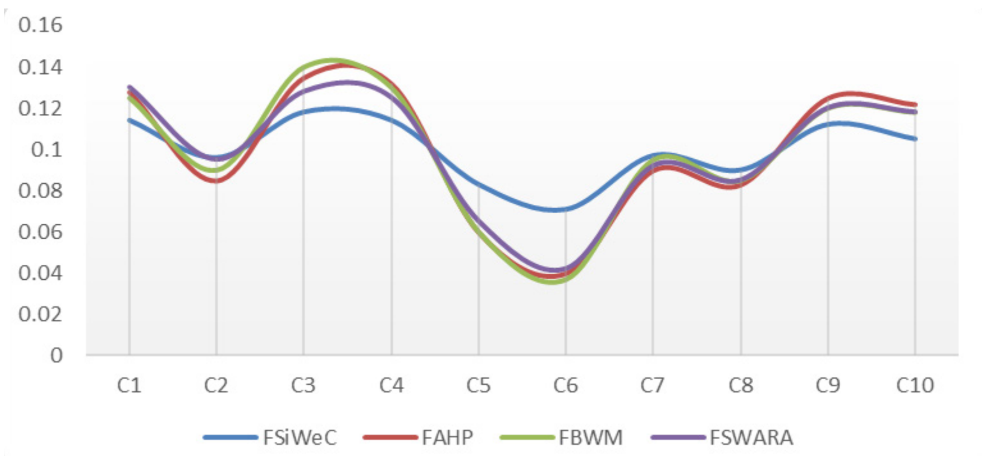
Table 7. Correlation matrix

Methods	**FSiWeC**	**FAHP**	**FBWM**	**FSWARA**
FSiWeC	1.000	**0.945**	**0.964**	**0.973**
FAHP	0.945	1.000	**0.976**	**0.964**
FBWM	0.964	0.976	1.000	**0.982**
FSWARA	0.973	0.964	0.982	1.000

Source: Authors

The greatest agreement was expressed with the FBWM-FSWARA method (ρ = 0.982), which shows that these are almost identical models. The FSiWeC method has the highest compatibility with the FSWARA method (ρ = 0.973), while the smallest but still high similarity is with the FAHP method (ρ = 0.945). Discrepancies are pronounced due to pairwise comparisons of methods and greater measurement discrimination. Method comparison results shows that the stability of the ranking is high, as well as the reliability of the expert data. The following chart 1 gives us a visualization of that.

Figure 1. Comparison with other subjective MCDM methods



Source: Authors

Precision agriculture research shows that operational accuracy and automation are key factors in improving productivity and lowering costs. At the outset, research in the field of precision agriculture (Wolfert et al., 2017) highlights the importance of digital technologies that enable the improvement of inputs and the improvement of production efficiency, which coincides with the high ranking of criteria C3 and C1 in this research.

Despite methodological rigor and the use of multiple fuzzy MCDM methods, this research has certain limitations that should be considered when interpreting the results. Namely, the research, firstly, relies on a relatively small number of experts (n=7), which may affect the representativeness of the results obtained. Although the experts were selected according to relevant skills and experience, a larger sample could increase the robustness and generalizability of the results. Second, subjective assessments of experts were used, which, although shaped through a fuzzy approach, may still have a certain degree of bias. Third, the research was carried out in a specific regional framework (agricultural sector of the Balkans), which may reduce the possibility of applying the results in other countries with a higher degree of digital maturity and more developed infrastructure. Fourth, the model does not include changes over time, ie. the analysis is static and does not take into account the development of technologies and changing market conditions.

In order to improve research and continue the development of the agricultural machinery digitization sector, the following directions of future research are recommended:

- First, subsequent research could include a larger sample of experts, including farmers, policy makers, and technology firms, thus ensuring a broader perspective and greater validity of the findings.
- Second, it is recommended to include objective methods for determining weights (eg Entropy, CRITIC, IDOCRIW), as well as hybrid models that combine subjective and objective methods.
- Third, an important direction of research is the application of advanced fuzzy and hybrid approaches (fuzzy MARCOS, fuzzy MABAC, fuzzy TOPSIS), along with integration with group decision-making methods (group decision-making).
- Fourth, further research can include dynamic models and time series, with the aim of studying the evolution of the importance of criteria over time, especially in the context of the rapid advancement of digital technologies.
- Fifth, it is recommended to combine the digital twin system with AI models, in order to enable simulations of various scenarios and optimization of decisions in real time.

Conclusions

In the paper, evaluation and ranking of tractor digitization criteria was carried out using the fuzzy multi-criteria decision-making method. Based on the collected evaluations of experts and the application of the fuzzy SiWeC method, the key criteria with the most significant impact on the digitalization process were determined. Research has shown that the criteria of Precision of operations (C3), the level of automation of work processes (C1) and digital connectivity (C4) are of key importance, while the criteria of system interoperability (C5) and analytics, and decision support systems (C6) have less impact.

As part of the validation of the results, a comparative analysis was performed using fuzzy AHP, fuzzy BWM and fuzzy SWARA methods. The obtained results show a high degree of agreement between the methods, which is confirmed by the high values of the Spearman correlation coefficients. This type of consistency confirms the robustness of the model and the reliability of the criterion ranks that were obtained.

Research shows that the digitalization of agricultural machinery is currently focused on improving operational efficiency and optimizing resources, while advanced features such as analytical systems and full interoperability are still less of a priority. This has significant consequences for decision makers, technology producers and agricultural policy makers.

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Conflict of interests

The authors declare no conflict of interest.

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DEVELOPMENT OF FADN IN SERBIA, MONTENEGRO AND BOSNIA AND HERZEGOVINA (EU CANDIDATE COUNTRIES) AND THE TRANSITION TOWARDS FSDN

Lana Nastić[1], Saša Todorović[2], Sanjin Ivanović[3], Vesna Očić[4]

**Corresponding author E-mail: sanjinivanovic@agrif.bg.ac.rs*

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A B S T R A C T

All the candidate countries for the European Union accession are obliged to establish Farm Accountancy Data Network as a way of recording and analyzing farm activities, agricultural policy creation and monitoring. Observed countries (Serbia, Montenegro and Bosnia and Herzegovina) are in different phases of establishing that system. The goal of the research was to discuss level of development of Farm Accountancy Data Network in observed countries and readiness of transition to Farm Sustainability Data Network. To achieve that goal qualitative comparative analysis was used. The results indicated the highest level of development in Serbia, while Bosnia and Herzegovina is still at the beginning of the process. Farm Accountancy Data Network development in Montenegro could be estimated as medium. It was concluded that observed countries face certain challenges when it comes to transformation of existing system towards broader concept of sustainability. All the countries should work on capacity-building strategies, particularly in Montenegro and Bosnia and Herzegovina, to provide successful transition to system which is more sustainability-oriented.

1 Lana Nastić, Ph.D., Research Associate, Institute of Agricultural Economics, Volgina Street no. 15, Belgrade, Serbia, Phone: +381 11 697 28 48, E-mail: lana_n@iep.bg.ac.rs, ORCID ID (https://orcid.org/0000-0003-1939-0718)

2 Saša Todorović, Assistant Professor, University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Zemun, Belgrade, Serbia, Phone: +381 (11) 441-3406, E-mail: sasat@agrif.bg.ac.rs, ORCID ID: (https://orcid.org/0000-0002-9897-473X)

3 Sanjin Ivanović, Ph.D., Full Professor, University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Zemun, Belgrade, Serbia, Phone: +381 (11) 441-3426, E-mail: sanjinivanovic@agrif.bg.ac.rs, ORCID ID: (https://orcid.org/0000-0002-2005-9910)

4 Vesna Očić, Ph.D., Associate Professor, University of Zagreb, Faculty of Agriculture, Svetošimunska cesta 25, 10000 Zagreb, Croatia, Phone: +385 1 239 3740, E-mail: vocic@agr.hr, ORCID ID: (https://orcid.org/000-0002-0323-6743)

Introduction

The Farm Accountancy Data Network (FADN) is a key tool used in the European Union (EU) to collect, analyze, and report detailed economic data on agricultural holdings. FADN system started in the 1965 (Hill and Bradley, 2016). It was done “by Council Regulation 79/1965, which provided the original legal basis for the organization of the system” (Juračak and Očić, 2021). Acording to Marongiu and Casolani (2026) “FADN has been the basis for economic and accounting information, aiming at the analysis of the impacts of European agricultural policy interventions. The evolution of policies and the inclusion of environmental and social elements in the evaluation of global farm sustainability have led to the conversion of FADN into FSDN”.

FADN provides essential information for policy development, monitoring of the Common Agricultural Policy (CAP), and assessing the economic performance and sustainability of farms across EU member states. By offering harmonized data on costs, revenues, and structural characteristics of farms, FADN supports evidence-based decision-making and facilitates cross-country comparisons. According to Pitulice and Gorgan (2013) FADN is “a data analysis tool designed to assess farm income and the impact of CAP”. Neuenfeldt and Gocht (2014) stated that “FADN is the only source of micro-economic data that is harmonised using bookkeeping principles”. According to Hill et al. (2016) “the benefit of FADN and national farm accounts surveys is dependent on the impact on decisions by users. If the data are unused or ignored, there is no benefit.

When it comes to individual farms involved in the sample, they do not have direct financial benefits, because participation in FADN and FSDN system is voluntarily. On the other hand there could be some additional reasons for farmers to be part of FADN/FSDN such as to obtain their individual financial reports and compare it with data of other farms having similar size and production type in the same region or other regions/countries (not only in Serbia, Montenegro or Bosnia and Herzegovina, but also in other European countries). Farms involved in FADN/FSDN are also able to perform temporal comparison of their individual business results, which enables farm managers to evaluate effects of their previous business decisions. Inclusion of additional indicators in FSDN system will provide farmers with better perspectives when it comes to social and ecological aspects, as well.

Discussing establishment of FADN in new member states (particularly Czech Republic, Estonia, Bulgaria and Croatia) Del’Homme and Aamisep (2009) mentioned some of key factors influencing FADN adoption such as strong organization and good managers (due to authors human resources are the key point for FADN). Authors also discussed the importance of time frame for establishing FADN – they indicated that it takes at least five years for FADN to become relevant.

Developing a functional FADN in candidate countries in the Western Balkans is a primary consideration for harmonizing with EU regulations, enhancing institutional development, and fostering competition in agriculture. At the same time, the FADN is not uniformly developed in these countries due to variations in the institutional, legal, and technical frameworks and statistical resources.

The purpose of this paper is to conduct a comparative study of the institutional development and the status of FADN in Serbia, Montenegro, and Bosnia and Herzegovina. Furthermore, the study examines the preparedness of these countries for the transition to the FSDN, which is a framework for incorporating sustainability metrics into agricultural accounting, thereby recognizing the significance of the environmental, social, and economic aspects of European agriculture. This research identifies the challenges, gaps, and emerging focal points in the region, enhancing the understanding of the regional dynamics of FADN development, as well as informing policy planning and the broader process of EU integration.

Methodology

This study uses qualitative comparative analysis by implementing a systematic cross-country comparison involving the institutional, legal, and technical dimensions of the FADN systems of the countries under study.

The focus of the analysis is the framework that identifies the critical parameters for the FADN evolution and the preparedness for the evolution towards the FSDN concerning institutional, legal, and technical infrastructure as well as human resource capacity and data availability.

Instead of employing an informal qualitative comparative analysis (QCA) methodology that uses calibration and truth tables, the authors prefer a structured qualitative comparative method that is most suitable for policy-related and cross-country oriented studies.

Data Collection

The study incorporates data from various reputable sources to ensure a diversified and triangulated approach:

- Official documents and national legislation: Relevant laws, regulations, and government strategies concerning agricultural data collection, rural development, and FADN governance were reviewed. These documents provided insights into the institutional frameworks, funding mechanisms, and organizational responsibilities for FADN implementation;
- European Commission documents: Progress reports, country analyses, and technical documents from the European Commission offered a regional and policy-level context for the status and evolution of FADN, especially concerning alignment with EU agricultural policies and readiness for transition to the FSDN;
- Scientific literature: Peer-reviewed articles, research reports, and case studies related to FADN methodology, institutional development, and agricultural data management in the Western Balkans enriched the analysis by presenting academic perspectives, methodological critiques, and empirical findings; and
- Statistical data: Where available, official statistical data from ministries of agriculture or statistical offices were incorporated to provide quantitative support for the assessment of FADN coverage, sample sizes, and data collection progress.

Comparative Analytical Approach

The institutional frameworks and legal bases were compared qualitatively across the three countries to identify commonalities, divergences, and gaps in the establishment and operation of FADN systems.

Statistical data were used descriptively to illustrate and summarize key indicators of FADN implementation, including the number of farms covered, sample size, regional distribution, and representativeness.

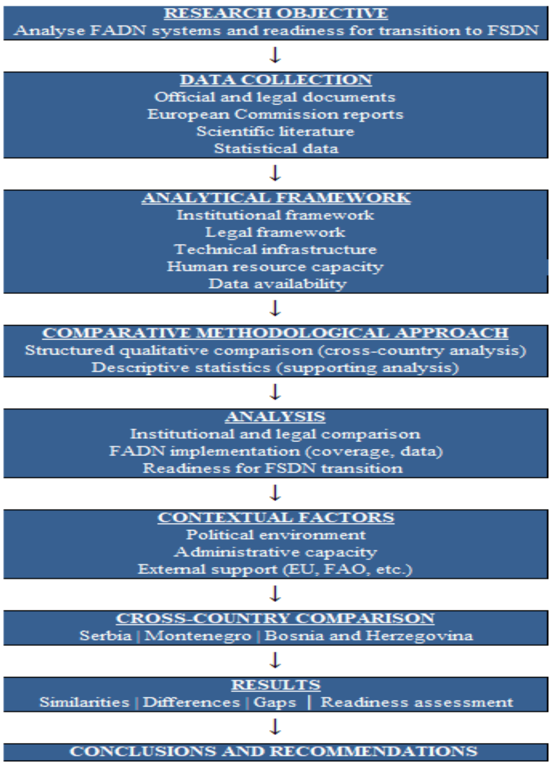
The study also evaluated the countries' preparedness for transition towards the FSDN by analyzing strategic plans, organizational readiness, and identified challenges within the institutional and legal frameworks.

Throughout the analysis, special attention was paid to contextual factors unique to each country, such as political environment, administrative capacities, and external support mechanisms (e.g., EU IPA projects, FAO assistance).

Research Design

Figure 1 illustrates the research design for this study. The figure outlines the steps for analyzing FADN in Serbia, Montenegro and Bosnia and Herzegovina and how information from different sources comes together for a comparative analysis.

Figure 1. Research design – comparative analysis of FADN and readiness for FSDN



As shown in Figure 1 the research process involves data collection, qualitative comparative analysis, and contextual assessment in a structured way. This visual summary helps make the research clear, repeatable and easy to compare across the three countries highlighting both the similarities and differences in FADN implementation and readiness for FSDN.

This approach works well for studies of countries that want to join the EU, where data is limited and requires a mix of comparative analysis methods making FADN and FSDN a good fit for this kind of research. The study focuses on FADN, in Serbia, Montenegro and Bosnia and Herzegovina to draw conclusions.

Certain limitations were faced during this research, primarily concerning data on FADN development in Bosnia and Herzegovina. The reason is division of the country in two entities which have separate FADN authorities and approaches. At the same time, not all data on FADN development are publically available (primarily considering results of certain pilot projects used for developing FADN system in Bosnia and Herzegovina).

The importance of this research is related to FADN system and its improved version (FSDN system), as a database for scientific exploration of various aspects of agricultural production (economic, social and ecological), but also database for broader scientific research (such as measurement of efficiency, discussion and analysis of farm resilience etc). Practical aspects are related to making better informed decisions on farm level as well as appropriate policy development and monitoring of its results in observed countries. The research provides the way for better understanding of processes and challenges related to establishment of FADN system in these countries (within EU integration process) as well as its transformation to FSDN (discussing broad range of topics such as appropriate legal framework, sampling structure, data collection and availability of obtained data etc).

FADN in Serbia

Establishment of FADN system in Serbia was initiated in 2011 with support of EU Instrument for Pre-accession Assistance (IPA) project covering period from 2011 to 2015 (FADN, 2026). According to the same source, in 2011 only 40 farms were involved in FADN, while in 2023 that number significantly increased to 1,825 farms. It could be noticed that there are two statistical regions in Serbian FADN – Serbia North (involving 547 farms in 2023 sample) and Serbia South with much bigger sample (1278 farms in 2023). FADN in Serbia is regulated by the Law on Agriculture and Rural Development (2021) which determines entities involved in FADN system, the way FADN activities are financed etc.

Although FADN data for Serbia covering year 2015 were published by the Ministry of Agriculture in the form of Farm Return and have been publically available (publication prepared by Stojanović et al., 2016) this practice did not continue in following years. One more research was partially related to FADN in Serbia, but it discussed only northern Serbian Province of Vojvodina (Vukoje et al., 2017) and was also based on the data for year 2015. After that, certain set of FADN data has been published every year by the Ministry of agriculture (as one element of publication called “Report on the situation of agriculture in the Republic of Serbia (the “Green Book”). According to Serbian current legislation on FADN system (Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia, 2023) it is possible to have an access to more detailed FADN data with approval of appropriate Ministry which is in charge for this system.

Number of research has been published by authors from Serbia concerning FADN system and methodology. Analyzing establishment of Serbian FADN Ivkov et al. (2013) concluded that “FADN institutional frameworks in EU member states as well as institutional framework of Serbia as candidate country have been established on the same bases”. Ivkov (2016) discussed various aspects of FADN and possibilities of its implementation in Serbian conditions (addressing issues such as organizational infrastructure, legislation problems, data collection, sample selection etc.). Various statistical aspects of Serbian FADN were analyzed by Janković Šoja (2016). It should be mentioned that Janković Šoja (2017) determined that economic size thresholds for commercial agricultural holdings in Serbia should be 2,000 EUR (which is lower than official threshold of 4,000 EUR). At the same time, Janković Šoja (2018) calculated appropriate size of FADN representative sample in Serbia (which is in total 2,000 farms), determining at the same time number of farms necessary for each farm type (and different economic sizes within farm types). Ivanović (2018) discussed some theoretical issues related to FADN in general, analyzed certain data available from Serbian FADN, as well as FADN data describing various types of livestock production in the EU countries. Marković et al. (2014) discussed FADN system in general and its particular features in Serbia, paying special attention to types of costs and determination of production value according to FADN methodology.

Ivanović et al. (2020b) used available FADN data to analyze productivity of Serbian milk producers, while Vukoje et al. (2022) also used FADN data to discuss factors influencing farm profitability. Miljatović et al. (2025) focused on Serbian FADN sample covering “seven-year period from 2015 to 2021” while concluding “that 54.38% of the observed farms in the Republic of Serbia are economically viable”.

Researchers in Serbia also compared available Serbian data to EU FADN data in order to make certain conclusions. For example, Ivanović et al. (2020a) apply FADN data do compare investment activity of Serbian farms (of certain types) to some neighboring countries, concluding that “Serbian farms have significant level of gross and net investments”. On the other hand, Ivanović et al. (2020c) compared other gainful activities in Serbian and EU farms (using FADN data) and determined that in Serbia “possibilities of agricultural holdings providing additional output through other gainful activities are not used sufficiently”.

Besides, authors from Serbia analysed EU FADN data and based on the results suggested certain consequences and advises for Serbian conditions. Ivanović et al. (2023) used FADN data to discuss costs of buildings, machinery and equipment for

European farms. Based on the results, authors suggested direction of future research for Serbian conditions primarily *"concerning importance of cereals, oilseeds and protein crops production for Serbian agriculture"*. Investigating economic efficiency of extensive types of livestock production in the EU countries (based on FADN data) Nastić et al. (2017) concluded that sheep and goat producers in Serbia might be able to compete with "other types of livestock production in the future" while "farmers who plan to become involved in cattle production in Serbia (other than dairy production) have to be aware of the necessity to keep investments in this production at a very low level". Similar approach to compare sheep and goat production in Serbia and EU was used by Nastić and Potrebić (2015).

FADN in Montenegro

Establishment of FADN system in Montenegro started in 2016 and was implemented by support of the Food and Agriculture Organization (FAO) of the United Nations (FAO, 2022). At the moment, FADN system in Montenegro is regulated by the Law on Agriculture and Rural Development (Government of Montenegro, 2021), which determines subjects involved in data collection, financing of FADN system, as well as activities and responsibilities of national committee and coordination team. According to a report published by the World Bank (2020) it is necessary to develop data management platforms such as FADN (as well as Integrated Administration and Control System - IACS) to provide Montenegro institutional development and agricultural strengthening. In the Montenegro 2020 report prepared by the European Commission (Commission staff working document, 2020) it was stated that "preparations continued to develop a pilot for the FADN". Long term plans related to FADN (according to Government of Montenegro, Ministry of Agriculture, Forestry and Water Management, 2023) involve agricultural extension service in future data collection and consulting activities for farmers.

FADN system in Montenegro was developed by FAO project "Technical support for the establishment of the FADN system in Montenegro", which was completed in 2021 (European Commission, 2023a). In the same document it was stated: "The Ministry and FAO have developed completely new FADN software, by preparing the software specification with FAO experts, and developing the software with a Montenegrin IT company. During 2022, it was not possible to collect data, because a cyber attack disabled the state network, so the FADN application had to be reinstalled, which caused the loss of certain data.

There are currently 32 farms in the FADN system in Montenegro. These 32 farms were not selected in accordance with the Selection Plan, but representative farms were selected by advisers from advisory services". On the official web site of the Government of Montenegro, Ministry of Agriculture, Forestry and Water Management (2024) it is also stated that appropriate FADN software was implemented in 2021. In 2023 there were 40 farms included in the FADN system, while majority of the data were collected by employees of agricultural extension service. According to the same source, new FADN sample (which is in line with the EU regulation) would be developed after new agricultural census (and consequently new farm typology and standard output coefficients, as well).

Nevertheless, preliminary results of agricultural census which was conducted in 2024 (MONSTAT, 2025) do not contain data on economic FADN indicators in Montenegro. According to Arias Navarro et al. (2024) the "efforts to further develop the FADN" in Montenegro "needs to continue". Having in mind that FADN data for Montenegro are not available yet, there is almost no research in this field. Only Joksimović (2021) theoretically discussed possibilities of applying FADN methodology in Montenegro for analysis of economic efficiency of milk processing at family farms. Processing of milk produced at farm is considered to be one of other gainful activities (OGA), so that author considered the way relevant costs and revenues are recorded. Author mentioned certain drawbacks of FADN methodology, as well (such as aggregation of data on the level of entire farm, without possibility to analyze economic performance of individual enterprises, including processing activities on the farm).

FADN in Bosnia and Herzegovina

The beginning of FADN establishment in Bosnia and Herzegovina in 2010 was supported by the EU project (Mrdalj and El Bilali, 2020). According to Falan (2021), process of establishing FADN system in Bosnia and Herzegovina started in 2010 through pilot research and continued in year 2012 within another project (devoted to agriculture and rural development). According to this author, activities on FADN were continued in 2013 in form of pilot research (in both entities). The research was continued in 2014 but only in one entity (Republic of Srpska). The same author stated that in 2012 an Action plan was provided concerning establishment and development of FADN (including state level as well as level of separate entities), questionnaires for data collection were improved and manual for FADN research was prepared.

To discuss possibilities of using FADN methodology on territory of Bosnia and Herzegovina Falan and Bogućanin (2021) used data (related to year 2011) from 143 farms. Authors concluded that FADN system could be successfully applied, but it requires long term approach (which should be organized and coordinated on the state level). Analysis of possibilities to establish FADN in Bosnia and Herzegovina was also performed by Falan (2016). Makaš et al. (2018) claimed that Bosnia and Herzegovina "does not have an Agricultural census as the basis for the establishment of the FADN system". According to Bosnia and Herzegovina report (European Commission, 2023b) the progress was not noticed when it comes to development of FADN system, as well as other important systems for Common Agricultural Policy (CAP) (such as Integrated administration and control system or Paying agency). Although fully functioning FADN system is a precondition for the EU integration process, Mujčinović (2022) also stated that FADN is still not developed in Bosnia and Herzegovina.

At the level of one entity of Bosnia and Herzegovina (Republic of Srpska) there is the proposal of Strategy for development of agriculture and rural areas (Government of the Republic of Srpska, 2021) (covering period from 2021 to 2027). It states that there is necessity to establish FADN comity as permanent professional body. According to this document, FADN system is established as pilot, and should be developed and strengthened through development of procedures, software solutions, sample enlargement etc.

The other entity (Federation of Bosnia and Herzegovina) also has its Strategy for agriculture and rural development prepared by Federal Ministry of Agriculture, Water Management and Forestry (2022) which covers the same period (from 2021 to 2027). In this document FADN was not discussed in details, but it was mentioned as an element of agricultural information system. Certain concerns were also discussed, such as limited financing available for development of such systems, as well as certain political disagreements about this issue.

On the state level of Bosnia and Herzegovina there is the Ministry of Foreign Trade and Economic Relations which prepared (in 2024) an outline of Strategic plan of rural development of Bosnia and Herzegovina (covering period from 2023 to 2027). In this strategic plan it was discussed that FADN does not exist in Bosnia and Herzegovina, although appropriate questionnaires are occasionally conducted on the level of individual entities to acquire such data.

Comparison of FADN in observed countries and transformation to sustainability oriented system

The comparative overview presented in Table 1 indicates significant differences in the level of development of FADN among the observed countries.

Table 1. Comparative overview of the development of the FADN in Serbia, Montenegro and Bosnia and Herzegovina

Indicator	Serbia	Montenegro	Bosnia and Herzegovina
Beginning of FADN establishment	2011	2016	2010
Type of support	EU IPA support	FAO support	EU supported pilot projects
Legal framework	Law on Agriculture and Rural Development	Law on Agriculture and Rural Development	Fragmented legislation at entity level
Current number of farms in the system	1,825 farms (2023)	40 farms (2023)	Pilot samples only. 120 farms (2010) 184 farms (2012)
Sampling structure	Two statistical regions (Serbia North and Serbia South)	Temporary sample	Pilot research conducted periodically
Data collection	Organized national system	Mainly through agricultural advisory service	Limited and irregular

Indicator	Serbia	Montenegro	Bosnia and Herzegovina
Availability of FADN data	Partial public availability	Not publicly available	Not available
Level of system development	Fully operational	Early stage of development	Initial / pilot phase
Key challenges	Data accessibility, expansion of research use	Small sample size, institutional strengthening	Lack of coordination at state level
Number of research based on available FADN data	Medium	None	Low

Source: Authors' compilation based on official documents and national legislation, European Commission reports and country analyses, relevant scientific literature, and available statistical data.

Serbia has established a fully operational system with a relatively large sample of farms, while Montenegro is still in the early stage of development. In Bosnia and Herzegovina, FADN activities are still mainly limited to pilot projects and institutional fragmentation represents a major obstacle for further development.

The FSDN is an evolution of the traditional FADN, aiming to integrate economic, environmental, and social indicators. While FADN primarily focuses on the economic performance of farms, FSDN expands its scope to assess environmental and social practices. This transition reflects the EU increasing emphasis on sustainable agriculture, in line with the European Green Deal (European Commission, 2019). The transition of FADN to FSDN is planed within Farm to Fork Strategy (2020a, 2020b) which calls for improved monitoring of the environmental and social impacts of agricultural production. According to Kwasek and Kowalczyk (2022) "the European Union F2F Strategy has set extremely ambitious challenges in terms of climate and environment. To a major degree, they refer to the agriculture and food production systems". As Marongiu and Casolani (2026) concluded, transformation of FADN to FSDN "will support evidence-based policy decisions, contributing to the future EU benchmarking system and helping farmers in the adoption of more sustainable farming practices as required by the EU strategies". Tomaš Simin et al. (2025) discussed indicators of agricultural holdings sustainability concluding that "sustainability of farms can be measured using the FADN database, and future research will be focused on this direction, evaluating each dimension separately". According to Floriańczyk et al. (2025) future research related to FSDN should include "challenges and implications not only for the EU member countries, but also the candidate countries". Transformation of existing system towards FSDN (in the case of neighbouring country Croatia, which is the latest EU member) requires capacity building "in terms of numbers, skills, and organization of the workforce" (Juračak and Očić, 2021).

In Serbia, the implementation of FSDN will follow preparatory activities for conversion of existing FADN data collection processes into a sustainability-oriented framework.

The transition involves adjustments in data collection protocols, training of field staff, and development of software solutions to handle a broader range of variables. According to Serbian Ministry of Agriculture, Forestry and Water Management (2025), transition of existing Serbian FADN to FSDN system requires “capacity improvement, higher involvement of farmers and development of digital infrastructure”. This process in Serbia was supported by the Policy and Legal Advice Centre (PLAC III) project funded by the EU (EU za tebe, 2026; FADN, 2026).

For Montenegro and Bosnia and Herzegovina, the transition to FSDN is still in the early planning stage. Currently, no comprehensive FSDN data collection exists in either country. Future steps are expected to depend on the establishment of fully operational FADN systems, national institutional capacity building, and alignment with EU sustainability reporting requirements. Generally, according to Makaš et al. (2023) “as a country aspiring to the EU, Bosnia and Herzegovina has committed to a stronger obligation to harmonize its environmental protection policy with the EU legal acquis and fulfill the obligations stipulated in the Green Agenda for the Western Balkans.” Therefore, the work on development of FSDN system in Bosnia and Herzegovina is expected to be performed within harmonization process. The same conclusion could be made for Montenegro (another candidate country), as well. Nevertheless, Makaš et al. (2025) stated that “Bosnia and Herzegovina remains in the early stages of alignment with the EU acquis” while FADN/FSDN “have not yet been incorporated into agricultural laws at either the Bosnia and Herzegovina or entity levels”.

The readiness of Western Balkan countries for the transition from the FADN to the FSDN could be assessed using six key indicators: institutional readiness, technical readiness, farm coverage, staff training, financial support, and implementation of sustainability indicators. Serbia demonstrates the highest overall readiness, with a ministry-led institutional framework, planned FSDN integration starting in 2026, broad farm coverage of 1,825 holdings, ongoing staff training. Montenegro shows moderate readiness, with limited farm coverage and developing technical and institutional capacity. Bosnia and Herzegovina exhibits the lowest readiness across all indicators, reflecting fragmented institutions, minimal technical infrastructure, pilot-level farm coverage, lack of coordinated training and limited resources for implementing FSDN. This analytical evaluation, based on authors’ assessment, highlights the varying stages of preparedness in the region and underscores the need for coordinated efforts to align with EU sustainability standards.

Conclusions

Establishment of fully functional FADN system is not only precondition for EU accession, but also an essential tool which provides data for policy making and improving performance and competitiveness of agriculture in each of observed Western Balkans countries. The research indicated different levels of development of FADN in these three countries. While FADN system in Bosnia and Herzegovina is still at the beginning of development, much better results are achieved in Montenegro. On the other hand, Serbian FADN system is fully operational for number of years, although it faces certain issues, as well.

At the same time, all observed countries face challenges related to transformation of FADN towards broader concept of sustainability. The Serbian FSDN will use the existing FADN infrastructure while incorporating additional indicators necessary for sustainability assessment. Two other countries are only in planning stage of transition to FSDN. Successful implementation of FSDN requires strong coordination between statistical offices, agricultural ministries, advisory services, and farm-level participants, as well as adequate technical and financial resources. Results indicate that FSDN implementation in the region needs targeted interventions to strengthen institutional and technical capacity, expand farm coverage, and integrate sustainability indicators, particularly in Montenegro and Bosnia and Herzegovina. Overall, the transition from FADN to FSDN represents a critical step for Western Balkan countries in aligning with EU sustainability standards, improving evidence-based agricultural policy, and promoting environmentally and socially responsible farming practices.

This analytical assessment highlights the differing stages of FADN development in the observed Western Balkans countries and underscores the need for tailored capacity-building strategies, primarily in Montenegro and Bosnia and Herzegovina, to support a successful transition to sustainability-oriented farm accounting. Future research should be focused on introduction of appropriate indicators measuring social and ecological aspects of sustainability in observed countries.

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Conflict of interests

The authors declare no conflict of interest.

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THE ENVIRONMENTAL ROLE OF NATURAL RESOURCES IN THE SPORTS INDUSTRY DEVELOPMENT MANAGEMENT

Igor Z. Radošević[1]

**Corresponding author E-mail: iradosevic@singidunum.ac.rs*

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A B S T R A C T

Environmental organizations are pressuring sports companies to modernize their production by redirecting ESG standards to conserve natural resources. The research used historical methods, description, synthesis and comparison to analyze the environmental role of natural resources in the sports industry development. Empirical research was conducted on the environmental impact on sports industry development and consumer priorities when choosing products made of eco or traditional materials. The results showed that 46% of participants declared themselves in favor of eco materials, 31% in favor of traditional materials, 23% declared that it doesn't matter for them. The organization of sports competitions for many sports today is conditioned by climate change, which can disrupt the organization and make it even more difficult to conduct competitions. To preserve natural resources from destruction, it is recommended to promote eco standards in the media, which should be introduced by law into regulations and procedures.

Introduction

The impact of natural resources on the sports industry's development is enormous because sports companies must redirect their production using eco materials, such as recycled cotton used instead of regular cotton, recycled rubber or seaweed used to make sneakers. The environment has become a strategic direction of sports companies' business, which increasingly affects competition and sustainability. Most of the sports company's business is in the most economically developed markets such as the USA, the EU and Asia, where eco standards (ESG, Green Deal) have become a mandatory part of modern business. Sports companies are increasingly turning to their consumers who are looking for environmentally conscious brands whose production does not impact environment destruction. Many sports companies and startups often turn to investors to get money to develop new sports technologies and products. Often, an investor's condition is compliance

1 Igor Z. Radošević, PhD, Assistant Professor, Singidunum University, Faculty of Physical Culture and Sports Management, Belgrade, Serbia, Phone: +38163325090, E-mail: iradosevic@singidunum.ac.rs, ORCID ID (https://orcid.org/0000-0002-6268-5274)

with ESG (Environmental, Social, Governance) standards, which are important because they affect ethical business and sustainability related to natural resources. The synergy of natural resources and the sports industry can be positive if it is well aimed at increasing environmental awareness (consumers do not want to destroy nature, they are great advocates of preserving natural resources), green building infrastructure that affects eco standards in the construction of sports venues, the use of recycling, and renewable energy sources, financing through revenues generated from sports tourism that are invested in the maintenance and conservation of natural resources. The sports industry is a market in which goods and services are exchanged simultaneously and on equal terms, i.e. some values, subjects and the internal and external environment of sports activities. The essence and center of the entire sports business is found in nature and phenomenon of sport and sports activity, which is the initiator of the entire subject process, with its external and internal surrounding world, and all of them together make up the sports industry. (Tomić, 47). Nature sports comprise a group of sporting activities that are developed and experienced in natural or rural areas, ranging from formal to informal practices. These practices are performed in a variety of natural contexts including on land (mountain biking, rock-climbing, trekking, etc.), in water (kayaking, sailing, surfing, windsurfing, etc.), and in the air (paragliding and hang-gliding, etc.). (Van Rheenen, 2021).

Sport has been developing rapidly for decades, creating an increasing number of competitions and thus developing sports companies that present new types of sports equipment on the market every year, which has attracted media interest. Sport has gone from being a simple amateur competition, thanks to the media that have led to commercialization and professionalization, it has managed to form its market of supply and demand, it has created its own media that deal only with sports, its target groups and consumers, and thus it has formed the sports industry. (Radošević et all). Thanks to the media, sport has become a global phenomenon that must be understood as a megatrend of economic and technological development, the distribution of social and financial power, and the imposed ideological scheme. This megatrend is a continuation of the previous megatrend - the industrialization of sports that began at the end of the 20th century, which also encompassed the entire society, all spheres from political to economic and cultural. (Krsmanović, 190). The heavy burden and unsustainable nature of taking on a mega sports event has proven over time to decimate the willingness of the host. (Geijer & Heijnen, 2024).

Materials and methods

Global environmental trends have been analyzed in this paper, and they have become an indispensable part of the business strategy that has affected the environmental production quality. Searching for new methods of business management, the sports industry has connected with other industries such as IT industry, fashion industry, construction industry, textile industry, environmental industry. (Radošević et all). In this paper, the author used the historical method, description, synthesis and comparison to analyze the environmental role of natural resources in the sports industry development. Empirical research was conducted on the environmental impact on sports industry development and consumer priorities when purchasing products made of eco or traditional materials that are among the biggest polluters and affect the destruction of natural resources. The globalization impact of sports market development was analyzed as well as the commercialization of sports itself by comparative method. The comparison was made between the sports company's business system and sports clubs that have focused on eco standards and those that are focused on the traditional way of business management.

In this paper, we have analyzed the environmental methods used by companies to promote their brand and their products. The research is focused on the topic: Do you prefer to buy sports products made of eco-friendly materials or traditional (non- eco) materials? The research was conducted in Period May 1.2024 – November 1.2025 in four largest cities in Serbia (Belgrade, Novi Sad, Niš and Kragujevac) where sports industry is developed, where sports competitions are organized and where is a significant offer of sports equipment through shops, shopping malls, and online sales through websites. The survey was conducted on a sample of 2384 participants, of which 1412 are men (59.23%), aged 18 – 50 years and 972 women (40.77), aged 18 – 50 years in Serbia.

The natural resources impact on the sports industry – environmental challenges

In the sports sector, the textile industry is one of the biggest polluters in the world with a major impact on natural resources due to the fast fashion model that is in a for-profit rush focused on the hyper-production of cheap sportswear. The textile industry is in third place in the world in terms of water consumption, where the production of a cotton T-shirt requires more than 2,700 liters of water! The textile industry uses chemicals (8,000 synthetic chemicals, mercury and lead) that are major water pollutants (streams, rivers, lakes, seas, oceans), where 20% of the world's water pollution comes from the finishing and dyeing of fabrics, which affects the ecosystems destruction. During the washing of clothes made of synthetic materials (nylon, polyester), microplastics end up in waterways, which enter the food chain. The textile industry is responsible for 10% of global $CO2$ (carbon dioxide) emissions from energy consumption, from global transport to man-made fibers that require oil. The problem of waste is enormous because only 1% of clothing is recycled, while the rest ends up in landfills, which, along with the huge amounts of pesticides necessary for the creation of natural fibers, affect soil degradation and biodiversity.

Table 1. Impact of Materials on Chemical Footprint, Biodegradability and Water Consumption

Material	Chemical imprint	Biodegradability	Water consumption
Coton (conventional)	High (pesticides)	Yes	Extremely high
Poliester	High (Petroleum products)	No (centuries)	Low
Organic flax	Minimal	Yes	Low
Recycled textiles	Intermediate	Depending on the composition	Minimum

Source: Authors' Research 2025

The increased production of sports equipment initially did not foresee what to do with the old worn-out sports equipment, which led to the accumulation of sports waste that takes 100-150 years to decompose naturally. Environmental standards rightly insist that sports companies switch to biodegradable materials production, with no negative environmental impact (*Table 1*).

The consequences are best described by the fact that "the Adidas Group uses more than 380 independent factories from 40+ countries for its products with 110 key manufacturing partners to produce the majority of products". (Adidas Group). The environment has a direct and indirect impact on the sports company's business. Direct impact refers to transport and logistics, energy consumption, and production costs, raw materials (recycled polyester and cotton), latex used to make balls and protective equipment, wool used for winter sports, wood used to make sports equipment, steel and aluminum for gym equipment, leather to make gloves and shoes. Indirect impact refers to brand reputation and image, market access, legal risks, and relationships with investors and sponsors. Cotton itself involves the use of large amounts of chemical fertilizers and pesticides, which affects the degradation of the soil. Polyester is considered a petroleum product whose production involves the consumption of a large amount of energy, while polyester products make up 60% of sportswear. Washing sports equipment releases microplastics that eventually end up in the seas and oceans, and then in the food chain.

The use of natural resources in sports production is necessary for sports infrastructure because new stadiums and halls, due to the excessive density of the existing infrastructure, are most often carried out on the outskirts of cities on agricultural land. The mountains are facing environmental challenges in the form of cutting down large numbers of trees and devastating forests to make ski tracks and building hotels that would attract many to enjoy the charms of mountain sports. In the lowlands, natural resources are also used to create golf courses that occupy large areas of land. Sports Industry 5.0 mandates that the sector confront these realities proactively. This involves greening the infrastructure: building energy-efficient, zero-carbon stadiums; sourcing renewable energy; implementing water recycling and waste reduction at venues. (Glebova & all, 2025)

Table 2. Characteristics of eco marketing (Authors' Research 2025)

Characteristic	Green sports club	Greenwashing (marketing)
Sponsors	Choose partners with eco-values	Oil companies as sponsors
Transport	Trains or eco buses for short distances instead of planes	Traveling short distances by plane
Transparency	Publish data on pollution	Eco-phrases without implementation
Operations	The buildings run on solar energy without the use of plastic	Recycling bins emptied to landfills

Source: Authors' Research 2025

One of the biggest environmental challenges associated with sports is transportation (*Table 2*). Mega events (Olympics, World Cup), require teams, officials and fans to travel around the world, which produces huge carbon dioxide emissions. To mitigate this, many sports organizations are implementing strategies to reduce the impact of travel. The use of public transport is encouraged, shuttle lines are provided, cycling routes are promoted, and new formats that require fewer international flights are increasingly chosen. Some leagues are implementing emissions offset programs through reforestation or investing in renewable energy, while others are experimenting with schedules that geographically group games to keep travel to a minimum. While transportation remains a significant challenge, creative solutions and collaborative efforts can significantly reduce the carbon footprint of sport. (Ekologija, 2025). Conflicts of interest can often be seen at the Paris 2024 Olympics, where organizers have been criticized for the main sponsor Coca-Cola, which is the biggest polluter in the world, with its plastic bottles (137 billion PET bottles per year, 250,000 bottles per minute) selling a carbonated beverage that is considered unhealthy and creates obesity and addiction. They produce 500g of plastic waste globally per capita. The company is the world's largest plastic polluter in 2026. Environmental pollution caused by sports equipment factories, Formula 1 races, water and electricity consumption at sports venues, irrigation of the field, as well as waste left after the organization of sports events in the form of glasses, bottles, paper and other types of waste are not negligible. In the last 10-15 years, the sports sector has begun to pay more attention to the contribution to the conservation of natural resources and the environment.

The non-profit sports organization "Green Sports Alliance" was created with the task of helping sports teams, sports venues and leagues improve their relationship with the environment. Recognizing the benefits of such cooperation, the Alliance went global in March 2011, bringing together sports workers from all over the world to share information and ideas on how to improve the situation across the environmental industry. The project, which started with six professional sports teams and five sports venues, now boasts a membership of nearly 170 professional and university sports teams and sports venues from 15 different sports leagues. (Pfahl, 2014).

The Impact of Sport Tourism Development on Natural Resources Destruction

Sports tourism is a combination of sport and nature, where consumers are offered the opportunity to engage in recreational sports or sports competitions in nature, in the form of mountains, oceans, seas, rivers and lakes. The sport tourism impact on economic development is often conflicting because it is impossible without the destruction of natural resources, although through sustainable development the damage can be reduced to a minimum. Natural resources can be used for sports development, but overexploitation can lead to the destruction of the tourist offer itself. Due to excessive urbanization and the race for profit, many mountains have destroyed the essence of their existence, which has jeopardized tourism development, affecting the non-arrival of dissatisfied and disappointed tourists who wanted to enjoy nature, and were greeted by a devastated environment. The ecosystem is the primacy in terms of infrastructure within sports tourism, which is related to the quality of air and water, which is why people choose to go to the mountains.

The negative impact is directed at the overload of natural resources: increased water consumption, which can affect the supplies needed by citizens and households; energy consumption necessary for the operation of sports venues; pollution related to waste left over after sports competitions; the use of harmful chemicals used for the maintenance of sports fields; conflicts that occur with the local population, because the development of tourism often bothers the locals, for whom it disturbs peaceful life and destroys natural resources, which primarily refers to winter sports, the destruction of natural habitats through infrastructure projects such as ski slopes, hotels, sports venues, which affects the destruction of biodiversity and ecosystems. The carbon impact of the Paris 2024 Olympic and Paralympic Games is estimated at 2.085 million tCO2-eq (tonnes of CO2 equivalent). This is approximately half the average for the London 2012 and Rio 2016 Games, and equivalent to the Tokyo 2020 Games, which were held without spectators. (EY, 2025)

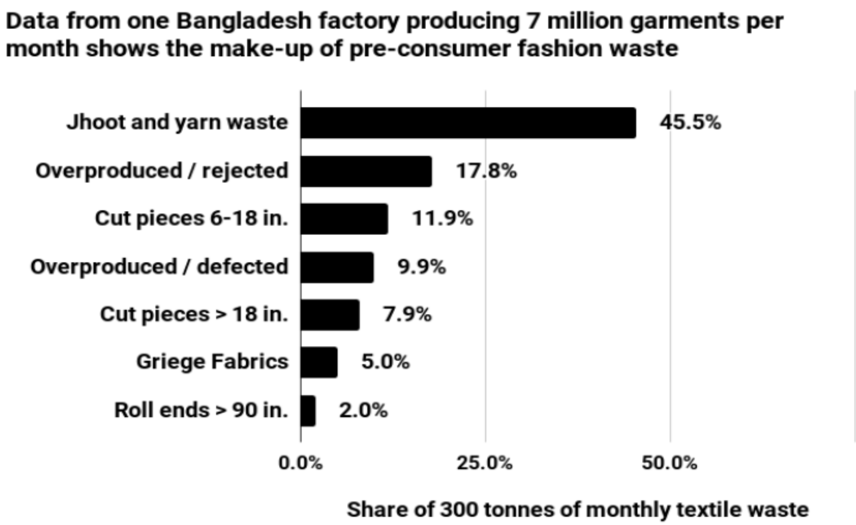
Environmental Impact on Consumer Sports Image

Sports companies rely on their image as a products quality guarantee they have been building for decades to better position themselves in the sports market. The image of each company shows the social responsibility that companies have towards consumers and the public. Image is a belief, impression and representation of a sports organization, athletes and their sports results, abilities and possibilities of determining their own position in the environment. (Tomić, 87). There are more clubs that have paid special attention to the environmental image, which is necessary today as an important segment of the business strategy. In the English Premier League, clubs must have a greenhouse gas emissions report and a sustainability strategy until the 2026/27 season. Tottenham Hotspur is the greenest club in England with zero waste and renewable energy. Barcelona Football Club has water recycling systems in place with huge areas under solar panels, while they were the first to promote recycled jerseys (Play Green) to inform their fan base.

In 2011, Greenpeace had launched the Detox My Fashion campaign, which revealed the pollution of waterways with hazardous chemicals, demonstrating the effects of pollution in the supply chain that are felt disproportionately in southern Cambodia, where sports equipment is produced in factories outsourced by Adidas, Nike and Puma. A 2017 study found that at least 25% of purchased materials went to waste, and some factories used almost half of the materials brought in. These materials are generally perfectly usable, but tight deadlines and minimal orders mean that neither suppliers nor designers have the space to use them effectively and instead create waste at a level that would not be tolerated in other industries. (Wohlgemuth, 2022).

Analyses have shown that certain products contain hazardous chemicals (perfluorinated (PFCs), nonylphenol ethoxylates (NPEs), phthalates and dimethylformamides (DMFs), which are present in textile products sold across three continents and have environmental and health consequences. These hazardous substances can be dissolved from products into the environment or enter the food chain. Some of them can potentially cause cancer, disrupt the hormonal system, or be toxic to reproduction. (Greenpeace, 2014). The problem is the fact that used donated clothes usually end up thrown into landfills, used to light fires, left by rivers or thrown into the sea (Figure 1). Greenpeace has called for a boycott of purchases of products from brands whose products destroy the environment, which has created a negative image and endangered the business of sports brands. The companies have pledged to phase out the use of toxic substances in their products and to start using eco-friendly materials such as recycled cotton, seaweed used to make sports shoes. Some brands offer consumers a 15% discount on their products if they bring them a bag full of used items that the company sends for recycling to show social responsibility and offer consumers to recycle their products when they are finished using them. One problem is if used clothes end up in landfills, but a much bigger problem is that 25-50% of unused materials are thrown into landfills and endanger the environment (example Bangladesh and China).

Figure 1. Percentage of unused materials in factories



Source: Cosgrove, 2019

A growing number of sports companies have pledged to ban the use of hazardous chemicals in their products. Adidas has developed a five-year strategy to reduce its environmental impact and invest in sustainability. The company has developed corporate volunteer programs and supports contributing to a healthy community that aims to make fitness available to children in underserved areas through a program – sports before school. Four keys for employees in sports organizations to get started with environmental issues are:

- Analyze and reduce energy and water consumption in combination with a waste diversion strategy.
- Work in a team or facility to achieve maximum environmental benefits.

- Identify and work towards a return on investment objectives to justify a long-term strategy of environmental values and align environmental issues with other key organizational strategic planning and elements.
- Maintain awareness of changes in technology as well as in other areas related to environmental changes. (Pfahl, 2014).

ESG standards in the sports industry

Environmental organizations are putting pressure on leading companies in various industries to force them to modernize their production in factories where they would redirect the use of environmentally, recycled and biodegradable materials according to eco standards. Environmental quality control is a procedure, standards and measurement that connects sustainable management, product safety, environmental safety and the sports industry, which means that it is looked at whether a product is good quality for both nature and athletes. Environmental quality control has the task of ensuring and harmonizing the quality of products with international standards and environmental regulations, to monitor and control the use of chemicals, energy and raw materials, to reduce the impact that sports services and products have on the environment. In 2026, the EU has tightened sanctions on eco-design, requiring companies to focus their production on longer-lasting clothing with alternative fibers derived from agricultural waste that is easier to recycle. The application refers to:

- Sports infrastructure focused on the use of renewable energy sources, air quality, energy efficiency, waste management after the competition
- Sportswear aimed at controlling CO2 in production, recycling and biodegradability, the presence of toxic substances, reducing water consumption
- Sports competitions focused on sustainable transport, banning single-use plastics, control of packaging waste, measurement of carbon footprint.

In the football industry, FIFA has built its own zero-emission headquarters (HQ) and has also developed “Green Goal” guidelines for its members - associations for organizing sporting events. The first major sporting event to be organized according to environmental standards was the Sydney Olympics in 2000, while the Athens Olympics in 2004 left behind a cleaner, healthier environment and a legacy in the form of raised awareness of the importance of concrete steps that will contribute to the preservation of the environment. The planned programs include the installation of new green areas, the construction of venues with materials that do not pollute nature, as well as improved waste disposal. (Masterman, 108). The 2022 FIFA World Cup, held in Qatar, brought new “green building” technological standards for the construction of sports stadiums. One of the new innovations is the Floating Offshore Stadium, which can be moved to any part of the world. Nine of the 12 stadiums are completely new and based on environmental principles with the use of eco-friendly materials without carbon dioxide emissions, using solar energy, while all stadiums are air-conditioned with an average temperature of 27 degrees. (FIFA, 2022).

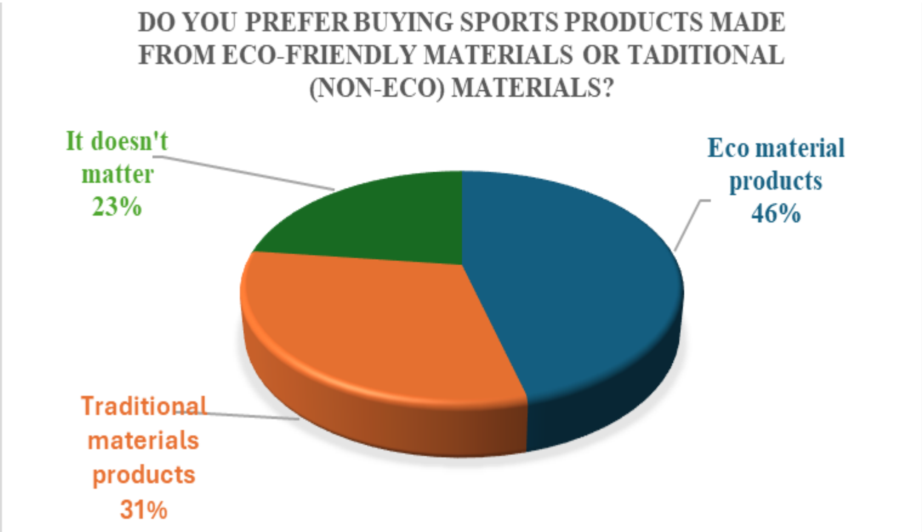
For example, the Olympic Stadium in London was built using only 10% of the steel used to build the Bird's Nest Stadium for the 2008 Beijing Olympics. (Černušenko, 2022). To keep up with the new standards, the construction industry has introduced "Green building" standards, which are applied to the construction of new sports venues (stadiums, halls, swimming pools) from special materials, while the use of solar panels that contribute to electricity savings has become increasingly popular. These are all examples where eco-standards have contributed to the development of the sports industry. Sports venues can only be a successful heritage if they are built regarding the preservation and protection of natural resources, not only because society demands it today, but also because it can be economically viable. (Mihoces , 2013). Overall, of the 126 clubs in the five major sports in the U.S., 38 clubs use renewable energy for a portion of their needs, while 68 clubs use an energy efficiency program, 18 sports venues have installed solar panels, and almost all clubs use recycling programs. For example, the Seattle Seahawks NFL stadium has 3,750 solar panels on the roof of the stadium. (Letteney, 2015). In Europe, sports clubs started to introduce environmental standards, and in 2009, Manchester United Football Club was among the first to say it had saved more than £200,000 by working with the Carbon Trust and introducing energy efficiency methods. To reduce water consumption, some clubs are using simpler methods with the help of efficient taps and showers installed at the stadiums of Arsenal, Exeter United and Sheffield United. Chelsea Football Club uses rainwater using artificial lakes and pipes under the pitches to irrigate the pitch. The Stade de Suisse in Bern and the Kaohsiung National Stadium in Taiwan have shown that the installation of solar panels can generate enough electricity for the stadium's needs, while excess energy would contribute to the community. (Letteney, 2015). English football club Forest Green Rovers has been named the greenest club in the world because they use 100% renewable energy, the jerseys are made of bamboo and recycled plastic, the fans are offered vegan food, the grass is maintained with the help of solar robotic lawn mowers. Adidas makes sneakers from plastic scraps from beaches, seas and oceans, while Nike's Move to Zero initiative has focused its business on zero waste and carbon emissions using Nike Grid – production scraps and recycled sneakers that are also directed to make running tracks.

ESG standards within the sports industry focus on the policies and practices that sports companies and clubs adopt to be socially responsible and sustainable. ESG standards have become an indispensable part of sports business because it affects the attraction of investors and sponsors, as well as the creation of a positive image. The environmental aspect refers to sustainability in the form of the use of renewable energy sources (solar panels), waste reduction, recycling, green initiatives in the form of investing in eco projects, sustainable production in the form of the use of eco materials in sports products. The social aspect is focused on responsibility in the form of connecting with local communities, safety aimed at fans and athletes, diversity aimed at intolerance of racism, sexual and ethnic intolerance, promoting diversity among fans, sports managers who run sports organizations and companies, as well as among athletes themselves. The governance aspect refers to transparency (financial, managerial, ethical, environmental), which includes public reporting on decision-making and financial management, risk management in the form of strategies, as well as ethics aimed at promoting fair play and preventing corruption. Corruption and financial malfeasance are present in clubs and companies where there is no transparency. Nature-dependent and nature-independent outdoor activities neither pollute nor consume nature, so these two categories are combined as nature-based activities. (Wicker, 2021)

Results

The survey results (Figure 2.) showed that 46% (1,097 participants) were in favor of purchasing sports products made of eco-friendly materials, while 31% (739 participants) were in favor of buying sports products made of traditional (non- eco) materials. Neutral participants, who said they don't matter (unimportant) were 23% (548 participants).

Figure 2. Researching consumer choice when purchasing sports products



Source: Authors' Research 2025

Analyzing the results of the survey, we can conclude that environmental awareness among citizens is quite present, compared to the period 10 – 15 years ago, that today among the participants of the research there is concern for natural resources protection that are endangered by the development of the textile industry, that younger participants (aged 18-30) have the most understanding and interest in the environment. In second place are participants aged 31-40 who show moderate interest in the environment, while the older generations of participants aged 41-50 showed the least interest in protecting natural resources and the environment.

Table 3. Percentage of survey participants by gender, age, and choice of purchase

Category	No of participants	%	Age 18-30	Age 31-40	Age 41-50	Eco material	Non-eco material	Don't matter
Men	1412	59,23%	631	523	258	15%	24%	14%
Women	972	40,77%	513	271	188	31%	7%	9%
Total	2384	100%	1.144	794	446	46%	31%	23%

Source: Authors' Research 2025

The results of the research (*Table 3.*) showed that out of the total number of participants who declared themselves in favor of purchasing sports products made of eco materials (46%), a larger number are women participants which declared themselves in favor of buying sports products made of eco materials (31%) compared to male respondents (15%). Of the total percentage of participants who declared themselves in favor of buying sports products made of traditional (non- environmental) materials (31%), male participants are the majority (24%) while less women declared themselves (7%). It should be noted that out of 2384 participants in the study, 538 participants (23%) said that it doesn't matter to them (unimportant) because the price of the product is what affects the purchase.

Discussions

Eco standards have become the main advertisement for promoting sports companies to attract the consumers' attention. Companies that do not adapt to market trends will be outperformed in the eyes of consumers. That is why the companies proudly point out that they have certificates such as: GOTS (Global Organic Textile Standard), which confirms that the company uses organic cotton in its products that do not have harmful substances; LEED (Leadership in Energy and Environmental Design) is the most widely recognized certification for green sports venues. Blue sign, which certifies that minimal energy and water consumption is used, as well as safety for consumers, B Corp, whose ownership means that the company operates with an environmental and ethical purpose.

Environment and natural resources open up opportunities for investment in innovations and new technologies that have influenced the development of the sports industry, which has helped to sustain some sports, such as winter sports, due to the lack of basic conditions caused by climate change, such as artificial snow in the mountains, while the latest technologies have enabled the emergence of indoor ski resorts that operate all year round. There is an increasing number of countries that are building indoor ski resorts near large cities (China – 50+ indoor ski resorts, Middle East – Dubai, Abu Dhabi, Saudi Arabia, EU – Norway, Germany, Netherlands, Great Britain), where fans of snow sports are allowed to fulfill their wishes without going to distant winter ski resorts. Environmental standards used to be part of marketing campaigns, but today they are an important part of business strategy. Cooperation between sports clubs and companies that decide not to comply with eco standards is quite difficult, it is more difficult to cooperate with sponsors because no one wants negative image to be damaged in public.

Environmental control methods include eco-certification of products, control of energy and water consumption, Life Cycle Assessment, measurement of CO2 emissions, and supply chain auditing. International standards and tools necessary for environmental quality control are ISO 14001 related to the environmental management system, FIFA / IOC compliance guidelines, ISO 9001 – ISO 14001 – related to quality and ecology, Global Recycled Standard, OEKO-TEX Standard 100 – which includes textiles that do not contain harmful substances. The development of the sports industry needs to function according to eco-standards for health reasons (which include reduced exposure to toxic substances and safer products for athletes), business reasons related to easier entry into the EU market, competition and brand strengthening, as well as environmental reasons related to the rationalization of natural resources and the reduction of pollution.

Sports brands are present on the public scene and are monitored by consumers, fans, clubs. Sports companies that do not want to comply with environmental standards are in risk of losing existing customers, will be attacked by environmental organizations that will criticize them for destroying natural resources in production for profit, which will affect the destruction of the image that companies have been building for years, and which will be a huge problem for them in negotiation with sports organizations for sponsorship, because no sports organization wants to be criticized for cooperation with companies that have a negative image reputation. Companies that comply with eco standards strengthen their image on a global level, maintain the loyalty of their consumers in a simpler and longer term.

The Impact of the State and Legal Regulations (Protection of Natural Resources)

The green transition in sport is designed to transform sports companies and clubs towards environmental sustainability in the form of a shift in the methodology of sports business such as event management, production of sports equipment or sports infrastructure construction. The green transition is crucial for the survival of the sport, which is endangered by climate change (extreme heat or rain, lack of snow), economic viability in the form of reducing energy costs aimed at savings. The state uses the development of all industries to generate additional revenues in the form of environmental taxes that are used to rehabilitate sites after sports competitions. Penalties for non-compliance with environmental rules in the sports industry can be financial (in the Balkan region 5,000-25,000 euros for legal entities, for responsible managers in sports clubs from 500-2,000 euros, in Germany there are fines of up to 100,000 euros) with which it is required to return to the original state. Subsidies relate to the use of renewable energy sources and energy efficiency. In Germany, sports programs subsidize environmental modernization through state institutions in the form of grants of 20-40% for solar panels and LED lighting, while in France, through the Sport and Sustainable Development program, clubs are influenced to reduce their carbon footprint through funds that finance up to 50% of the cost of solar water heating in changing rooms. Slovenia, as a leader in the region, is considered the most environmentally friendly country through the Slovenian Environmental Public Fund, where clubs have the option of applying for subsidies of 20-25% of the costs for lighting, insulation and energy efficiency. The green transition in sport allows clubs to reduce costs (LED lighting reduces consumption by 70% compared to halogen floodlights with a return on investment in 4-5 years, provides better quality lighting during sports competitions and attracts sponsors who are increasingly looking for Eco-friendly sports clubs that promote sustainability).

Conclusions

Awareness of the importance of natural resources is present among citizens and has greatly influenced the attitudes of respondents who care about environmental protection. According to the answers, we can notice that the younger generation of participants are, the higher is the percentage of support for the purchase of sports products made of eco materials, while this percentage decreases the older the respondents are, which confirms the that younger generations are more interested in environment and natural resources that are necessary for a better quality of life in the future. Sports companies follow current market trends to keep up with the competition, and to adapt their products to their target groups in time, which has influenced the introduction of ESG standards aimed at protecting natural resources. Consumers are very interested in whether the sports products they spend their money on have consequences for the environment or natural resources. The sports industry began to develop rapidly, and due to the increased production of sports equipment in factories, sports companies faced the problem of accumulated waste in the form of old equipment and props. The results of the survey showed that participants are largely aware of the consequences of the production of sportswear on the environment, and that is why 46% of participants choose brands that apply eco standards, to conserve their natural resources. The organization of sports competitions for many sports today is conditioned by climate change, which can disrupt the organization and make it even more difficult to conduct competitions. Many mountains have difficulty organizing sports competitions due to lack of snow.

Conflict of interests

The authors declare no conflict of interest.

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RETHINKING FINANCIAL DISTRESS DETERMINANTS: INSIGHTS FROM THE AGRO-INDUSTRIAL SECTOR

Miroslav Čavlin[1], Jelena Vapa Tankosić[2], Veljko Dmitrović[3], Stella Suljić Nikolaj[4], Dejan Mikerević[5]

**Corresponding author E-mail: cmiros@gmail.com*

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ABSTRACT

This paper examines the determinants of financial distress in the agro-industrial sector of the Republic of Serbia. The empirical analysis is based on panel data for 20 large companies from the food production sector in the period 2019–2024. Financial distress was operationalized using the revised Altman Z′ indicator, with an extended classification threshold ($Z' < 1.8$). Binary logistic regression was applied to assess the impact of selected variables. The findings have shown that the capital structure is the dominant determinant of financial distress, while indicators of profitability and operating cash flows do not show a statistically significant influence. At the same time, company size stood out as a significant factor, with larger companies more likely to face financial difficulties. The findings indicate that financial distress is not primarily conditioned by operational performance, but primarily by the structural characteristics of financing indicating the need for the development of integrative and multidimensional analytical approaches in this area.

1 Miroslav Čavlin, PhD, Full professor, University Business Academy, Faculty of Economics and Engineering Management in Novi Sad, Cvećarska 2, 21000 Novi Sad, Serbia, E-mail: cmiros@gmail.com, ORCID ID (https://orcid.org/0000-0001-7465-7441)

2 Jelena Vapa Tankosić, PhD, Full professor, University Business Academy, Faculty of Economics and Engineering Management in Novi Sad, Cvećarska 2, 21000 Novi Sad, Serbia, E-mail: jvapa@fimek.edu.rs, ORCID ID (https://orcid.org/0000-0001-8062-1154)

3 Veljko Dmitrović, PhD, Full professor, University of Belgrade, Faculty of Organizational Sciences, Jove Ilića 154, 11000 Belgrade, Serbia; E-mail: veljko.dmitrovic@fon.bg.ac.rs, ORCID ID (https://orcid.org/0000-0001-8924-9758)

4 Stella Suljić Nikolaj, PhD, Assistant professor, University of Rijeka, Faculty of Economics and Business, Ivana Filipovića 4, 51000 Rijeka, Croatia; E-mail: stella.suljic.nikolaj@efri.uniri.hr, ORCID ID (https://orcid.org/0000-0002-0435-4047)

5 Dejan Mikerević, PhD, Full professor, University of Banja Luka, Faculty of Economics in Banja Luka, Bosnia and Herzegovina, E-mail: dejan.mikerevic@ef.unibl.org, ORCID ID (https://orcid.org/0009-0005-1757-2923)

Introduction

Since the 2000 market reforms and the EU Stabilization and Association process, WBC have expanded trade and strengthened economic cooperation, with the EU perspective driving regional integration (Monastiriotis, 2008; Handjiski, Lucas, Martin, & Sarisoy Guerin, 2010). Economic integration brings benefits such as greater stability, easier access to EU funds, expanded markets, stronger competition, and faster adoption of international food standards (Tomić, Popović, Vlahović, 2010). "Agriculture and the food industry in the strategic planning and development documents of the Republic of Serbia represent one of the sectors on whose comparative advantages the country's economic policy should be based and which are expected to start a new investment and development cycle" (Vapa Tankosić & Mirkov, 2025, p.1506). Vapa Tankosić and Stojsavljević (2014, p.196) also point out that "agricultural and food industry provide over 15 million workplaces in the EU, accounting for 8,3% of all employed citizens of the Union". However, the results indicate that the agricultural sector in AP Vojvodina is underdeveloped due to low farm specialization and small farm size, with an average economic size of €8,953—about three times lower than the EU-28 average (Đurić, Prodanović, Čavlin, & Lukač Bulatović, 2020).

The European Union recognizes Serbia's potential providing financing through IPA support for the development of the agricultural sector "as new opportunities for farmers are present in the next program period from 2021-2027 within the IPARD III program, with the main focus on young farmers, organic agriculture and all investments that are in line with the Green Agenda" (Vapa Tankosić, 2023p. 963). The climate change and environmental focus create new opportunities to stimulate green sustainable investment (Ivaniš, Vapa Tankosić, Ignjatijević & Lekić, 2025), also in the agro-industrial sector.

The contemporary research on financial distress pointed to its importance as one of the key problems in corporate finance, in the context of increased uncertainty and volatility in the business. Although a number of models have been developed to identify financial difficulties, the results of these studies have not always been consistent, especially when looking at different sectors and institutional contexts (Campbell et al., 2008). The previous literature was mainly based on the assumption that profitability and liquidity are key indicators of financial distress. However, recent research indicated that the predictive power of these indicators may be limited (Balcaen & Ooghe, 2006). Despite this, there is still no unified view on which dimensions of financial operations play a dominant role in explaining financial distress. Modern financial crises indicate and make visible the shortcomings of traditional financial systems (Čavlin, Vapa-Tankosić & Egić, 2021).

A particular problem in the literature was related to insufficient understanding of the interrelationships between different financial indicators. Most of the existing models were based on linear combinations of variables, whereby the complexity of interactions between different dimensions of the company's financial position remained insufficiently explored. This is especially pronounced in sectors with a specific financing structure and pronounced investment cycles, such as the agro-industrial sector.

Although some studies indicated the importance of structural factors, such as capital structure, their relative role in relation to operational performance was not sufficiently empirically confirmed, especially in the context of developing countries and specific sectors of the economy. This situation indicated the existence of a research gap in understanding the determinants of financial distress.

Based on the aforementioned doubts and limitations in the existing literature, the aim of this research was to identify the key determinants of financial distress in the agro-industrial sector of the Republic of Serbia, with a special focus on the relative importance of different dimensions of the financial position of companies. The research starts from the assumption that financial distress cannot be adequately explained by individual indicators, but is the result of the interaction of several business dimensions.

In accordance with the set goal, the main research hypothesis was formulated that the structural factors of financing have a statistically significant impact on financial distress in relation to the operational performance of the company. In addition, auxiliary hypotheses related to (1) the limited discriminatory power of profitability indicators and operating cash flows, as well as (2) the statistically significant impact of company size on the probability of financial distress were tested.

Unlike the majority of previous research that looks at financial distress through isolated financial indicators, this research starts from the assumption of a differentiated and mutually conditioned influence of different dimensions of the financial position of the company, with a special focus on the sector-specific context of agro-industry.

Literature review

Financial distress is one of the central research questions in the field of financial analysis and corporate finance. In the literature, it is most often defined as a state in which a company has difficulties in meeting its financial obligations, which may precede insolvency or bankruptcy (Altman, 2000; Beaver, 1966). Unlike formal bankruptcy proceedings, financial distress is viewed as a process that develops over time, and its symptoms can be identified through financial indicators.

Early empirical models of financial distress were based on the analysis of individual financial raids. Beaver (1966) was among the first to show that certain financial indicators can have significant predictive power in identifying companies in financial difficulties. Later, Altman (1968; 2000) developed multiple discrimination models (Z-score), which combine multiple financial indicators into a single index of financial stability. These models represent the basis of modern approaches to the analysis of financial distress.

Further development of the methodology led to the application of probabilistic models, such as logistic regression (Ohlson, 1980), as well as hazard models (Shumway, 2001), which enable a dynamic assessment of the probability of the occurrence of financial distress. These approaches emphasize the importance of combining several financial indicators and represent the methodological basis of modern empirical research.

In the literature, financial distress is most often explained through several key dimensions of financial operations, among which profitability, liquidity, indebtedness, and efficiency of operations stand out (Altman, 2000; Campbell et al., 2008). In certain sectors, especially those with pronounced investment cycles and a specific financing structure, structural factors can play a dominant role in explaining financial distress.

In this sense, a growing number of authors indicate the need for integrative approaches in the analysis of financial distress, which overcome the limitations of models based on individual indicators or linear combinations of variables (Balcaen & Ooghe, 2006). More modern approaches point to the importance of hybrid and interpretable models that enable the integration of different dimensions of the financial position and their better understanding (Čavlin et al., 2025). Such approaches start from the assumption that financial distress is a multidimensional phenomenon, resulting from the mutual interaction of various aspects of the company's financial operations.

Starting from the mentioned theoretical assumptions, this research aims to examine the relative importance of different dimensions of the financial position of the company in explaining the financial distress in the agro-industrial sector. Special focus is placed on the relationship between operational performance and structural characteristics of financing, as well as on their mutual interaction in the context of the financial stability of the company.

Materials and methods

The aim of this research is to identify the key determinants of financial distress in the agro-industrial sector of the Republic of Serbia, using a quantitative approach based on financial indicators and statistical modeling. The empirical analysis is based on panel data that includes observations on a company-year basis for the period from 2019 to 2024. The sample consists of 20 large companies from sector 10 (food production), which includes companies with more than 500 employees, which are legally required to report ESG in the Republic of Serbia. The data were collected from official financial reports available through the database of the Agency for Business Registers of the Republic of Serbia (https://www.apr.gov.rs, 2026).

The revised Altman Z′-score model is used as a proxy for financial distress and is defined as:

$$Z' = 0.717X_1 + 0.847X_2 + 3.107X_3 + 0.420X_4 + 0.998X_5$$

where: X_1 = working capital / total assets, X_2 = retained earnings / total assets, X_3 = EBIT / total assets, X_4 = equity / total liabilities, X_5 = sales / total assets

The model classifies firms into three zones: safe ($Z' > 2.90$), grey ($1.23 < Z' < 2.90$), and distress ($Z' < 1.23$) (Altman, 2000). Financial distress was operationalized as a binary dependent variable, based on the value of the revised Altman Z′ indicator. In order to ensure a sufficient number of distressed observations and stability of the model, an extended classification criterion ($Z' < 1.8$) was applied, which included companies with an increased risk of financial difficulties (Altman, 2000). At the same time, this threshold enables the inclusion of a wider range of companies with potential financial difficulties, which improves the analytical relevance of the model. Different dimensions of a company's financial position are the independent variables used in the model. Thus, continuity indicators include Q1 (EBITDA margin) and Q2 (operating cash flow to current liabilities), while profitability includes R1 (return on assets) and R2 (return on sales). Then, activity indicators include A1 (asset turnover ratio) and A2 (accounts receivable turnover ratio), while structural indicators include S1 (equity to total assets ratio) and S2 (operating cash flow to total liabilities). In addition, firm size (SIZE), measured as the natural logarithm of total assets, is included as a control variable.

First, a descriptive statistical analysis was conducted, with the aim of looking at the basic characteristics of the distribution of variables (Hair et al., 2019). Then the classification of companies according to zones of financial distress was carried out. In the next step, a correlation analysis was conducted, in order to identify potential multicollinearity between the independent variables and to improve the specification of the model (Gujarati & Porter, 2009).

Finally, binary logistic regression was applied to assess the impact of selected variables on the probability of financial distress. The logistic model can be represented by the following function:

$$P(Y=1) = \frac{1}{1 + e^{-(\beta_0+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_k X_k)}}$$

where P(Y=1) represents the probability of occurrence of financial distress, Xi-independent variable, while βi - denote the estimated parameters of the model.

Logistic regression has been widely applied in financial distress research, as it allows estimating the probability of occurrence of a binary outcome based on a set of financial indicators (Hosmer, Lemeshow, & Sturdivant, 2013; Ohlson, 1980).

The model was evaluated based on standard statistical indicators, including the Likelihood Ratio test and the pseudo coefficient of determination (Nagelkerke R^2), which provided an assessment of its statistical significance and explanatory power.

This methodological approach enables a systematic analysis of financial distress as a complex phenomenon, while simultaneously looking at different dimensions of the company's financial position and their mutual relationship.

Results and discussion

Empirical analysis in this paper aims to identify the key determinants of financial distress in the agro-industrial sector of the Republic of Serbia, based on a set of financial indicators that include various dimensions of business operations. The analysis is based on panel data that includes observations by company-year principle, for selected large companies from Sector 10 (production of food products), in the period 2019-2024. The sample includes companies from key sub-sectors of the food industry, including meat processing, dairy production, confectionery industry and production of other food products, thus providing basic sectoral coverage of the agro-industrial system. In accordance with the methodological framework defined in the previous chapter, financial distress is operationalized as a binary variable, based on the value of the revised Altman Z′ indicator. In addition to the standard threshold, an extended criterion ($Z < 1.8$) was applied in the analysis, in order to include a wider range of companies with an increased risk of financial difficulties and to ensure the statistical stability of the model. The empirical part of the research is structured in several interconnected steps. First, the structure and representativeness of the sample is analyzed. Then, an overview of the descriptive statistics of the selected financial indicators is given, with the aim of seeing their distribution and variability.

Table 1. Structure of the sample

Number of firm-year observations	120
Analysis period	2019-2024
Distressed observations	31
Non-distressed observations	89
Average employees (2024) - Mean	953
Median (2024)	845.5
Total assets (2024) - Mean	14.87
Median (2024)	12.96
Operating revenues (2024) - Mean	14.15
Median (2024)	12.42

Note: Financial values are expressed in millions of RSD.
Source: Authors' data elaboration

The structure of the sample shown in Table 1 indicates that the distribution is of particular importance, because the mentioned sub-sectors are characterized by different production cycles, levels of capital intensity and cost structures, which can affect their financial performance and exposure to financial distress. This ensures that the analysis does not reflect the specifics of one segment, but a wider spectrum of business models within the agro-industrial sector.

In addition to numerical representation, the sample also ensures an appropriate level of representativeness in terms of key economic indicators, such as total assets, income and employment. This enables the results of the analysis to reflect the structural characteristics of the sector, and not just the individual specifics of the analyzed companies.

Based on the above, it can be concluded that the sample provides an adequate basis for conducting empirical analysis and making relevant conclusions about the determinants of financial distress in the observed sector.

Table 2. Values of financial indicators

Code	Mean	Median	Std.Dev	Min	Max	P 0.25	P 0.75
K1	0.11	0.10	0.06	-0.02	0.33	0.07	0.23
K2	0.38	0.21	0.62	-1.01	4.31	0.09	0.40
R1	0.02	0.04	0.02	0.00	0.05	0.00	0.04
R2	0.02	0.03	0.02	0.00	0.05	0.01	0.04
A1	0.96	1.03	0.10	0.85	1.08	0.03	1.06
A2	4.98	4.81	0.38	4.47	5.59	4.66	5.24
S1	0.54	0.52	0.18	0.15	0.91	0.40	0.68
S2	0.24	0.16	0.37	-0.37	2.22	0.07	0.27

Source: Authors' data elaboration

The results of the values of financial indicators, shown in Table 2, indicate significant variability of financial indicators within the observed sample, which reflects the heterogeneity of the analyzed companies and additionally confirms the complexity of the agro-industrial sector.

Differences between mean and median values, as well as a wide range of minimum and maximum values of individual indicators, indicate the presence of asymmetric distributions and potential extreme values. In such conditions, the median can be considered a more reliable indicator of central tendency, which is in line with recommendations in empirical research on financial performance (Hair et al., 2019). In particular, the presence of asymmetry in certain indicators is indicated by differences between the median and interquartile values.

Observed by groups of indicators, it can be observed that indicators of operating cash flow and liquidity (K2) show pronounced variability, which indicates different levels of the ability of companies to service short-term liabilities from operating flows. On the other hand, profitability indicators (R1) show relatively lower values and limited dispersion, which may indicate a weaker differentiation of the company in terms of profit performance.

Capital structure indicators (S1) indicate significant differences in the way companies are financed, whereby some companies have a high proportion of their own capital, while others are more dependent on external financing. These differences may play an important role in explaining financial distress, which will be further examined in the regression analysis.

Overall, descriptive statistics confirm that the analyzed set of variables includes different dimensions of the company's financial position and provides an adequate basis for further empirical analysis, especially in the context of identifying the determinants of financial distress.

Table 3. The results of the classification of companies

Description	Criteria	Number of observations	Share
	Altman standard		
Distress zone - standard	<1.23	15	12.50%
Grey zone	1.23< Z'<2.9	70	58.33%
Safe zone	>2.9	35	29.17%
Total		120	100.00%
Distress zone - extended	< 1.8		
Distress zone	<1.8	31	25.83%
Safe zone	>1.8	89	74.17%
Total		120	100.00%

Source: Authors' data elaboration

The results of the classification of companies according to zones of financial distress, shown in Table 3, indicate a significant presence of companies with an increased risk of financial difficulties. Additional analysis of the structure of distress observations indicates their distribution in several sub-sectors of the agro-industry, without a clear concentration in one segment. Distressed companies were identified within the meat industry (Zlatiborac, Carnex, Yuhor), the fruit and vegetable processing sector (Nectar), the dairy industry (Imlek), the bakery industry (Don-Don), as well as in the confectionery industry and snack production segments (Pionir, Nestlé).

At the same time, it is noticeable that some companies record the continuity of distress over several consecutive years (eg Zlatiborac, Imlek, Pionir), while in others distress occurs in shorter episodes. This pattern indicates that the financial distress in the agro-industrial sector is not exclusively determined by the sector, but is the result of a combination of specific financial and operational characteristics of the company.

In accordance with the methodological approach, for the purposes of logistic regression, the distress zone is coded as a value of 1, while all other observations are classified as 0.

Table 4. Results of the correlation analysis

Code	K2	R1	S1	SIZE
K2	1	-0.183406792	0.225007488	0.251024072
R1		1	-0.074623453	0.217528596
S1			1	0.04867199
SIZE				1

Source: Authors' data elaboration

The results of the correlation analysis shown in Table 4 indicate a low degree of mutual connection between the selected independent variables, which confirms the absence of pronounced multicollinearity in the model.

Most of the correlation coefficients are in the low to moderate range, with no correlation exceeding the 0.8 threshold, which is often used in the literature as indicative of potential multicollinearity problems (Gujarati & Porter, 2009).

Table 5. The results of the binary logistic regression

Variable	B	Std. Error	p-value	Exp(B)
K2	-0.451	0.488	0.356	0.637
R1	-11.044	13.36	0.408	< 0.001
S1	**-9.082***	2.072	**< 0.001**	0.0001
SIZE	**1.185***	0.423	**0.005**	3.27
Constant	-15.419**	6.47	0.017	—

Source: Authors' data elaboration
*** $p < 0.01$, ** $p < 0.05$
Dependent variable: Distress (Z′ <1.8)

The results of the binary logistic regression, shown in Table 5, indicate that the overall statistical significance of the model was confirmed by the value of the Likelihood Ratio test ($p < 0.001$), while the value of the pseudo coefficient of determination (Nagelkerke $R^2 = 0.289$) indicates a satisfactory level of explained variance for models of this type.

The analysis of individual coefficients shows that the capital structure indicator (S1 – the ratio of own capital and total assets) has the most statistically significant impact on financial distress ($p < 0.001$). The negative sign of the coefficient indicates that a higher share of own capital reduces the probability of financial difficulties. The extremely low odds ratio (Exp(B) ≈ 0) further confirms the strong protective effect of the capital structure, suggesting that financial stability largely depends on the way the company is financed.

In addition, company size shows a statistically significant positive effect on the probability of financial distress ($p = 0.005$). The value of the odds ratio (Exp(B) = 3.27) indicates that an increase in firm size increases the probability of financial distress by approximately three times, controlling for other variables. This finding may indicate greater business complexity and greater exposure to risks in larger companies.

Unlike the mentioned variables, indicators of operating cash flow (K2) and profitability (R1) did not prove to be statistically significant in explaining financial distress. Although they have the expected signs of the coefficients, their statistical insignificance suggests that in the observed sector operating performance alone is not sufficient to reliably distinguish between distressed and non-distressed companies.

Taken as a whole, the results indicate that financial distress in the agro-industrial sector is not primarily determined by short-term operational results, but above all by the structural characteristics of financing, with the significant role of company size as a controlling factor, which additionally confirms the need for a multidimensional approach in the analysis of financial distress.

Table 6. Results of the adequacy of the applied logistic model

Statistic	Value
Pseudo R^2 (Nagelkerke)	0.289
LLR p-value	< 0.001

Source: Authors' data elaboration

The quality indicators of the model, shown in Table 6, confirm the adequacy of the applied logistic model for the analysis of financial distress.

The value of the pseudo coefficient of determination (Nagelkerke $R^2 = 0.289$) indicates a moderate level of explained variance, which is in line with expectations for binary logistic regression models in financial distress research, where the occurrence of this phenomenon is influenced by a wider set of factors that go beyond the framework of financial indicators. This result additionally confirms that financial distress is a complex and multidimensional phenomenon, which cannot be fully explained by a limited set of financial indicators.

The statistical significance of the model as a whole was confirmed by the Likelihood Ratio test (LLR $p < 0.001$), which indicates that the set of included variables significantly contributes to the explanation of the probability of the occurrence of financial distress. This result confirms that the model has a satisfactory discriminating ability between distressed and non-distressed observations.

The results additionally indicate the differentiated role of individual variables in the model. Firm size shows a positive and statistically significant effect, with the odds ratio (Exp(B) = 3.27) indicating that an increase in firm size increases the probability of financial distress by approximately three times, controlling for other factors.

This finding suggests that financial distress cannot be viewed exclusively through business performance, but requires a broader analytical framework that includes the interplay of different dimensions of the company's financial position.

This confirms the need for an integrative approach in the analysis of financial distress, which overcomes the limitations of individual indicators and enables a deeper understanding of the mechanisms that lead to financial difficulties.

Overall, the results presented in Tables 1–6 indicate a consistent analytical structure in which the descriptive characteristics of the sample, the distribution of financial distress, and the interrelationships between variables together provide a reliable basis for identifying the key determinants of financial distress in the agro-industrial sector. The results of the empirical analysis indicate the differentiated role of certain financial dimensions in the explanation of financial distress, whereby certain dimensions are distinguished by their importance in relation to others. In this sense, the next chapter is dedicated to a more detailed interpretation of the obtained findings and their review in the context of the existing literature and the specifics of the agro-industrial sector.

Discussion

The results of the empirical analysis indicate a specific structure of the determinants of financial distress in the agro-industrial sector, which differs to a certain extent from the findings of previous research. Although numerous works have identified profitability and liquidity as key predictors of financial distress (Altman, 2000; Beaver, 1966), the results of this research indicate that the capital structure plays a dominant role in the observed sector, while operating indicators do not show a statistically significant impact.

The dominant importance of the capital structure indicator (S1) is consistent with research findings that emphasize the importance of financial leverage and the ratio of own and others' capital in explaining financial distress (Ohlson, 1980; Shumway, 2001). This finding is consistent with recent research emphasizing that financial stability and vulnerability are not determined solely by firm-level performance indicators, but also by structural and institutional factors within the financial system, including regulatory mechanisms and risk-sharing arrangements (Suljić Nikolaj et al., 2022). In this context, firm-level financial indicators should be interpreted as part of a wider set of interrelated factors that jointly shape financial vulnerability across sectors and economic environments.

Companies with a larger share of own capital have greater resistance to shocks and a lower risk of insolvency, which is confirmed by the results of this paper. However, the intensity of this effect, expressed through an extremely low odds ratio, may indicate a potentially more significant role of the financing structure in the agro-industrial sector compared to other sectors.

On the other hand, the lack of statistical significance of profitability indicators (R1) and operating cash flow (K2) represents a finding that deviates from classic models of financial distress. In the literature, profitability is often cited as one of the key early indicators of financial difficulties (Beaver, 1966; Altman, 2000), while cash flows reflect a company's ability to service obligations in the short term. However, the results of this research suggest that in the observed sector these variables do not have sufficient discriminatory power between distressed and non-distressed companies. These findings are consistent with the underlying structure of the Altman Z' model, which incorporates leverage and financial structure as key components, further reinforcing the observed importance of capital structure in explaining financial distress.

This finding can be explained by the specifics of the agro-industrial sector, which is characterized by relatively stable operating flows, but at the same time significant dependence on the financing structure and long-term investment cycles. Similar findings are recorded by more modern research, which indicates that in certain sectors, traditional financial indicators lose their predictive power, while structural factors become dominant (Campbell et al., 2008).

A particularly interesting result refers to the company size variable (SIZE), which shows a positive and statistically significant impact on financial distress. This finding contradicts a body of literature that suggests that larger firms have a lower risk of distress (Fama & French, 1993). However, the results of this research indicate that larger companies in the agro-industrial sector may be exposed to greater operational and financial risks, due to the complexity of operations, greater investment requirements and greater exposure to market fluctuations. This implies the development of new financial products and services that are particularly relevant for environmental protection (Tarkhanova, 2018).

In the literature, the interdependence of profitability and liquidity is often highlighted as a key factor in business efficiency (Prdić, 2023). However, the results of this research indicate that in the observed sector these dimensions do not have a statistically significant impact on financial distress, which suggests that their role may be limited in a specific sectoral context. The obtained results are partially in accordance with previous research in the agro-industrial sector (Čavlin et al., 2023a; Čavlin et al., 2023b), but at the same time indicate a more dominant importance of structural factors. Additionally, the distribution of distressed companies by sub-sector does not indicate their concentration in one segment, but the presence of financial difficulties in different parts of the agro-industry, which further confirms the complexity and multidimensional nature of this phenomenon.

This finding represents a contribution to the existing literature, as it indicates that the determinants of financial distress do not act uniformly, but that their relative importance depends on the sectoral and structural context, which calls into question the universality of traditional models based on linear combinations of financial indicators. This confirms the need for integrative approaches in the analysis of financial distress, which enable the simultaneous observation of multiple dimensions of the company's financial position (Čavlin & Vapa-Tankosić, 2021). Taken as a whole, the results of this research indicate that financial distress cannot be adequately explained by individual indicators, but represents a multidimensional phenomenon arising from complex relationships between different dimensions of the company's financial position. The absence of statistical significance of certain indicators does not imply their irrelevance, but indicates their dependence on the wider context in which they operate.

Conclusion

Through a theoretical framework that indicates the limitations of traditional approaches, a methodological approach based on panel analysis and logistic regression enabled an empirical insight into the complexity of this phenomenon in a specific sectorial context of the financial position of companies in the agro-industrial sector of the Republic of Serbia.

The findings indicated a clear differentiation between the role of individual financial indicators. While operating indicators, such as profitability and cash flows, showed a limited ability to distinguish between distressed and non-distressed companies, capital structure stood out as a dominant factor in financial distress. At the same time, the size of the company showed a statistically significant impact, whereby larger companies may be exposed to a higher level of financial risks, which indicates the more complex nature of their operations. The findings have confirmed that financial distress is not the result of individual financial weaknesses, but the result of the interaction of different dimensions of the company's financial position. These findings directly answer the research question of the work and indicates the need to overcome approaches based on isolated observation of financial indicators.

The contribution of this work is reflected in the empirical confirmation of the sectoral specificity, as well as in indicating the dominant role of structural factors in relation to operational performance. This contributes to the existing literature, especially for sectors with pronounced investment and financial specificities. At the same time, the results point to the need to develop analytical approaches that enable an integrated view of multiple dimensions of financial operations.

The limitations of the research are the size of the sample and its sectoral orientation, which may affect the possibility of generalizing the results. In addition, the analysis is based on financial indicators available from standard reports, which does not include the potential impact of non-financial factors.

In this sense, future research can be aimed at expanding the sample to other sectors and countries, as well as at including additional dimensions of financial and non-financial operations. A particularly significant direction of further research is related to the development of integrative and diagnostic models that enable the simultaneous observation of multiple dimensions of the company's financial position. Viewed in a broader context, the understanding of financial distress requires a shift in focus from individual indicators to more complex analytical frameworks that reflect the real dynamics of modern business operations.

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Conflict of interests

The authors declare no conflict of interest.

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ARTIFICIAL INTELLIGENCE IN SUSTAINABLE AGRICULTURE: OPTIMIZING WATER USE IN THE CONTEXT OF CLIMATE CHANGE

Dragan Ugrinov[1], Magdalena Nikolić[2], Željko Grujičić[3], Brankica Pažun [4], Zlatko Langović [5]
**Corresponding author E-mail: magdalena.nikolic@fim.rs*

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A B S T R A C T

This paper examines the application of artificial intelligence (AI) in organic agriculture using the Analytic Hierarchy Process (AHP). A multi-criteria analysis evaluated four key criteria: AI use in optimization, factors affecting precision irrigation, benefits of AI application, and implementation challenges, alongside three alternatives: price, personnel, and terrain. Results show that "implementation problems and challenges" are the most significant criterion (39.52%), while "personnel" is the most important alternative (63.45%), emphasizing the crucial role of human resources in adopting technological solutions. The study also demonstrates high consistency (CR = 0.0274), confirming the reliability of the findings. The paper highlights the need for institutional support, educational programs, improved water resource management, and affordable AI solutions, particularly for small farmers, while proposing directions for future research and policies to advance sustainable agriculture.

1 Dragan Ugrinov, Assistant Professor, Research Associate, University"Union Nikola Tesla" Belgrade, Faculty of Management, Njegoševa 1a, Sremski Karlovci, Serbia, Phone: +381631068311, E-mail: dragan.ugrinov@famns.edu.rs, ORCID ID (https://orcid.org/0000-0002-5387-820X)

2 Magdalena Nikolić, Senior Lecturer, Research Associate, Academy of Applied Studies – Polytechnic, Katarine Ambrozić 3, Belgrade, Serbia, Phone: +381116410990, E-mail: mnikolic@politehnika.edu.rs, ORCID ID (https://orcid.org/0000-0002-2021-153X)

3 Željko Grujčić, Full Professor, University "Union - Nikola Tesla", School of Engineering Management, Vojvode Mišića Boulevard no. 43, 11000 Belgrade, Serbia, Phone: +381644642015, E-mail: zeljkogruicic@fim.rs, ORCID ID (https://orcid.org/0000-0002-5488-0176)

4 Brankica Pažun, Associate Professor, University "Union - Nikola Tesla", School of Engineering Management, Vojvode Mišića Boulevard no. 43, 11000 Belgrade, Serbia, Phone: +381114140420, E-mail: brankica.pazun@fim.rs; ORCID ID (http://orcid.org/0000-0002-9452-5064)

5 Zlatko Langović, Full Professor, University of Kragujevac, Faculty of Hotel Management and Tourism in Vrnjačka Banja, Vojvodjanska bb, 36210 Vrnjacka Banja, Serbia, Phone: +381365150024, E-mail: zlangovic@kg.ac.rs, ORCID ID (http://orcid.org/0000-0002-0248-0453)

Introduction

Sustainable agriculture is becoming crucial in addressing global challenges such as climate change, resource depletion, and the growing demand for food. Agriculture accounts for more than 70% of global freshwater consumption (FAO, 2020), making water conservation essential for both food production and environmental preservation. Climate change further exacerbates water scarcity due to more frequent droughts and unpredictable rainfall patterns. Although droughts vary geographically, they have socio-economic and environmental consequences, such as water and food insecurity, and deterioration of the environment. Ecosystem. Thus, effective drought management strategies must be implemented, including monitoring and AI applications (Thelma et al., 2024). For instance, in the Middle East and Africa, fear of fertile lands and ores turned into deserts (Mfarrej, 2025). Traditional irrigation systems are often inefficient, leading to excessive water use. Innovative technologies, particularly artificial intelligence (AI), offer significant potential for optimizing water use and reducing environmental impact.

AI tools, including machine learning, sensor networks, and satellite data, enable farmers to make informed decisions regarding water management, consumption reduction, and productivity enhancement. This paper explores how AI can contribute to agricultural sustainability, with a specific focus on water use optimization in the context of climate change (FAO, 2020). With increasingly frequent droughts and changing rainfall patterns, effective water resource management becomes critical for sustainable food production and environmental preservation.

Although irrigation resources are declining in many regions, the tradition of mass irrigation has not significantly changed in recent decades. Traditional irrigation systems often lead to excessive water consumption and inefficient use of available resources. Therefore, recognizing innovative technologies allows for precise and efficient water use in agriculture and becomes key to minimizing negative environmental impacts (Nica et al., 2018; Hussnain et al., 2020).

Artificial intelligence (AI) has emerged as a key technology in recent decades, enabling significant changes across various industries, including agriculture. Given the increasing challenges of climate change, dwindling natural resources, and the growing need to increase food production, the application of AI in agriculture represents a potential solution for optimizing resources and improving production efficiency (Smith & Brown, 2020). Also in urban areas, water scarcity can be managed by introducing AI tools (Maldonado et al., 2025). One of the major challenges facing agriculture is water use, which is a fundamental resource for plant growth and development (Smith & Brown, 2020).

The introduction of AI technologies can significantly improve the precision of water use and reduce waste, which is particularly important in the context of climate change (Miller & Thomas, 2022). The major threat presents different types of waste. Thus, sustainable agriculture depends not only on knowledge, but also on applying AI tools as well. Protecting the environment, we protect the arable land (Nikolić et al., 2023;Pantović et al., 2026). In agriculture, AI encompasses a wide range of technologies, including machine learning, deep learning, sensor technology, and satellite data, which enable farmers to make better real-time decisions. By using predictive models and automated irrigation systems, AI can greatly reduce water consumption while simultaneously increasing agricultural production efficiency (Lopez-Moreno et al., 2018).

The benefits of these technologies include the ability to precisely measure soil moisture, forecast water needs based on weather conditions, and automatically adjust the amount of water used—directly contributing to loss reduction and more efficient resource use. AI-based systems can use data on climate conditions, soil types, crop status, and water consumption to predict exact irrigation needs during different plant growth stages (Perez et al., 2021).

For example, by using soil moisture sensors in combination with AI, it is possible to optimize irrigation dynamics, significantly reducing water usage while improving plant health and yield (Alami et al., 2020; Milojević & Milanović, 2025). Furthermore, research has shown that the application of AI technologies in agriculture is not only beneficial for large farms and commercial farmers in developed countries but also for those in developing regions, where access to advanced technology can bring significant benefits in terms of water savings and yield increases (Gómez et al., 2019).

This paper examines the application of artificial intelligence in optimizing water use in agriculture. We will focus on technologies that enable precision irrigation, as well as the benefits and challenges of implementing AI in farming. In addition, we will analyze specific case studies that demonstrate successful applications of AI in reducing water consumption on farms, along with the challenges of deploying these technologies.

Technologies Enabling Water Use Optimization in Agriculture

There are several key AI technologies that enable water use optimization in agriculture. First, soil condition monitoring sensors and devices allow farmers to track soil moisture and irrigation needs in real time (Sun et al., 2021). Another important tool is machine learning, which uses data on soil conditions, weather, and crop types to predict when and how much water is needed. Additionally, automated irrigation systems use AI to precisely determine the amount of water used, reducing waste and increasing efficiency (Miller & Thomas, 2022). These technologies allow farmers to make better decisions about when and how much water to use, significantly reducing water consumption while simultaneously improving crop quality and yield (Smith & Brown, 2020). One of the most prevalent technologies in artificial intelligence is machine learning (ML), which enables systems to "learn" from data and make decisions without explicit programming. In agriculture, machine learning is used to analyze large volumes of field-collected data, including weather conditions, soil types, and crop status, gathered through soil moisture monitoring and water usage sensors (Kumar et al., 2019; Pantić et al., 2025). Machine learning algorithms provide farmers with better insights into crop growth patterns and optimal irrigation conditions, significantly increasing water use efficiency (Garcia et al., 2020).

Furthermore, deep learning (Zhang & Liakos, 2020), sensors (Sharma et al., 2018), drones (Ravi & Rani, 2020), and satellite data (Zhang et al., 2021; Miljković & Arsić, 2025) also play important roles. Today, advanced irrigation systems are central to water efficiency. Machine learning enables these systems to predict water usage based on sensor data and weather forecasts. For example, in arid regions, artificial intelligence can use soil and climate data to optimize the precise amount of water delivered to a plant, thus reducing excessive use and improving irrigation efficiency (Raj & Devanand, 2020).

Materials and methods

This study is based on the analysis of secondary data from relevant research and case studies on the application of AI in agriculture using the MCDM tool. Sustainable agriculture has multiple problems regarding water scarcity, pollutants in soil, air and water, climate change, etc. Agricultural decision problems must be solved independently bearing in mind that agriculture has economic and social benefits and constrains. Therefore applying Multi-criteria decision-making (MCDM) techniques, particulary the analytical hierarchy process (AHP) this paper can bring the optimal solution in various complex decision-making problems like agriculture-related irrigation problems. The basis of the methodological obstacle is the structured/hierarchical problem of optimization of water use in agriculture using artificial intelligence, which is based on four criteria and three alternatives. The analyzed alternatives are respectively Price, Personnel and Land relief, and the criteria are: Use of AI in optimizing water consumption, factors affecting precise irrigation, benefits of AI in rationalizing water consumption and problems/challenges of AI implementation. The problem was analyzed using the MCDM tool, that is, the AHP method, which consists of several steps. The first step involves defining a matrix of comparison pairs. Data generation implies that the decision maker assigns relative scores to attribute pairs at all levels of the hierarchy except zero (the target is not compared). The results of the comparison of elements at a certain hierarchy level are entered in the corresponding comparison matrices $A = [a_{ij}]_{nxn}$.

The reciprocal value of the comparison result is placed in the corresponding position $a_{ji} = {}^{1}/_{a_{ij}}$ in order to maintain the consistency of the argumentation. The weights of the criteria and/or alternatives are to be determined by evaluating their coefficients. The relative importance matrix A is formed from these relative importance coefficients (Saaty, 2008).

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \dots a_{1n} \\ 1/a_{12} & 1 & \dots a_{2n} \\ \vdots & \vdots & \\ 1/a_{1n} & 1/a_{2n} & \dots 1 \end{bmatrix} \quad (1)$$

The second step consists of the matrix normalization of the comparison pairs. In the third step we develop the value λmax.

$$\lambda_{max} = \sum_{i=1}^{n}\left(\sum_{i=1}^{n} a_{ij}\right) w_j \tag{2}$$

In the fourth step the consistency index, as a measure of deviation n from λmax, has been calculated.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{3}$$

Then, next step includes the degree of consistency, calculated as quotient of the consistency index and the random index, RI, (Random Index):

$$CR = \frac{CI}{RI} < 0.1 \sim 10\% \tag{4}$$

For the purposes of this research, a secondary data analysis approach was used, including a review of relevant papers and case studies on the use of AI in agriculture. A systematic approach was applied to select literature published in the last five years in order to capture the most recent trends and approaches.

Results and Discussion

The use of AI technologies in agriculture has demonstrated significant water savings. For example, machine learning for predicting required water amounts and precision irrigation can reduce water consumption by up to 40%. Tables 1 and 2 present the implementation of various AI technologies, while Table 3 shows specific results related to water consumption reduction in agriculture using AI systems. Increased efficiency in irrigation and water resource conservation is evident in cases where soil moisture sensors, automated irrigation systems, and satellite data were used.

Table 1. Use of Artificial Intelligence Technologies in Agriculture (Implementation Percentage)

Technology	Implementation Percentage (2020–2022)	Application Description
Machine Learning (ML)	22%	Use of predictive models to analyze crop water requirements
Deep Learning (DL)	7%	Use of complex algorithms for image analysis and plant health assessment
Soil Moisture Sensors	42%	Precise measurement of soil moisture and automatic irrigation control
Drones and Satellite Data	12%	Used for crop monitoring and irrigation need assessment
Automated Irrigation Systems	17%	AI-based automatic regulation of irrigation systems

Source: Eurostat, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Artificial_intelligence_statistics_-_statistics_on_the_use_by_enterprises; Adapted from relevant research in (Wei et al., 2024)

Table 1 presents the implementation levels of various artificial intelligence (AI) technologies in agriculture from 2020 to 2022, along with descriptions of their applications. The most widely implemented technology—soil moisture sensors (50%)—has become a standard practice in many agricultural systems, indicating the importance of precise soil moisture measurement and automatic irrigation control. Their relatively easy integration into existing systems may be one reason for their high adoption rate. This is followed by machine learning at 30%, while deep learning (15%) shows the lowest adoption. The data indicate that sensor technologies and machine learning dominate water use optimization in agriculture, while more advanced AI methods such as deep learning and drones are experiencing slower adoption.

Key challenges for AI technologies include cost, infrastructure availability, and technical expertise. However, as these technologies continue to evolve and become more accessible, their application is expected to grow further, increasing efficiency and sustainability in agriculture.

Table 2. Factors Influencing Precision Irrigation Using Artificial Intelligence (Percentage Impact)

Factor	Impact Percentage (%)	Description
Weather conditions (rain, temperature)	35%	Inclusion of climate data for accurate irrigation prediction
Soil type (sandy, clay)	20%	Soil characteristics determine water retention and irrigation needs
Crop health (stress, disease)	25%	Plant symptom analysis to assess water requirements
Soil moisture sensors	10%	Devices that directly monitor soil moisture levels
Satellite data and drones	10%	Use of high-precision technologies for analyzing and mapping water demand

Source: Adapted from relevant research in precision agriculture
(Ravi & Rani, 2020; García et al., 2020)

Table 2 outlines the factors that influence precision irrigation using artificial intelligence (AI) and their relative share in overall analysis. These factors play a crucial role in optimizing water use in agriculture, enabling more efficient resource use and reducing negative environmental impact.

Weather conditions, including rainfall and temperature, have the greatest influence (35%) on precision irrigation. This is expected, as climate factors directly affect crop water needs. Soil type (e.g., sandy, clay, loamy) significantly impacts water requirements, accounting for 20% of the influence. Crop health, including stress from drought, disease, or pests, contributes 25% to the assessment of irrigation needs.

Satellite data and soil moisture sensors, as well as drones, have a relatively smaller impact (10%), but are crucial for real-time soil moisture monitoring. According to Table 2, weather conditions and crop health are the key factors for precision irrigation that significantly influence decision-making. Although soil type and sensors have a lower overall share, they are valuable for large-scale analysis and mapping.

Table 3. Impact of AI Technology on Water Consumption Reduction in Agriculture (Percentage Reduction)

Technology	Water Consumption Reduction (%)	Description
Machine learning for prediction	25%	Use of predictive models for more accurate determination of required water
Precision irrigation with sensors	40%	Use of soil moisture sensors for targeted irrigation
Automated irrigation systems	20%	Use of systems for real-time irrigation adjustment
Drones and satellites for crop analysis	15%	Real-time data collection on crop conditions and water needs

Source: Based on research in agriculture (Kumar et al., 2019; Zhang et al., 2021)

Table 3 evaluates the reduction in water consumption in agriculture achieved through various artificial intelligence-based technologies. These technologies enable more efficient water use, minimize waste, and contribute to agricultural sustainability and resource conservation. A detailed commentary on each technology helps clarify its specific impact.

According to Table 3, machine learning and precision irrigation using sensors are the most effective, reducing water usage by 20% to 40%. Automated irrigation systems and drones/satellites also play a key role in optimizing water usage, although their individual impact is slightly lower.

Overall, the application of these technologies contributes to greater efficiency, sustainability in agriculture, and conservation of water resources—all of which are essential in addressing climate change and the growing global demand for food.

Table 4. Problems and Challenges in Implementing AI for Optimizing Water Consumption in Agriculture

Challenge / Problem	Percentage of Farmers Facing the Problem (%)	Description of the Problem
High Initial Implementation Costs	(30%)	Technological investments in sensors, irrigation systems, and artificial intelligence can be substantial.
Lack of Training and Technical Support	(20%)	Farmers lack adequate training for implementing AI technologies.
Limited Availability of Quality Data	(25%)	Many regions lack the necessary data on weather conditions, soil, and crops.
Complex Algorithms and Large Data Set Requirements	(15%)	AI models require large datasets for accurate analysis, which can be challenging.
Misalignment with Local Conditions and Legislation	(10%)	Water regulations and policies in many regions may hinder the application of these technologies.

Source: Eurostat, *Source: :* https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agriculture_statistics_-_family_farming_in_the_EU https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Artificial_intelligence_statistics_-_statistics_on_the_use_by_enterprises

Table 4 presents the main challenges and problems faced by farmers when implementing artificial intelligence (AI) for optimizing water consumption in agriculture. These issues can significantly slow down the widespread adoption of these technologies, despite their significant resource-use efficiency benefits.

Among the challenges presented in the table, high initial implementation costs are the most significant problem, while the lack of training and technical support is also a major barrier to the wider adoption of AI technologies in agriculture. Moreover, access to quality data and the complexity of algorithms remain technical obstacles to effective implementation.

By improving data collection infrastructure, providing farmer training, and reducing implementation costs, these challenges can be overcome, enabling broader use of AI in agriculture and further reducing water consumption.

Although AI technologies have demonstrated significant potential in reducing water consumption, their implementation faces several challenges. According to some studies, high initial implementation costs, a lack of training for farmers, and data quality issues remain major barriers. On the other hand, research in Serbia shows that climate changes, such as increased droughts, further elevate the need for precision irrigation, making artificial intelligence critical for the future of agriculture in this region. Several examples of AI applications in Serbia have been considered, but there are still significant limitations that must be overcome with stronger support and education.

Results Obtained Using the AHP Method

The application of the AHP method within this research has proven to be an extremely effective and transparent instrument for structuring the complex problem of rationalizing water consumption in organic agriculture. The results enabled the quantification of the relative importance of criteria and alternatives, indicating critical barriers (challenges to AI implementation) and key resources (human factor/staff) as dominant influences in the process of AI implementation in agriculture.

Table 5. AHP Pairwise Comparison Matrix for Criteria Evaluation in AI-Based Water Optimization

Criterion Relationships	AI Usage in Water Consumption Optimization	Factors Influencing Precise Irrigation	Benefits of AI in Water Consumption Rationalization	AI Implementation Challenges
AI Usage in Water Consumption Optimization	1	1	1	1/2
Factors Influencing Precise Irrigation	1	1	2	1/2
Benefits of AI in Water Consumption Rationalization	1	1/2	1	1/2
AI Implementation Challenges	2	2	2	1

Criterion Relationships	AI Usage in Water Consumption Optimization	Factors Influencing Precise Irrigation	Benefits of AI in Water Consumption Rationalization	AI Implementation Challenges
CI: 0.0202				
CR: 0.0227				
λ: 4.0607				

CI: Consistency Index **CR**: Consistency Ratio λ: Principal Eigenvalue

Source: Author's own elaboration based on the Analytic Hierarchy Process (AHP) methodology

Table 5 shows the pairwise comparison matrix used in the Analytic Hierarchy Process (AHP) to evaluate the priorities among the four criteria in the context of the application of artificial intelligence (AI/AI) in the optimization of water consumption. The criteria are:

1. The use of AI in the optimization of water consumption
2. Factors affecting precision irrigation
3. Benefits of AI in the rationalization of water consumption
4. Problems/challenges of AI implementation

Comparison consistency (CI and CR)

Consistency Index (CI) = 0.0202 and Consistency Coefficient (CR) = 0.0227, which is less than the maximum allowed value of 0.10 (or 10%). This indicates that the estimates of relative importance among the criteria are consistent and reliable, and that the results of the AHP analysis have a good degree of validity.

Table A shows a well-structured and balanced assessment of the impact of various factors in the context of the use of artificial intelligence for irrigation.

Emphasizing implementation challenges as the most important criterion indicates the need to resolve infrastructural, technical and possibly regulatory/legal obstacles before other benefits can be fully realized.

Table 6. AHP Pairwise Comparison Matrix of Factors Influencing AI Use in Water Consumption Optimization

AI Usage in Water Consumption Optimization	Price	Staff	Terrain Relief
Price	1	1/5	1/3
Staff	5	1	4
Terrain Relief	3	1/4	1
CI: 0.0430			
CR: 0.0827			
λ: 3.0860			

Source: Author's own elaboration based on the Analytic Hierarchy Process (AHP) methodology

Table 6 shows a matrix of pairwise comparisons of the criteria - "Use of AI in the optimization of water consumption", among the considered alternatives, which affect the optimization of water consumption in agriculture. Alternatives considered are:

1. Price
2. Farmers
3. Land relief

The consistency of the assessment of the criterion "Use of AI in the optimization of water consumption" among the considered alternatives suggests that the CI (Consistency Index) is 0.0430, and the CR (Consistency Coefficient) has a value of 0.0827, which is less than the permissible threshold of 0.10. This means that the comparisons are sufficiently consistent, so the results can be considered reliable and valid for further decision-making**.** The analysis of interrelationships shows that the alternative - Personnel with a rating of 5 is dominant in relation to the alternative - Price which is rated with 1 and to the alternative - Ground relief which is assigned with a rating of 4.

Table B shows a rationally structured perception of criteria/alternatives, with a clear focus on the human factor as the key to success in implementing AI in irrigation systems. Although relief and price are extremely important, the emphasis is placed on farmers, which is in line with the real challenges of applying advanced technologies in agriculture. Good consistency shows that expert judgments were stable and thoughtful**.**

Table 7. AHP Pairwise Comparison Matrix for Factors Influencing Precision Irrigation

Factors Affecting Precision Irrigation	**Price**	**Staff**	**Terrain Relief**
Price	1	1/5	1/3
Staff	5	1	3
Terrain Relief	3	1/3	1
CI: 0.0192			
CR: 0.0369			
λ: 3.0383			

Source: Author's own elaboration based on the Analytic Hierarchy Process (AHP) methodology

Table 7 presents a pairwise comparison of the criteria "Factors affecting precision irrigation" in relation to the alternatives: Cost, Farmers, Topography, and their importance for the application of artificial intelligence in precision irrigation. The consistency of the estimate shows that the CI is 0.0192 and the CR value is 0.0369, which is well below the maximum allowable value of 0.10. This implies that decisions by comparing criteria/alternatives are highly consistent and reliable, which provides a valid basis for conclusions. The analysis of mutual relations indicates that - Farmers evaluated as the most important alternative shows that the human factor (expertise, training, engagement) is considered crucial for successful precision irrigation using AI.

Table C indicates that the successful implementation of AI in precision irrigation is most reliant on personnel, which is consistent with the complexity of the technology and the need for technical competence. Terrain has an impact, but is obviously of secondary importance compared to human resources. Price, although important, is not a decisive element for the successful application of AI in irrigation, which indicates a strategic approach to investing in precision agriculture.

Table 8. AHP Pairwise Comparison Matrix of Benefits of AI in Water Consumption Optimization

Benefits of AI in Water Consumption Rationalization	**Price**	**Farmers**	**Terrain Relief**
Price	1	1/5	1/3
Staff	5	1	2
Terrain Relief	2	1/2	1
CI: 0.0267			
CR: 0.0513			
λ: 3.0534			

Source: Author's own elaboration based on the Analytic Hierarchy Process (AHP) methodology

Table 8 shows the analysis of the significance of the criterion "Benefits of artificial intelligence (AI) in the rationalization of water consumption" which contributes to the usefulness of the AI system in the optimization of water use. The scores presented in Table 8 are consistent and methodologically acceptable where the CI value is 0.0267 and the CR value is 0.0513.

In the context of the use of AI in water rationalization, the human factor (personnel) is seen as a key component of success – due to its role in system operation, data analysis and decision-making. The relief of the ground has a moderate influence, while the price is the least relevant in the assessment of benefits, which indicates a strategy aimed at long-term performance rather than initial costs.

Table 9. AHP Pairwise Comparison Matrix of Challenges in Implementing AI for Water Consumption Optimization

Problems/Challenges in AI Implementation	**Price**	**Farmers**	**Terrain Relief**
Price	1	1/5	1/3
Staff	5	1	2
Terrain Relief	3	1/2	1
CI: 0.0021			
CR: 0.0041			
λ: 3.0042			

Source: Author's own elaboration based on the Analytic Hierarchy Process (AHP) methodology.

Table 9 shows pairwise comparisons of the alternatives - Cost, Farmers, and Terrain against the criterion "Problems/Challenges of AI Implementation". The goal is to determine which of these factors most contribute to the difficulties in introducing and using artificial intelligence (AI) in water rationalization systems.

The CI is 0.0021 and the CR value is 0.0041, which is extremely low and far below the acceptable threshold of 0.10. This indicates an extremely high degree of consistency in the assessments made, so the assessment is reliable and methodologically very precise.

Table 10. AHP-Derived Weights of Evaluation Criteria for AI in Water Consumption Optimization

Criteria	**Use of AI in Water Consumption Optimization**	**Factors Affecting Precise Irrigation**	**Benefits of AI in Water Consumption Rationalization**	**Problems/Challenges in AI Implementation**
Price	0.1007	0.1047	0.1125	0.1095
Staff	0.6738	0.6370	0.7089	0.5816
Terrain Relief	0.2255	0.2583	0.1786	0.3090

Source: Author's own elaboration based on the Analytic Hierarchy Process (AHP) methodology.

Table 10 shows the ratio of weights assigned to the criteria for each alternative. Farmers dominates all the main criteria, with values between (0.58)min and (0.71)max, which supports the analysis that the human factor is crucial in the successful application and utilization of AI for irrigation. The relief of the ground has a moderate importance, and it is the most intense in the AI implementation criteria and is (0.3090)max, which is logical, because more complex terrain makes technical realization difficult. Price has the least importance in all criteria from (0.1007)min to (0.1125)max, which correlates with other results and shows that cost is not considered the main limiting factor.

Table 11. Priority Ranking of Criteria for AI-Based Water Consumption Optimization Using AHP

Ranking of Criteria	**Result**
Use of AI in Water Consumption Optimization	0.1976
Factors Affecting Precise Irrigation	0.2390
Benefits of AI in Water Consumption Rationalization	0.1682
Problems/Challenges in AI Implementation	0.3952

Source: Author's own elaboration based on the Analytic Hierarchy Process (AHP) methodology.

Table 11 refers to the ranking of the criteria and shows that the greatest importance is assigned to the criterion "Problems/challenges of AI implementation" with a weight of 0.3952 or 39.52%, which shows that implementation challenges and obstacles are perceived as the most critical segment in the successful rationalization of water consumption using AI. They are followed by the criterion "Factors affecting precision irrigation" with 23.9%, which shows the importance of technology and local conditions. The criteria "Usage of VI in optimization" and "Benefits of AI" have lower values, which may mean that they are understood as consequential effects, while challenges and success factors are in focus.

Table 12. Aggregated Priority Scores of Alternatives Based on AHP Criteria Evaluation

Criteria	Use of AI in Water Consumption Optimization	Factors Affecting Precise Irrigation	Benefits of AI in Water Consumption Rationalization	Problems/ Challenges in AI Implementation	Result
Price	0.0199	0.0250	0.0189	0.0433	0.1071
Staff	0.1331	0.1522	0.1192	0.2298	0.6345
Terrain Relief	0.0446	0.0167	0.0300	0.1221	0.2584

Consistency Ratio (CR): 0.0274

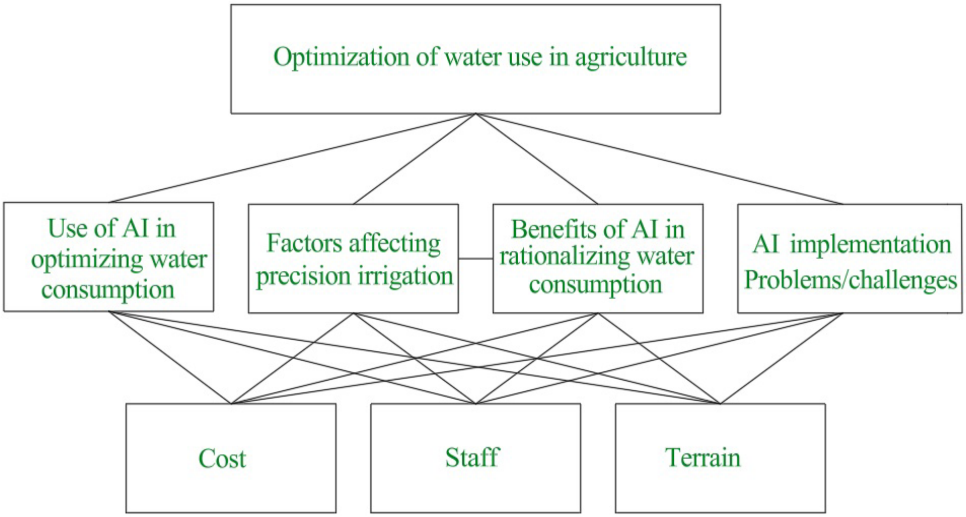
Source: Author's own elaboration based on the Analytic Hierarchy Process (AHP) methodology

Table 12 presents the structure and score/rank of the alternatives. Alternative - Personnel with a score of 0.6345 is the best ranked alternative and shows that the human factor plays a dominant role in optimizing water use in agriculture. Alternative - Land relief takes second place with a score of 0.2584, and it is most pronounced in the criterion "Implementation problems/challenges". Price is the least significant alternative with a score of 0.1071, thus confirming the perception that investment costs are not the biggest obstacle, but that the challenges lie in human and physical terrain factors. The importance of artificial intelligence (AI) in the optimization of water use in organic agriculture analyzed by the AHP method, as a whole, shows a high consistency (CR = 0.0274), which means that the decision-making was stable and rational. Personnel as the most significant alternative for each criterion - confirms that the success/implementation of AI systems is closely related to human resources. The biggest challenge is the implementation of AI, which suggests that strategies should focus on removing technical, educational and organizational barriers. Price is not perceived as a major problem, which opens up space for investment in training, infrastructure and customer support.

Conclusion

The conducted research, using the Analytic Hierarchy Process (AHP), enabled the identification and ranking of key criteria and alternatives in the process of optimizing water consumption in organic agriculture through the application of artificial intelligence (AI). The analysis included four criteria: the use of AI in optimization, factors affecting precision irrigation, benefits of AI application and implementation problems/challenges, as well as three alternatives: price, farmers, and terrain. The criterion "Problems/ challenges in AI implementation" (0.3952) received the highest weight in the ranking of criteria, indicating that barriers in implementation are perceived as a key obstacle to rational water resources management. This is followed by the criterion "Factors influencing precision irrigation" (0.2390), which indicates the importance of technical and agro-ecological conditions in AI implementation. Criteria related to the benefits of AI (0.1682) and the use of AI itself (0.1976) have a lower priority, suggesting that in current practice, greater importance is attached to overcoming challenges than to the achieved gains. When it comes to alternatives, "farmers" is by far the highest ranked alternative (0.6345), indicating that the human factor, i.e. knowledge, competencies and training of personnel, is a key prerequisite for the successful implementation of AI in agriculture. Terrain relief (0.2584) is also a significant factor, especially in the context of implementation challenges, while cost (0.1071) received the lowest weight, indicating that initial costs were not perceived as a major obstacle. The value of the consistency index (CR = 0.0274) confirms high reliability and stability in the decision-making process. Overall, the research shows that the successful implementation of artificial intelligence to optimize water consumption in agriculture depends primarily on developed human resources, as well as on adequate adaptation of technical solutions to agro-ecological conditions, while costs are not seen as a dominant obstacle. The results are indicative and can serve as a basis for formulating education strategies, technological support, and public policies in the field of sustainable water resources management in agriculture. Next, the AHP results are presented and discusses their implications for decision-making and policy (Fig. 1)

Figure1. Hierarchical model for the selection of water optimization in agriculture



Source: Author’s own elaboration based on the Analytic Hierarchy Process (AHP) methodology

Challenges in Implementing Artificial Intelligence in Agriculture

Although AI-based technologies offer great potential for optimizing water usage in agriculture, several challenges hinder their widespread application. One of the biggest barriers is the high initial implementation costs, which may be a deterrent for small and medium-sized farmers. Additionally, there is a lack of high-quality data necessary for proper analysis and prediction of water needs. Reliable data on soil conditions, irrigation, and crop types are essential for the efficiency of AI technologies. Furthermore, many farmers lack the training and knowledge needed to use these technologies, which further complicates their implementation (National Institute for Agricultural Research, 2023). Analyses show that in other economic sectors, such as tourism, the use of information and communication technologies is largely determined by age and level of education. (Langović et al., 2025).

Policy Recommendations and Institutional Support

In conclusion, it is crucial to recognize the role of public policy and institutional support in promoting and expanding the use of AI in agriculture. Governments and relevant institutions should develop policies that encourage the research and development of AI technologies while facilitating access for small and medium-sized farmers. Furthermore, direct support in the form of subsidies for the implementation of new technologies, as well as educational programs to help farmers effectively use AI tools, is necessary (Smith & Brown, 2020).

It is also essential to develop localized strategies for implementing AI technologies in different agro-ecological zones, taking into account specific conditions such as soil types, climate, and crop varieties. Active collaboration between academic institutions, the private sector, and governments can enable faster and more efficient adoption of artificial intelligence, contributing to sustainable agriculture and reducing environmental impacts. Additionally, mechanisms should be introduced to encourage partnerships between research centers and farmers, ensuring that technologies are developed based on the real needs of the users (Petrović & Jovanović, 2024).

In the context of Serbia and Southeastern Europe, investment in infrastructure for collecting data on soil, climate, and crops is essential, as well as training farmers to use advanced AI systems (National Institute for Agricultural Research, 2023). Similarly, the application of ICT in the economy and thus in a particular sector has a positive impact on the economy, i.e. it has an effect on the growth of the sector's competitiveness and on economic development (Pažun et al., 2025)

Additional Recommendations for Future Research

1. Economic Analysis of AI Implementation in Agriculture: A detailed cost-benefit analysis of the implementation of AI technologies in agriculture is needed, with a particular focus on small farms and farmers in both developed and developing countries. This would allow for a deeper understanding of the financial impact and identify economic barriers to wider adoption (White & Green, 2021).

2. Development of Affordable AI Solutions for Small Farmers: It is recommended to develop inexpensive AI tools and systems that will be economically accessible to small producers. Such solutions could be key to ensuring sustainable agricultural production and reducing environmental impacts (Miller & Thomas, 2022).

3. Development of Localized Water Management Algorithms: Specific artificial intelligence models should be developed to consider the unique climatic, pedological, and agronomic characteristics of different regions. These models could significantly improve irrigation accuracy and reduce water consumption at the local level (Smith & Brown, 2020).

4. Strengthening Education for Farmers: Education and training for farmers on the use of artificial intelligence in agriculture is essential for the proper adoption and expansion of this technology. Developing specialized educational programs that focus on basic AI tools and precise irrigation methods can greatly contribute to their effectiveness (National Institute for Agricultural Research, 2023).

5. Supporting Legislative Framework: Introducing legislative initiatives that stimulate the adoption of innovations in agriculture, as well as reducing regulatory barriers, can facilitate easier application of AI and more efficient resource management (Petrović & Jovanović, 2024).

By addressing these areas, further research can contribute to a more efficient and equitable application of artificial intelligence in agriculture, promoting sustainable practices and improving water management on a global scale.

Conflict of interests

The authors declare no conflict of interest.

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THE IMPACT OF DIGITALIZATION ON THE PERFORMANCE OF COMPANIES IN THE AGRICULTURAL SECTOR

Miloš Milanović[1], Nikola Pavlović[2], Marko Savić[3]

**Corresponding author E-mail: nikola.pavlovic@akademijakm.edu.rs*

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A B S T R A C T

This research examines the relationship between the level of digitalization and the returns achieved by companies operating in the agricultural sector. The study is based on a review of the available literature and aims to determine the impact of digitalization on the performance of agricultural companies. The research relies on panel data analysis and utilizes the EViews software. The dataset includes daily data for the period from 2014 to 2024. To investigate this impact, an OLS regression model was applied, revealing the relationship between independent and dependent variables. The results indicate that there is a highly systematic and complex relationship between the degree of digitalization and company performance. Although digitalization is of strategic importance, its impact on returns can be negative due to the costs associated with organizational transformation.

Introduction

Agriculture is increasingly adopting digital technologies. Global digital corporations, local startups, and state institutions are providing and supporting a wide range of solutions aimed at creating the "smart" farmer – from self-driving tractors to drones that detect soil diseases, as well as from farm management applications to milking robots. Smart agriculture is often described as a place of agricultural production that uses software-driven "smart" technologies (Bertschi, 2018) and "big data" (Protopop & Shanoyan, 2016).

1 Milos Milanović, PhD, Assistant Professor, University Pristina, Faculty of Economics, Kosovska Mitrovica, Kolašinska 156, 38220 Kosovska MItrovica, Serbia, Phone +381 28 497934, E-mail: milos.milanovic@pr.ac.rs, ORCID ID (https://orcid.org/0000-0002-4684-6306)

2 Nikola Pavlović, PhD, Professor of Applied Studies, Academy of Applied Studies Kosovo and Metohija, Dositeja Obradovića bb, 38218 Leposavić, Serbia, Phone +381 28 83780, E-mail: nikola.pavlovic@akademijakm.edu.rs, ORCID ID (https://orcid.org/0000-0001-5466-576X)

3 Marko Savić, PhD, Professor of Applied Studies, Academy of Applied Studies Kosovo and Metohija, Dositeja Obradovića bb, 38218 Leposavić, Serbia, Phone +381 28 83780, E-mail: marko.savic@akademijakm.edu.rs, ORCID ID (https://orcid.org/0000-0002-0254-8171)

The agricultural sector is undergoing a major transformation due to digitalization. The impact of digitalization is observed not only in terms of technology but also in economic terms. The positive impact of digitalization is reflected in the efforts of economic policymakers to encourage farmers to engage more in electronic forms of trading and to be less dependent on state subsidies and state-supported pricing mechanisms (Chand, 2016).

The use of digital technology (in terms of the application of information and communication technologies) is based on digital platforms that provide the buyer with a certain degree of transparency, high speed, and transaction efficiency. Sellers also benefit from the use of markets in a much easier way, while the available information is highly detailed. All this leads to a shift in the procurement process of agricultural products from traditional oral auctions to digital methods. Digitalization affects numerous aspects of business operations, including information technology, strategy and business models, products and services, internal and external processes, organization, and company culture. In this paper, the phenomenon of digitalization particularly digital transformation—is examined from the perspective of relevant literature. The knowledge obtained comes from case studies. Finally, a synthesized conceptual framework model is presented and analyzed (Francois et al., 2014; Gavrilović et al., 2025; Liu et al., 2020).

The subject of this research is the analysis of the impact of digitalization on the financial performance of companies operating in the agricultural sector, with a particular focus on publicly listed companies. The main objective of the paper is to empirically examine whether and to what extent the level of digitalization affects the returns achieved by these companies, as well as to determine the direction and significance of this impact. In line with the stated objective, the study is based on the hypothesis that digitalization has a statistically significant effect on the returns of companies in the agricultural sector, with the assumption that this effect may be negative in the short run due to the high costs of digital transformation and the adjustment of organizational processes. The proposed hypotheses are tested using panel regression analysis, while the obtained results are thoroughly discussed and interpreted in the Results and Conclusion sections, thereby ensuring the logical and methodological consistency of the entire research. First, the introduction to the research is presented. Based on the literature, key insights are outlined. After that, the research method is discussed in the following chapter. The next chapter provides the research results, followed by the conclusion and references.

Literature Review

Questions related to the impact of digitalization on agriculture depend on whether and how it is integrated into policies, as noted by MacPherson et al. (2022). Garske et al. (2021) investigate the ecological opportunities and limitations regarding digitalization in the agricultural sector through the implementation of qualitative governance analysis. Here, agriculture is recognized as a highly important area for the application of digital advancements, including artificial intelligence. The authors examine the impact of agricultural education, staffing issues in rural areas, and the development of certain practical and promising methods. They conclude that there is a growing importance of highly qualified education in the agricultural sector, a demand for unskilled labor, increasing automation of processes, and similar trends (Akramovich, 2022).

They also analyzed small family farms and their position during the COVID-19 pandemic. Major negative consequences were observed, such as a decline in sales due to the closure of hospitality venues, delays in the delivery of certain inputs, and so on. However, these challenges contributed to the development of digitalization in agriculture and created new opportunities (Blažková et al., 2023; Barović et al., 2025). The authors Chung et al. (2021) examine whether advertising via digital media has the potential to efficiently support and improve the work of agricultural holdings, concluding that farms located in certain rural areas benefit more from digital media advertising.

The authors Xu et al. (2024) investigate the resilience of rural households to risks and how these risks impact their long-term strength. They determine that the resilience index of rural households in China is influenced by the digital economy through employment effects, income structure, and the safety of household members. Additionally, Wang et al. (2024) analyze how the implementation of internet technology in rural development has contributed to the improvement and modernization of agriculture. The findings indicate that internet access improves the participation of farmers in professional cooperatives.

The authors Fang et al. (2020) emphasize the importance of enhancing digital skills among farmers and using functional platforms, along with improving innovative mechanisms through the connection between companies and farmers, as well as the crucial role of policy-makers. Competitive advantage in the economy is based on knowledge and digitalization, which cannot be achieved without the application of modern technological solutions, organizational efficiency, and the functioning of production and social processes (Kučera & Látečková, 2006).

In their study, Benner and Ranganathan (2017) refer to the work of several other authors who investigated the relationship between market value of stocks and the disclosure of digitalization-related information, concluding that awareness of digital activities increases a company's value. From this, the assumption follows that investments in digital technologies influence a company's success in the stock market. Given the favorable relationship between market value and digital investments, it is expected that publicly traded companies have a high level of digital activity.

However, the authors were not able to confirm this assumption. Namely, 53% of the surveyed organizations had insufficient implementation of digitalization, 34% of the sample did not possess digital tools or advanced digital technologies, and only 13% of publicly traded Italian firms had fully integrated and used tools such as business intelligence, analytics, and big data (Truant et al., 2021).

Broccardo et al (2023) further investigated companies listed on the Italian stock exchange in 2021. The focus of the study was to examine how digitalization affects financial performance, as well as how sustainability is integrated into business strategy. The research revealed a surprising correlation between digitalization, sustainability, and profitability in Italian public companies. The paper emphasizes the importance of integrating sustainability into business strategy and the likely impact of digitalization on the implementation and efficiency of sustainable practices.

Similar results were presented by Ionașcu et al (2022). Their research, within the framework of the European Green Deal, deals with the digital transformation of companies listed on EU stock exchanges. The aim of the study was to examine the relationship between digitalization, financial performance, and sustainability. Based on 986 observations (companies over different years), the authors created a digitalization index using quantitative analysis of annual reports from 2018 to 2020. The results showed, particularly in terms of environmental protection, a positive relationship between digitalization projects and corporate social responsibility. Moreover, the study demonstrated a positive link between digital transformation efforts and market performance, indicating that companies that have made significant progress in digital transformation are more valuable to investors. These results have implications for both EU policymakers and the strategies of large publicly traded companies in Europe.

Although much research has been conducted on digitalization, relatively few studies explore the link between digitalization and company performance. Particularly significant in this context is the study by Truant et al. (2021), which uses a sample of Italian publicly traded companies from different sectors to examine the effect of digitalization on business performance. Although the adoption of digital technologies to support everyday business activities is still in its early stages, the results indicate that digitalization has a clear impact on company performance.

The Impact of Digitalization on Company Operations

One of the key processes transforming society and business—drawing considerable attention from both the academic community and practitioners—is digitalization. Although it is currently at the forefront of attention, related terms are often used interchangeably without clearly established and unified definitions. The rapid development of information and communication technologies has enabled the introduction of digital capabilities into products that were previously exclusively physical (Hirsch-Kreinsen, 2016).

One definition of digitalization refers to the transformation of analog content into digital form. Digitized data can be transmitted accurately, quickly, and economically. However, digitalization alone does not alter value-creating activities (Verhoef et al., 2021).

Thanks to this technological shift, it is now possible to develop digital technologies such as the Internet of Things, cloud services and mobile applications, artificial intelligence, big data, analytics, social networks, and embedded devices. All of these technologies can profoundly transform industries and societies (Mihardjo et al., 2019).

Digitalization explains changes in existing systems, corporate structures, and revenue streams resulting from the application of digital technologies. It is most commonly implemented through projects and digital initiatives that modify specific business processes (Bloomberg, 2022).

The application of digital technologies can be found in various areas of business. Digitalization helps improve customer experience, streamline operations, and transform entire business models (Nyagadza, 2022).

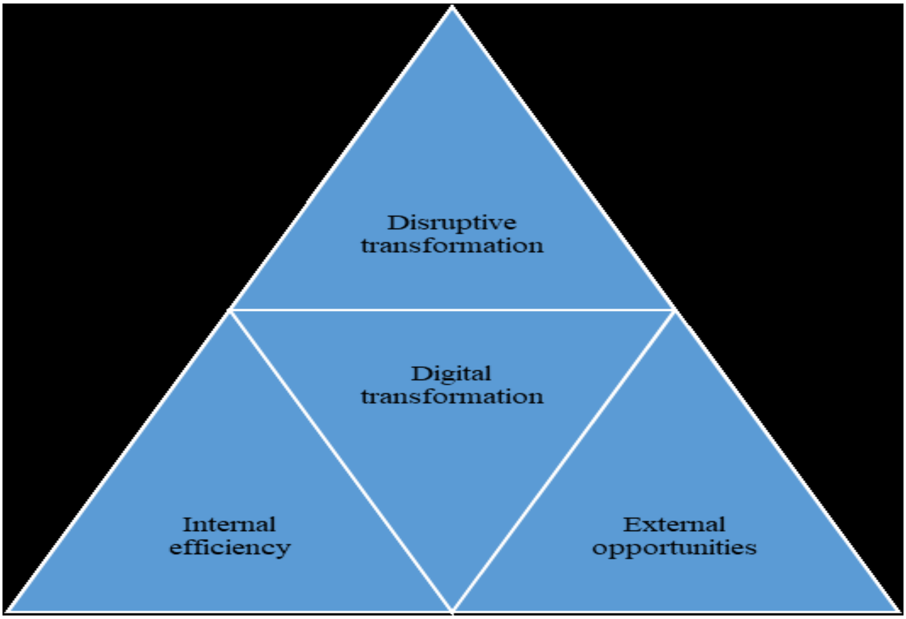
As already noted, digitalization is reshaping how companies function and their overall business environment. Ignoring digitalization carries the risk of losing position in highly competitive markets. Digitalization can impact the internal operations and the overall operational environment of a company. It can also lead to the discontinuation of existing business models, alter the roles of participants in the value chain, and create new business opportunities. For instance, digitalization can eliminate traditional intermediaries in the supply chain and introduce new ones, as a result of direct consumer access and the growing use of mobile devices.

Therefore, three distinct perspectives help in understanding the effects and objectives of digitalization for a company:

1. **Internal efficiency** – involves improving work processes through the use of digital tools and reorganizing internal procedures;
2. **External potential** – involves leveraging new business opportunities within the existing industry (new services, new clients, etc.);
3. **Disruptive transformation** – implies that digitalization fundamentally changes roles and relationships in business operations.

These three perspectives on the impact of digitalization can be illustrated in Figure 1.

Figure 1. Three Perspectives on the Impact of Digitalization



Source: Tagscherer, F., & Carbon (2023)

Data and method

The analysis of the impact of digitalization on return performance is conducted using daily data for the period 2014–2024, obtained from the Stooq stock exchange and the financial statements of the companies. In order to determine the level of digitalization of each company, computer-assisted text analysis is applied to the annual reports of each company (Drechsler et al., 2023).The territorial scope of the research includes publicly listed companies from the agricultural sector operating on the international market, with data obtained from the Stooq platform. The analyzed sample consists of companies registered in different countries and regions, which positions the study at a global level rather than being limited to a single national economy. Although the sample includes a relatively small number of companies (five), its representativeness is reflected in the fact that the selected firms are publicly listed, have been active over a long period (2014–2024), and provide high-frequency (daily) data, resulting in a large number of observations. Such a panel dataset enables the derivation of statistically relevant conclusions regarding the relationship between digitalization and company returns in the agricultural sector, while acknowledging certain limitations related to the sample size, which are considered in the interpretation of the results.

The analysis observes the dependent variable, represented by the daily return of each company, while the independent variable is digitalization. Thus, the impact of digitalization on each company's return will be examined. Following the approach of Kádárová et al. (2023), the following formula is proposed:

$$Y_{it} = \alpha + \beta X_{it} + \varepsilon_{it}$$

where is:

Y_{it} - dependent variable for company *i* at time *t;*

X_{it} – independent variable for observations *i* at time *t;*

α – const;

ε_{it} – error term for company *i* at time *t*.
that is:

$$Return_{it} = \beta_0 + \beta_1 DigiTech_{it} + \varepsilon_{it}$$

where is:

$Return_{it}$ – return of company *i* at time *t;*

$DigiTech_{it}$ – digitalization level of company *i* at time *t;*

β_0 - const;

ε_{it} – error term for company *i* at time *t*.

Research Results

Based on the collected data, the descriptive statistics of the research results will first be presented (Table 1).

Table 1. Descriptive Analysis of the Observed Variables

	Mean	Median	Maximum	Minimum	Std Dev	Skewness	Kurtosis	Jarque Bera
Gobarto SA	-0.017458	0.000000	9.691001	-17.60913	1.345383	0.547140	20.51911	32377.94
KSG AGRO SA	-0.025198	0.000000	16.71364	-35.47149	2.355366	-2.355123	50.42477	238675.3
Agroton Group of Companies	0.007353	0.000000	12.62449	-22.14142	1.927115	0.185955	15.36243	16074.39
Agroliga Group PLC	-0.007043	0.000000	9.569633	-32.22193	1.702555	-2.514282	57.53855	315222.7
Deere & Co	0.028411	0.029354	5.497167	-6.586570	0.792098	-0.294823	11.45101	7541.539

Source: Authors' calculations

In Table 1, a descriptive statistical analysis is presented, indicating that there are significant differences in the average values among the observed companies. The average values of the observed variables suggest that most companies, on average, recorded either negative or very slightly positive performance indicators during the observed period. As shown, Deere & Co is the only company among those analyzed that recorded a positive average value (0.0284), while on the other hand, Gobarto SA, KSG AGRO SA, and Agroliga Group PLC had negative average values. Additionally, Agroton Group showed a slightly positive average value (0.0073). Furthermore, the medians of the observed companies were all zero.

In addition, KSG AGRO SA had the highest standard deviation (2.36), which may suggest that returns for this company are unstable and highly volatile. Conversely, Deere & Co had the lowest standard deviation (0.79), indicating relatively stable business performance.

In terms of skewness, significant negative skewness was observed in KSG AGRO SA and Agroliga Group, which may indicate that negative values occurred more frequently and were more pronounced. However, Gobarto SA and Agroton Group exhibited slight positive skewness, while Deere & Co showed an almost symmetric distribution.

The high kurtosis values observed across all companies suggest the presence of "fat tails" and a greater frequency of extreme values compared to a normal distribution. The most extreme case is Agroliga Group PLC, which had a kurtosis value as high as 57.5, while other companies also displayed significantly elevated values.

To examine the impact of digitalization—and whether such an effect exists—a panel regression analysis was conducted using the Panel Least Squares method. This analysis included a sample of five companies observed over the period from 2014 to 2024. The conducted research is directly related to the agroindustrial sector, as all analyzed companies operate within agriculture or agroindustry, including agricultural production, agro-processing, and the development of agricultural machinery and technologies.

Therefore, the observed effects of digitalization on company performance should be interpreted within the specific characteristics of the agricultural sector, such as high capital intensity, seasonal production, and significant implementation costs. The obtained results are consistent with findings from similar international studies, which indicate that digitalization in agriculture may have a negative or limited impact on financial performance in the short term, primarily due to the costs of digital transformation, while remaining essential for long-term competitiveness and sustainability.

The following table presents the results of the panel regression analysis – OLS model (Table 2).

Table 2. Results of the Panel Regression Analysis – OLS Model

Variable	Coef	Std error	t-statistic	p-value
Const (C)	19,279.52	1,100.44	17.52	0.0000
DigiTech	-3,419.95	708.18	-4.83	0.0000
Indicator	**Value**			
R^2	0.0017			
Adjusted R^2	0.0016			
Std error of the Regression	80,835.83			
Number of Observations	13,818			
Number of Companies (cross-sections)	5			
Durbin-Watson Statistic	1,833			
F-Statistic	23.32			
p-value (F)	0.0000			

Source: Authors' calculations

The results of the regression analysis indicate that the level of digitalization exerts a negative and statistically significant impact on company returns**.** The estimated coefficient suggests that an increase in the degree of digitalization within a firm is associated with a decline in its return, with this effect being statistically significant at the 1% confidence level**.** This finding may be interpreted as evidence that investments in digital technologies, although potentially enhancing efficiency and competitiveness in the long run, often impose substantial costs in the short term.

In capital-intensive sectors such as agriculture, digitalization and automation frequently require considerable upfront investments and involve significant adjustment costs, which can adversely affect short-term financial performance (Acemoglu & Restrepo, 2020). The process of digital transformation typically entails the acquisition of new equipment and software, extensive employee training, and the restructuring of organizational processes, all of which may exert downward pressure on current firm performance.

Moreover, it is plausible that some firms intensify their digitalization efforts during periods of weak performance, implying that digital transformation may represent a strategic response to existing challenges rather than the primary cause of declining returns. Importantly, digitalization does not inherently guarantee positive financial outcomes; its effectiveness depends critically on the quality of implementation, organizational readiness, and the specific characteristics of the sector in which the firm operates. In this regard, the findings align with Bloom et al. (2012), who emphasize the central role of managerial quality and organizational capabilities in realizing the potential benefits of digital technologies.

Furthermore, the estimated Durbin–Watson statistic amounts to 1.833**,** indicating the absence of significant autocorrelation and confirming that the error terms in the model are independent. This result supports the overall validity and reliability of the regression estimates.

The observed negative short-term effect of digitalization on company returns is also consistent with the findings of Brynjolfsson & Hitt (2000), who argue that digital investments require complementary organizational changes and sufficient time before generating measurable financial gains.

Overall, the obtained results suggest the existence of a complex and potentially paradoxical relationship between digitalization and firm financial performance. While digital transformation is undeniably crucial for long-term growth and competitiveness, its immediate impact on returns may be negative due to the substantial costs of transformation and various implementation challenges. These findings underscore the need for further research incorporating a broader set of control variables, as well as explicitly accounting for time lags between digital investments and the realization of positive business outcomes. The results are also consistent with the study conducted by Chen et al. (2024).

Conclusion

The obtained results indicate the existence of a complex and potentially paradoxical relationship between digitalization and the financial performance of the observed companies. Although digitalization is recognized as a key factor in long-term development, competitiveness, and adaptation to modern market demands, the regression analysis results show that its immediate impact on company returns can be negative. This effect can be explained by the fact that the process of digital transformation involves significant investments in technology, employee training, and the reorganization of business processes, which in the short term may impose a burden on a company’s financial operations.

Furthermore, the results suggest the possibility that certain companies tend to invest more intensively in digitalization during periods of weaker business performance, meaning that digitalization acts not as a cause, but as a consequence of recovery efforts and adaptation to change. The success of digitalization does not depend solely on the level of investment, but also on the quality of implementation, the organization's readiness to embrace change, and sector-specific characteristics.

In addition, the results indicate that the model does not suffer from autocorrelation of residuals, as confirmed by the Durbin-Watson statistic of 1.833, which further supports the reliability of the conclusions. However, given the low explanatory power (R^2), the findings should be interpreted with caution, and it should be acknowledged that digitalization is not the only factor influencing company returns.

Therefore, it is recommended that future research include a broader set of control variables, such as company size, industry sector, investment in research and development, and stages of digital maturity. It is also advisable to analyze the time lag between investment in digitalization and the realization of positive financial effects. Such an approach would allow for a deeper understanding of the dynamics of digital transformation and its long-term impact on company performance.

This study is subject to several limitations. First, the analysis is based on a relatively small sample of publicly listed companies, which may limit the generalizability of the results to the broader agricultural sector, particularly to small and medium-sized farms and privately held firms. Second, the level of digitalization is measured using computer-assisted text analysis of annual reports, which may not fully capture the actual depth, quality, or effectiveness of digital technology implementation. Third, although the panel dataset includes a large number of observations due to the use of daily data, the model does not incorporate additional control variables such as firm size, market conditions, or macroeconomic factors, which could influence company returns. Finally, the analysis does not explicitly account for time lags between digital investments and their potential long-term financial effects, which should be addressed in future research.

Conflict of interests

The authors declare no conflict of interest.

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COMPETITIVENESS AND MARKET REORIENTATION IN MOLDOVA'S AGRI-FOOD EXPORTS TO THE EUROPEAN UNION

Liliana Cimpoies [1], Corina Stoianoglo[2]

**Corresponding author E-mail: lcimpoies@ase.md*

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ABSTRACT

This paper examines how Moldova's trade in agricultural and food products has changed between 2013 and 2024, against the background of closer economic integration with the European Union (EU). The analysis covers 24 agri-food product groups, including both agricultural commodities and processed foods, using official data from the National Bureau of Statistics and a set of standard trade competitiveness indicators. The results reveal uneven patterns of competitiveness across product groups. While sectors such as meat, fish, and dairy continue to face structural weaknesses, products like cereals, oilseeds, fats and oils, and beverages retain strong competitive positions and positive trade balances. Trade in processed food products shows a moderate but gradually increasing level of intra-industry exchange, suggesting slow and uneven upgrading. Research results underline a continuing transformation of Moldova's agri-food trade and highlight the importance of targeted policies to strengthen competitiveness, diversify exports, and support deeper integration into EU value chains in a context of increased global uncertainty.

Introduction

Competitiveness in the agri-food sector is no longer understood in terms of cost efficiency or static comparative advantage. Recent research presents competitiveness as a multidimensional concept shaped by structural transformation, policy frameworks, innovation capacity, and sustainability constraints. In integrated markets such as the European Union (EU), agri-food competitiveness depends not only on productivity growth and technological change, but also on institutional quality, research and development, and compliance with increasingly demanding environmental, sanitary,

1 Liliana Cimpoies, Associate Professor, Academy of Economic Studies of Moldova, 61 Banulescu-Bodoni Street, Chisinau, Republic of Moldova, Phone +373 79 295 721, E-mail: lcimpoies@ase.md, ORCID ID: (https://orcid.org/0000-0003-3709-9406)

2 Corina Stoianoglo, PhD Student, Academy of Economic Studies of Moldova, 61 Banulescu-Bodoni Street, Chisinau, Republic of Moldova, Phone +373 60 536 600, E-mail: corina.stoianoglo@gmail.com, ORCID ID: (https://orcid.org/0009-0006-8198-3855)

and quality standards (Bojnec & Fertő, 2018; Bojnec & Fertő, 2025). From this perspective, sustained competitiveness is closely linked to the ability of agri-food systems to upgrade along value chains rather than relying primarily on natural factor endowments or price-based advantages.

The drivers of competitiveness and structural change in European agri-food value chains are examined by various researchers (Bojnec & Fertő, 2018; Bojnec & Fertő, 2025; Ambroziak et al., 2024; Charlebois et al., 2025). Recent studies emphasize the role of resource efficiency, innovation, and sustainability performance in shaping competitive positions within EU agriculture and food industries (Charlebois et al., 2025; Rodino et al., 2025). Comparative analyses of food producers operating in the EU market further show that competitive pressure has intensified in recent years, particularly following market disruptions linked to geopolitical instability (Ambroziak et al., 2024; Régnier & Aubert, 2025). Ambroziak et al. (2024) find that intensified competition in the EU agri-food market increasingly favors quality differentiation and structural upgrading over price-based competitiveness.

At the same time, deeper market integration does not automatically result in upgrading (Zdráhal, 2025; Ambroziak et al., 2024; Pătărlăgeanu et al., 2025). Many countries remain concentrated in primary or semi-processed exports due to technological constraints, scale limitations, and insufficient investment capacity (Zdráhal, 2025; Régnier & Aubert, 2025). Empirical analyses based on revealed comparative advantage and intra-industry trade indicators further show that competitiveness gains tend to be selective and product-specific, with limited spillover effects across the agri-food sector (Ignjatijević et al., 2025; Pătărlăgeanu et al., 2025). Evidence from non-EU trade relationships further supports this conclusion. According to Zhelev (2024), even where comparative advantages exist, export diversification and value-added upgrading remain constrained by structural and institutional factors.

Within Central and Eastern European (CEE) countries, EU accession and deeper integration into the Single Market have triggered significant adjustments in agricultural production and trade flows. Evidence suggests that EU membership has generally supported productivity growth, export expansion, and a reorientation of agri-food trade toward EU markets, although outcomes vary considerably across countries and product groups (Marković et al., 2021; Bojnec & Fertő, 2025). In several cases, integration has facilitated a gradual shift toward higher-value agri-food exports, particularly in beverages, processed foods, and niche segments, while other parts of the sector remain characterized by low value added and persistent import dependence (Popović et al., 2025; Hamulczuk & Cherevyk, 2025). However, these benefits are frequently accompanied by increased exposure to international price volatility and external shocks, which may constrain long-term upgrading and deepen structural asymmetries within agri-food sectors (Grujić Vučkovski et al., 2025; El Bilali & Ben Hassen, 2024).

The literature on trade liberalization agreements, including Association Agreements and Deep and Comprehensive Free Trade Areas (DCFTAs), highlights their role in reshaping trade geography, institutional alignment, and market access conditions. While some studies point to adjustment costs, increased competitive pressure, and rising import dependence, empirical evidence generally confirms positive effects on export performance and market diversification in partner countries (Popović et al., 2025; Régnier & Aubert, 2025). These benefits, however, are frequently accompanied by heightened exposure to international price volatility and external shocks, which may amplify existing structural weaknesses and constrain long-term upgrading (Grujić Vučkovski et al., 2025; Hamulczuk & Cherevyk, 2025).

In the specific case of the Republic of Moldova, existing studies confirm that the EU–Moldova Association Agreement and the DCFTA have contributed to a reorientation of agri-food trade toward EU markets and improved competitiveness in selected product groups (Cimpoieș, 2021). Nevertheless, most prior analyses adopt static or short-term perspectives, offering limited insight into how competitiveness, specialization, and trade integration evolve across different phases of economic adjustment and external shocks. Recent regional research highlights persistent challenges related to technological upgrading, diversification, and deeper integration into EU agri-food value chains, particularly under conditions of increased volatility associated with the COVID-19 pandemic and regional geopolitical instability (Maśniak & Jędruchniewicz, 2024; El Bilali & Ben Hassen, 2024). Despite progress in market reorientation, Moldova's agri-food exports remain largely dominated by raw and semi-processed products, while value-added processing and intra-industry trade with the EU remain uneven.

Overall, there are both opportunities and limitations of trade liberalization and EU integration for agri-food competitiveness in small and transition economies. While improvements in market access and selective competitiveness gains are well documented, persistent structural constraints, uneven upgrading, and vulnerability to external shocks remain key challenges. These unresolved issues require an empirical analysis of Moldova's agri-food trade dynamics over time, particularly within the framework of DCFTA and EU candidate status while accounting for recent global disruptions.

The aim of this research is to analyze the evolution of Moldova's trade in agricultural and food commodities, with a focus on structural transformations and competitiveness shifts associated with the country's deepening economic integration with the European Union. The study examines trade dynamics across product groups and trading partners, considering the effects of trade liberalization and major external shocks over the period 2013–2024.

Based on the objectives of the study, the following hypotheses are tested:

- Moldova's agri-food exports have undergone a gradual structural transformation following the implementation of the DCFTA, reflected in a reorientation toward the European Union market.

- Moldova maintains a comparative advantage primarily in raw and semi-processed agricultural products, while competitiveness in processed food products has improved more slowly.
- The depth of Moldova's integration into EU agri-food value chains remains uneven, with higher levels of intra-industry trade concentrated in a limited number of processed food product groups.

Materials and methods

The methodological approach of this study combines quantitative analysis of trade indicators with comparative and structural evaluation techniques to assess Moldova's agri-food trade competitiveness and specialization between 2013 and 2024**.** The research relies primarily on secondary data obtained from National Bureau of Statistics of the Republic of Moldova, ensuring consistency and comparability across years and product categories. The analysis is conducted at the two-digit level of the Harmonized System (HS 01-24), which encompasses both agricultural commodities (HS 01-15) and processed food products (HS 16-24). To capture the multi-dimensional nature of trade competitiveness, three complementary analytical tools were applied:

- Revealed Trade Advantage (RTA) Index - integrates export and import performance to provide a more balanced measure of comparative advantage (Vollrath, 1991). The RTA was computed for each HS group annually, distinguishing between total trade and trade with EU countries, to observe competitiveness dynamics and structural shifts over time.
- Intra-Industry Trade (IIT) Index (Grubel-Lloyd, 1975) the intensity of intra-industry trade was calculated for each agri-food product group. This measure allows differentiation between vertical (quality-based) and horizontal (product variety-based) trade integration patterns and helps to identify structural upgrading tendencies in Moldova's agri-food sector.
- Product Mapping (RSCA-TBI Framework)-based on the Revealed Symmetric Comparative Advantage (RSCA) and Trade Balance Index (TBI) were combined to map product groups into four quadrants representing different competitiveness positions (Widodo, 2009):

  - *Group A:* Competitive net exports (RSCA > 0, TBI > 0)
  - *Group B:* Competitive imports (RSCA > 0, TBI < 0)
  - *Group C:* Non-competitive exports (RSCA < 0, TBI > 0)
  - *Group D:* Non-competitive imports (RSCA < 0, TBI < 0)

This mapping approach allows for visual comparison of product positioning and provides insight into structural asymmetries between agricultural raw materials and processed food exports. In this study, sustained positive RTA values and consistent placement in the competitive RSCA - TBI quadrants are interpreted as indicators of strong competitiveness, whereas marginal or highly volatile values are considered as indication of sensitive or transitional competitive positions.

The combined use of these indicators allows for a structured and comparative assessment of Moldova's agri-food trade beyond aggregate export shares and general market reorientation trends. While each indicator captures a distinct dimension of competitiveness, their joint application makes it possible to distinguish between persistent export specialization, structural import dependence, and emerging signs of product-level upgrading and integration with EU markets across individual HS groups. This integrated analytical framework supports a differentiated interpretation of competitiveness dynamics across agri-food product groups and facilitates the identification of sectors with stable advantages, transitional characteristics, or structural vulnerabilities.

Data analysis was conducted using Microsoft Excel. The chosen period (2013 - 2024) captures key period influencing Moldova's trade dynamics. During 2014 - 2016, the implementation of the DCFTA agreement with the EU marked a key phase of trade liberalization; 2020 - 2021 trade flows were disrupted by COVID-19 pandemic followed by a recovery period; while 2022 - 2024 are characterized by regional instability due to the war in Ukraine which imposed several shocks and price volatility.

Results and discussions

Trade liberalization and structural changes have significantly influenced Moldova's integration into international markets. The agri-food sector has remained a key source of external stability, consistently generating a positive trade balance, while the overall trade balance has remained negative due to high import dependence on energy and gas resources. Between 2013 and 2024, agri-food exports maintained a relatively stable share in total exports, with only limited fluctuations. (Table 1).

This pattern indicates that, although agri-food products remain central to Moldova's exports, other sectors, as manufacturing and services are slowly gaining importance. At the same time, trade in both agricultural and non-agricultural goods has expanded, reflecting deeper integration into regional and global value chains and a gradual shift toward a more diversified trade structure.

Table 1. Moldova's trade dynamics, 2013-2024

Year	Total Exports (USD thousand)	Total Imports (USD thousand)	Agri-food Exports (USD thousand)	Agri-food Imports (USD thousand)	Agri-food Exports (% of total exports)	Agri-food Imports (% of total imports)
2013	2,428,303.0	5,492,393.1	1,015,545.5	783,795.6	41.8	14.3
2014	2,339,529.6	5,316,958.9	1,065,351.0	719,325.6	45.5	13.5
2015	1,966,837.2	3,986,820.3	914,488.7	586,576.3	46.5	14.7

Year	Total Exports (USD thousand)	Total Imports (USD thousand)	Agri-food Exports (USD thousand)	Agri-food Imports (USD thousand)	Agri-food Exports (% of total exports)	Agri-food Imports (% of total imports)
2016	2,044,538.6	4,020,356.9	945,477.8	608,048.5	46.2	15.1
2017	2,424,972.0	4,831,335.3	1,130,872.5	705,206.9	46.6	14.6
2018	2,706,173.3	5,760,057.1	1,167,316.7	774,312.4	43.1	13.4
2019	2,779,164.4	5,842,484.3	1,211,141.3	815,899.1	43.6	14.0
2020	2,467,106.1	5,415,988.3	1,087,847.2	846,073.2	44.1	15.6
2021	3,144,504.5	9,218,978.7	1,435,973.5	1,010,286.6	45.6	11.0
2022	4,332,145.1	9,218,978.8	1,936,222.9	1,289,311.9	44.7	14.0
2023	4,048,604.9	9,065,184.7	1,730,929.5	1,281,138.8	42.7	14.1
2024	3,555,061.7	9,065,184.7	1,624,289.9	1,464,520.6	45.7	16.2

Source: based on data from National Bureau of Statistics

Following the entry into force of the EU - Moldova Association Agreement and the DCFTA in 2014, Moldova's integration into the European economy accelerated markedly. These institutional changes facilitated the alignment of quality and safety standards, improved access to the EU market, and supported export-oriented investment in the agri-food sector. As a result, the European Union has become Moldova's main trading partner, absorbing more than half of agri-food exports in recent years. In parallel, the value of agri-food exports increased from about USD 1.07 billion in 2014 to nearly USD 1.94 billion in 2022, before moderating to USD 1.62 billion in 2024, reflecting both structural changes and recent market volatility (Table 1).

Over the same period, the agri-food sector consistently accounted for a substantial share of total exports, fluctuating within a relatively narrow range between 42.7% and 46.6%. This stability indicates that, despite the expansion of other export sectors, agri-food products remain a core component of Moldova's export structure. At the same time, agri-food imports also increased, particularly after 2020, reaching USD 1.46 billion in 2024 and raising their share in total imports to 16.2%, which points to continued dependence on external suppliers of processed and higher value-added food products.

The evolution of Moldova's agri-food trade between 2013 and 2024 reflects not only quantitative expansion but also a fundamental reorientation of export and import geography. Recent trends are also influenced by increased volatility in global agricultural markets in the later years of the period. Changes in export values over the period analyzed reflect the combined effects of volume dynamics and price movements, particularly during periods of increased commodity price volatility. In recent years, international price fluctuations, especially for cereals, oilseeds, and energy-intensive processed products, have amplified trade values without necessarily implying proportional changes in physical export volumes or underlying competitiveness.

Accordingly, the analysis of competitiveness in the later years focuses on relative positions and structural patterns across product groups, rather than on short-term fluctuations in trade values. However, the implementation of the DCFTA and Moldova's gradual alignment with EU trade and quality standards supported a clear reorientation of trade flows away from traditional eastern markets toward the European Union and other global destinations (Table 2).

Table 2: Geographical distribution of agri-food trade flows, 2013-2024, USD thousand

		2013	2014	2017	2019	2021	2023	2024
exports	EU countries	379,516.1	441,327.2	649,508.7	592,329.7	649,123.8	1,194,837.9	1,047,709.7
	C.I.S. countries	396,538.9	185,894.8	89,115.1	94,216.8	89,159.6	244,513.7	148,041.3
	Other countries	239,490.5	192,533.9	278,457.5	287,711.1	318,992.8	291,577.7	428,538.9
imports	EU countries	267,766.1	270,790.7	303,170.7	357,197.6	451,011.2	601,023.6	672,334.7
	C.I.S. countries	339,730.8	283,720.2	275,583.8	300,129.1	348,227.1	407,779.2	110,476.6
	Other countries	176,298.7	164,814.7	126,452.2	158,572.3	211,048.3	272,335.9	681,709.2

Source: authors calculations based on data from National Bureau of Statistics

The data on Moldova's agri-food trade between 2013 and 2024 reveals a profound structural transformation in the country's trade geography (Table 2). Over the twelve-year period, Moldova's agricultural exports have shifted decisively toward the European Union (EU), reflecting the country's growing economic integration with European markets and the effects of the EU-Moldova Deep and Comprehensive Free Trade Area (DCFTA) established in 2014. In contrast, exports to the Commonwealth of Independent States (CIS) have dramatically decreased, highlighting a lasting reorientation away from traditional eastern partners. Meanwhile, trade with countries outside both the EU and CIS - grouped as "others" - has expanded steadily, particularly after 2020, suggesting successful diversification toward new global markets.

In 2013, Moldova's agri-food exports were almost evenly split between the EU and CIS, with the CIS slightly ahead (USD 396.5 million versus USD 379.5 million). However, the geopolitical and economic shocks following 2014, including the Russian trade embargo and the implementation of the DCFTA, led to a sharp collapse in exports to the CIS. By 2016, exports to the CIS had fallen by nearly 80%, while those to the EU had increased by more than 40%. This westward reorientation accelerated in subsequent years, and by 2021, exports to the EU exceeded USD 649 million - nearly four times higher than those to the CIS. The peak came in 2022-2023, when exports to the EU reached over USD 1.15 billion, reflecting favorable prices and improved access to the European market (Table 2). Although 2024 registered a moderate decline (-12%), the EU remains Moldova's dominant export destination, accounting for most of the agricultural trade.

At the same time, the “other countries” category has become an increasingly important component of Moldova’s export portfolio. Exports to these markets increased from USD 239 million in 2013 to more than USD 428 million in 2024, showing consistent growth despite global disruptions such as the COVID-19 pandemic and regional instability. This trend likely reflects Moldova’s strategic outreach to Middle Eastern and Asian markets for products like cereals, wine, and vegetable oils, helping the country mitigate risks associated with overdependence on a single region.

On the import side, trade patterns reveal a clear geographical reorientation over the period under review. Imports originating from European Union member states expanded continuously, increasing from USD 267.8 million in 2013 to USD 672.3 million in 2024, which corresponds to more than a two-and-a-half-fold increase (Table 2). This evolution points to Moldova’s progressive integration into European agri-food markets and value chains, alongside a growing demand for EU-sourced food products, agricultural inputs, and related technologies.

By contrast, imports from CIS countries declined sharply over the same period. From a level of USD 339.7 million in 2013, they fell to approximately USD 110.5 million in 2024, reflecting a substantial contraction of trade relations with traditional partners such as Russia and Ukraine (Table 2). This downward trend can be associated with geopolitical tensions, trade disruptions, and Moldova’s strategic shift away from its historical dependence on eastern suppliers.

At the same time, imports from other countries gained importance, particularly after 2020. Their value increased markedly, reaching USD 681.7 million in 2024. This development suggests a deliberate diversification of import sources beyond the EU and CIS regions, likely driven by the need to mitigate supply risks and adapt to global market volatility and regional instability.

Beyond this territorial reorientation, Moldova’s agri-food trade has also undergone important structural transformations in terms of product composition. These changes reflect both the country’s natural resource endowment and the relatively gradual pace of its integration into global value chains. The structure of agri-food exports and imports highlights Moldova’s existing comparative advantages, as well as its continued reliance on external markets for certain categories of agricultural and food products.

Moldova’s agri-food trade structure reveals a clear imbalance between export specialization and limited domestic value-added capacity (Table 3). Exports are concentrated in a small number of product groups - mainly oilseeds, cereals, fruits and nuts, fats and oils, beverages, and processed fruit and vegetable products - reflecting strong advantages in primary production but also greater exposure to price, climate, and policy risks. The dominance of raw and minimally processed exports indicates that the sector remains largely resource-based, with limited technological upgrading.

By contrast, imports are more diversified and largely oriented toward processed and final consumption goods, including dairy products, beverages, and miscellaneous food preparations (Table 3). This contrast highlights persistent structural constraints and points to the need for greater investment in processing, innovation, and product diversification to retain more value within the domestic agri-food sector.

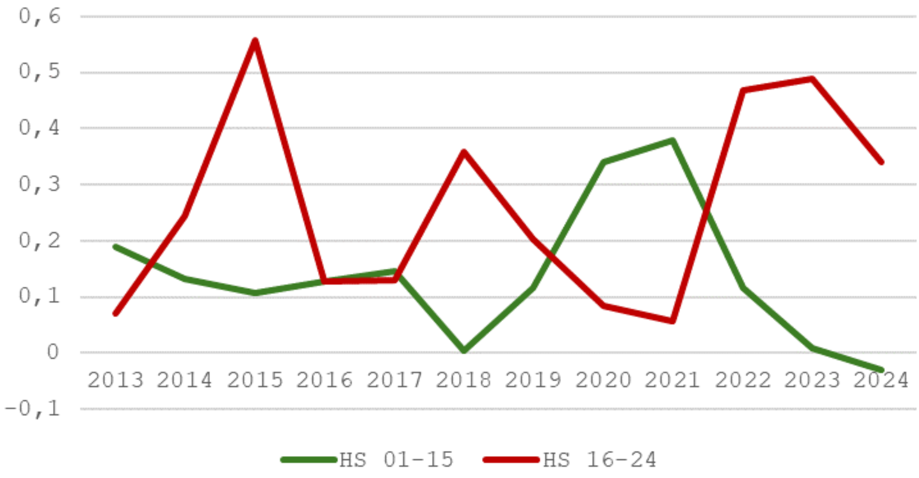
Table 3. Agri-food trade structure by commodities, 2013-2024

HS	Exports, USD thousand	Share, %	Imports USD thousand	Share, %	HS	Exports, USD thousand	Share, %	Imports USD thousand	Share, %
01 Live animals	0.1	0.0	7,951.1	2.0	13 Lac; gums, resins	17.9	0.00	826.4	0.2
02 Meat	96.5	0.01	26,046.9	6.7	14 Vegetable plaiting materials	414.0	0.06	13.7	0.00
03 Fish and crustaceans	41.5	0.01	14,333.3	3.7	15 Animal or vegetable fats and oils	98,736.5	14.2	7,321.6	1.89
04 Dairy produce	8,975.5	1.29	39,010.9	10.1	16 Preparations of meat or fish	57.7	0.01	10,316.7	2.6
05 Products of animal origin	110.2	0.02	5,809.5	1.5	17 Sugars	15,274.2	2.2	8,669.9	2.2
06 Live trees and other plants	236.6	0.03	14,516.5	3.7	18 Cocoa	4,733.8	0.68	11,560.4	2.9
07 Edible vegetables	2,597.7	0.37	17,637.1	4.5	19 Preparations of cereals	14,398.1	2.07	22,723.7	5.86
08 Edible fruit and nuts	105,163.4	15.1	20,800.1	5.3	20 Preparations of vegetables, fruit, nuts	51,528.2	7.4	16,114.1	4.16
09 Coffee, tea, mate and spices	1,010.5	0.15	8,799.8	2.2	21 Miscellaneous edible preparations	3,078.5	0.44	32,985.6	8.5
10 Cereals	131,632.2	18.9	15,864.6	4.09	22 Beverages, spirits and vinegar	67,342.4	9.6	33,013.2	8.5
11 Products of the milling industry	2,621.2	0.38	5,931.4	1.5	23 Residues and waste from the food industry	11,149.2	1.6	27,198.8	7.02
12 Oil seeds and oleaginous fruits	174,301.8	25.1	27,048.8	6.9	24 Tobacco	1,236.8	0.18	13,128.5	3.39

To complement the structural and geographical perspectives of Moldova's agri-food trade, the assessment of revealed trade advantage (RTA) offers insight into the country's export competitiveness at the product group level (Figure 1).

For agricultural commodities (HS 01-15), Moldova exhibited a consistent positive trade advantage throughout most of the analyzed period, with RTA values fluctuating between 0.10 and 0.38, except for slight downturns in 2018 and 2024, when the index approached zero or negative territory (-0.03 in 2024). This trend confirms Moldova's long-standing specialization and comparative strength in primary agricultural production. The improvement in RTA in 2020-2021 (rising from 0.11 to 0.38) coincides with strong export performance in oilseeds and cereals, boosted by favorable harvests and high global commodity prices (Figure 1). The modest decline in 2023-2024 suggests that while Moldova remains competitive in bulk agricultural exports, this advantage is somewhat sensitive to external price shifts, production variability, and input cost pressures.

Figure 1. Evolution of Moldova's Revealed Trade Advantage (RTA) index for agricultural and food products, 2013-2024.



Source: authors calculations based on data from National Bureau of Statistics

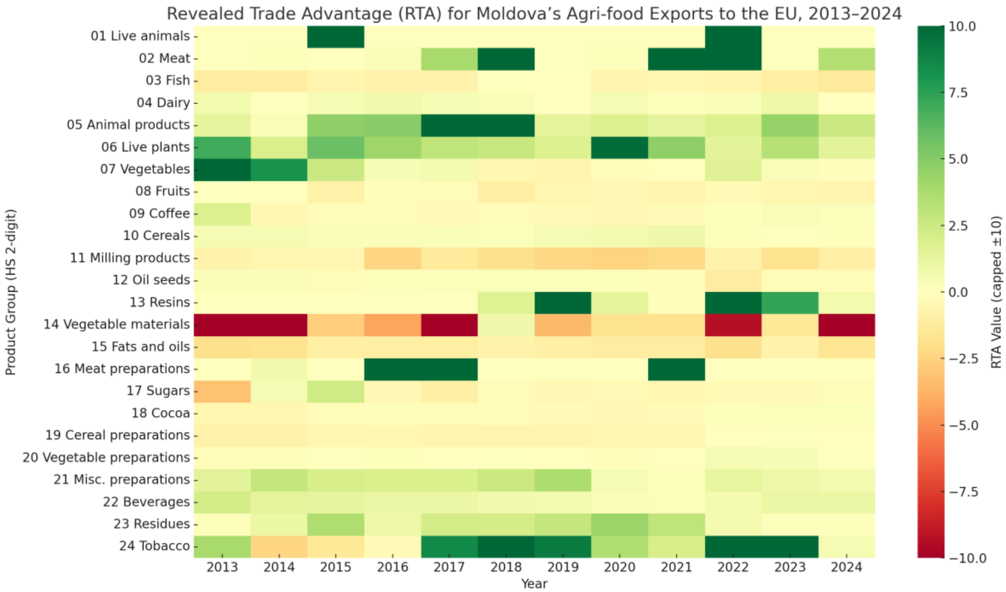
In contrast, the processed food products group (HS 16-24) demonstrates a more dynamic and upward trend in competitiveness. The RTA index rose from 0.07 in 2013 to around 0.34 in 2024, peaking at 0.56 in 2015 and again at 0.49 in 2023 (Figure 1). These results indicate that Moldova's comparative advantage in value-added food processing has strengthened over the past decade, supported by the expansion of wine, beverage, and preserved fruit exports, as well as growing access to European markets through the EU Association Agreement. Despite some year-to-year volatility, the persistence of positive RTA values confirms that the country has gradually improved its export performance beyond primary agriculture.

The RTA analysis for Moldova's agri-food trade with the European Union reveals distinct patterns of competitiveness and specialization between 2013 and 2024. Moldova has maintained a relatively narrow but persistent set of comparative advantages, with signs of gradual transition from raw agricultural exports toward more processed, value-added agri -food products (Figure 2).

Moldova's natural resource base and the expansion of horticulture are reflected in sustained comparative advantages for live plants, selected animal products, and edible vegetables (HS 05–07). Strong RTA values in these categories between 2016 and 2021 coincide with favorable weather conditions, growing EU demand and gradual improvements in compliance with European quality standards. By contrast, traditional bulk products such as oilseeds and cereals show more volatile and generally weaker RTA performance, reflecting intense price competition and limited progress toward higher value-added activities (Figure 2).

Among processed food products, only a few categories show a clear improvement in competitiveness (Figure 2). Beverages, miscellaneous edible preparations, and animal feed register positive RTA values, suggesting selective integration into European agri-food value chains. In contrast, the unusually high RTA levels for tobacco products are likely driven by re-export or contract processing arrangements rather than by strong domestic competitiveness.

Figure 2. Revealed Trade Advantage (RTA) for Moldova's Agri-food Exports to the EU, 2013-2024



Source: authors calculations

The impact of important external factors on trade performance is also reflected in the evolution of RTA values. Between 2014 and 2016, Moldova's agri-food exports experienced a first adaptation to Deep and Comprehensive Free Trade Area (DCFTA) framework, which expedited structural reorientation away from traditional CIS partners and redefined market access conditions. COVID-19 problems during the 2020–2021 period initially limited demand and logistics, but they were followed by a significant export recovery, particularly in higher-value food products. Finally, between 2022 and 2024, the war in Ukraine and related logistical challenges reshaped Moldova's trade routes and pricing environment, producing greater volatility in RTA values-particularly for cereals, oilseeds, and energy-dependent processed goods.

While the RTA results reveal Moldova's product-level export competitiveness and specialization patterns within the EU market, they do not assess the degree of structural integration between exports and imports. To complement this perspective, the Grubel-Lloyd index is employed to assess the intensity of intra-industry trade and the extent to which Moldova's agri-food exchanges with the EU reflect vertical specialization or diversification within the same product categories. Comparing the two indicators allows for a more comprehensive understanding of Moldova's trade position-where high RTA values signal strong export advantages, but low Grubel-Lloyd scores may indicate a continued reliance on inter-industry trade in primary goods rather than balanced participation in integrated agri-food value chains.

The results of the Grubel-Lloyd index presented in Table 4 provide complementary evidence to the RTA analysis by assessing the degree of intra-industry trade (IIT) within Moldova's agri-food sector. Overall, the findings indicate that Moldova's trade remains predominantly inter-industry in nature, though a gradual increase in product overlap-particularly with EU partners-suggests a slow integration into more complex agri-food value chains.

Table 4: Intra-industry trade level for agri-food commodities, %

HS	All trading partners	EU countries	HS	All trading partners	EU countries
1	78.20	0.00	**13**	10.74	2.29
2	37.56	0.33	**14**	48.53	20.65
3	0.16	0.52	**15**	50.31	16.66
4	46.71	42.31	**16**	1.60	0.41
5	14.11	3.24	**17**	71.10	70.14
6	17.73	3.53	**18**	44.40	60.94
7	33.88	26.79	**19**	51.42	82.21
8	51.12	33.47	**20**	54.93	47.94
9	13.83	22.15	**21**	23.97	14.49
10	20.72	25.29	**22**	47.57	65.39
11	20.09	48.15	**23**	78.54	43.07
12	33.91	28.36	**24**	37.45	25.54

Source: authors calculations based on data from National Bureau of Statistics

At the aggregate level, IIT values are considerably higher for all trading partners than for EU trade alone, reflecting Moldova's continued engagement in two-way exchanges with traditional non-EU markets, where product differentiation is less pronounced. However, several categories reveal notable EU-linked integration. High intra-industry trade shares are observed for dairy products (HS 04, 42.31%), milling products (HS 11, 48.15%), cocoa-based goods (HS 18, 60.94%), processed cereal foods (HS 19, 82.21%), and beverages (HS 22, 65.39%) - all of which correspond to processed food industries that also exhibit positive RTA values (Table 4). While the Grubel–Lloyd index does not allow for a direct empirical separation between vertical and horizontal intra-industry trade, the observed increase in two-way trade for selected processed food categories suggests a gradual move toward more differentiated trade structures.

Overall, the evidence indicates selective upgrading and closer EU market integration, rather than broad structural transformation of the agri-food sector.

By contrast, primary agricultural commodities such as live animals (HS 01), fish (HS 03), and oilseeds (HS 12) show low or near-zero intra-industry trade with the EU, reinforcing the pattern of unidirectional exports and limited reciprocal flows of similar products (Table 4). These findings complement the RTA results by illustrating that while Moldova has achieved comparative advantage in several agri-food sectors, the depth of integration into EU supply chains remains concentrated in a few high-value product groups.

Taken together, the RTA and Grubel-Lloyd analyses reveal a dual structure in Moldova's agri-food trade: strong specialization in raw agricultural exports alongside emerging, though still limited, intra-industry exchanges in processed food segments. Further the RSCA-TBI mapping approach (Widodo, 2009) was applied to characterize the structural positioning and to identify the balance between export specialization and net trade performance across agri-food product groups.

The mapping approach identified two significant trends in Moldova's agri-food trade system (Table 5). The Group A quadrant contains Moldova's main exports, which combined account for about 90% of the country's total agri-food exports (RSCA > 0; TBI > 0). These consist of processed fruits and vegetables (HS 20), oilseeds (HS 12), fats and oils (HS 15), cereals (HS 10), edible fruits and nuts (HS 08), and beverages (HS 22). These industries' strong export orientation and continued competitiveness are demonstrated by their positive comparative advantage and trade balance. Their emphasis also aligns with previous RTA findings that emphasized Moldova's advantages in primary and semi-processed agricultural goods. Only sugar (HS 17), which has a positive TBI but a negative RSCA, is included in Group C.

However, Group D is dominated by structurally weak or import-dependent industries (RSCA < 0; TBI < 0). Meat and meat products (HS 02, HS 16), dairy products (HS 04), prepared foods (HS 19, HS 21), and animal feed (HS 23) are among the categories that lack the ability to produce or process commodities on a competitive scale, despite their rising domestic demand (Table 5). Significantly, a few high-import categories, including dairy (HS 04) and other food preparation products (HS 21), have substantial import shares (above 8–10%) in the EU trade structure, reflecting Moldova's dependence on imports for basic materials and processed foods. The Group B and Group D positions, characterized by a mismatch between comparative advantage and trade balance, illustrate transitional or vulnerable sectors (Table 5). For instance, live plants (HS 14) and residues (HS 23) demonstrate competitive potential but a mixed trade orientation, suggesting opportunities for value chain upgrading through processing or diversification.

The persistence of key product groups in the same RSCA–TBI quadrants over multiple years indicates that Moldova's agri-food competitiveness is largely structural rather than transitory, reflecting stable specialization patterns rather than short-term trade fluctuations.

Table 5: Product Mapping - Moldova's agricultural trade commodity structure with EU (exports and imports, USD thousand)

RSCA>0	**Group B:**					**Group A:**				
	HS	Exports, USD thousand	Share in export, %	Imports, USD thousand	Share in imports, %	**HS**	Exports, USD thousand	Share in export, %	Imports, USD thousand	Share in imports, %
						08	105,163.3	15.14	20,800.1	5.37
						10	131,632.2	18.95	15,864.6	4.09
						12	174,301.8	25.09	27,048.8	6.98
						14	414.01	0.06	13.7	0.00
						15	98,736.5	14.21	7.321.6	1.89
						20	51,528.3	7.42	16,114.04	4.16
						22	67,342.4	9.69	33,013.2	8.52
RSCA<0	**Group D:**					**Group C:**				
	HS	Exports, USD thousand	Share in export, %	Imports, USD thousand	Share in imports, %	**HS**	Exports, USD thousand	Share in export, %	Imports, USD thousand	Share in imports, %
	01	0.135	0.00	7,951.1	2.05	**17**	15,274.2	2.20	8,669.9	2.24
	02	96.46	0.01	26,046.9	6.72					
	03	41.51	0.01	14,333.4	3.70					
	04	8,975.4	1.29	39,010.9	10.06					
	05	110.22	0.02	5,809.5	1.50					
	06	236.63	0.03	14,516.5	3.75					
	07	2,597.72	0.37	17,637.1	4.55					
	09	1,010.4	0.15	8,799.8	2.27					
	11	2,621.2	0.38	5,931.3	1.53					
	13	17.9	0.00	826.4	0.21					
	16	57.7	0.01	10,316.7	2.66					
	18	4,733.8	0.68	11,560.4	2.98					
	19	14,398.2	2.07	22,723.7	5.86					
	21	3,078.5	0.44	32,985.6	8.51					
	23	11,149.2	1.60	27,198.8	7.02					
	24	1,236.8	0.18	13,128.4	3.39					
	TBI <0					**TBI>0**				

Source: authors calculations based on data from National Bureau of Statistics

Taken together, the RSCA-TBI mapping confirms that Moldova's agricultural trade with the EU remains concentrated in a few high-performing export sectors, primarily raw and semi-processed goods, while import dependence persists in high-value food segments. These structural asymmetries underline the importance of shifting from comparative to competitive advantage, as integration into EU agri-food value chains remains limited and uneven, requiring stronger processing capacity, product differentiation, and technological upgrading in most sectors.

Conclusions

This study examined the evolution of Moldova's agri-food trade over the period 2013–2024, with a focus on competitiveness, structural change, and market reorientation in the context of deeper integration with the European Union. The results confirm that the implementation of the DCFTA marked a clear turning point, accelerating the redirection of agri-food exports toward the EU and reducing Moldova's dependence on traditional eastern markets.

The analysis shows that Moldova's agri-food exports remain concentrated in a limited number of product groups, particularly oilseeds, cereals, fruits and nuts, fats and oils, beverages, and selected processed foods. While these sectors benefit from strong comparative advantages, the overall export structure continues to be dominated by raw and semi-processed products. Competitiveness in processed food products has improved only selectively, and integration into EU agri-food value chains remains uneven, as reflected by moderate levels of intra-industry trade concentrated in a small number of categories.

These findings point to persistent structural constraints, but also to clear opportunities. The agri-food sector continues to play a key role in Moldova's external competitiveness, while also offering a pathway for gradual modernization. However, sustaining competitiveness will require greater investment in processing capacity, innovation, and product diversification, in order to retain more value domestically and reduce vulnerability to external shocks.

The results should be interpreted as indicators of structural trade positioning rather than short-term performance, especially given the high price volatility observed in recent years. Overall, the study provides a comprehensive overview of Moldova's evolving agri-food trade structure and offers relevant insights for policymakers seeking to support targeted upgrading and deeper integration into European markets. Future research could extend this analysis by exploring firm-level dynamics, product quality differentiation, or the role of sustainability standards in shaping agri-food competitiveness.

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Conflict of interests

The authors declare no conflict of interest.

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INFERENCES BETWEEN SMART FARMING AND SUSTAINABLE DEVELOPMENT OF AGRICULTURE

Raluca Andreea Ion[1], Georgiana Raluca Ladaru[2], Mirela Stoian[3], Ionut Laurentiu Petre [4], George Cristian Popescu[5]

**Corresponding author E-mail: laurentiu.petre@eam.ase.ro*

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A B S T R A C T

Agriculture faces significant challenges related to global population growth, climate change and pressure on natural resources. In this paper, the positive impact of integrating digitalization into farming practices to promote sustainability and efficiency in the agricultural sector is explored. The research aims to highlight the importance of smart farming in the sustainable development of agriculture. This analysis will be carried out at the level of scientific studies conducted according to the Scopus database. The main results show that the interest in exploring IoT and digitalization in agriculture has increased in the last ten years, mostly because adopting sustainable practices and regenerative technologies minimizes the environmental impact and promotes biodiversity. The findings add knowledge to the literature and contribute to a better understanding of the benefits of implementing digitalization in agriculture; as such, farmers make more informed decisions about fertilization, irrigation, and crop protection, while reducing resource use and environmental impact.

1 Raluca Andreea ION, PhD, Full Professor, Bucharest University of Economic Studies, 6 Piata Romana, Bucharest, Romania, Phone: +40213191900, E-mail: raluca.ion@eam.ase.ro, ORCID ID (https://orcid.org/0009-0000-0469-8934)

2 Georgiana Raluca LADARU, PhD, Full Professor, Bucharest University of Economic Studies, 6 Piata Romana, Bucharest, Romania, Phone: +40213191900, E-mail: raluca.ladaru@eam.ase.ro, ORCID ID (https://orcid.org/0000-0003-2124-7590)

3 Mirela STOIAN, PhD, Full Professor, Bucharest University of Economic Studies, No.6 Piata Romana, Bucharest, Romania, Phone: +40213191900, E-mail: mirela.stoian@eam.ase.ro, ORCID ID (https://orcid.org/0000-0001-6251-5577)

4 Ionut Laurentiu PETRE, PhD, Lecturer, Bucharest University of Economic Studies, No.6 Piata Romana, Bucharest, Romania, Phone: +40213191900, E-mail: laurentiu.petre@eam.ase.ro, ORCID ID (https://orcid.org/0000-0002-2360-6844)

5 George Cristian POPESCU, Senior Lecturer, University of Bucharest, 36-46, M. Kogălniceanu, Bucharest, Romania, Phone: +40213059730, E-mail: cristian.popescu@faa.unibuc.ro, ORCID ID (https://orcid.org/0000-0002-1995-1469)

Introduction

Sustainable development has been a ubiquitous topic since the Brundtland Report promoted the concept in 1987. Each country has adapted to the 2030 Agenda, the strategy approved by the United Nations since 2015 (UN, 2015). This sets goals for 2020 and targets for 2030, all encompassed in the 17 Sustainable Development Goals (Jeronen, 2020; Andrei et al, 2023). Among them, agriculture is also targeted.

Agriculture can become a significant source of pollution if appropriate practices and technologies are not adopted to manage environmental impacts (Conway and Pretty, 2013). The main ways in which agriculture can contribute to pollution include water pollution, soil erosion, green-house gas emissions, agricultural waste, and biodiversity loss (Evans et al., 2019; Adegbeye et al., 2020; Singh et al., 2021). To reduce the negative environmental impact of agriculture and promote its sustainable development, durable agricultural practices such as organic farming, efficient water management and promotion of crop diversity must be adopted. Investment in research and innovative agriculture can also contribute to the development of more efficient and environmentally friendly solutions (Streimikis and Baležentis, 2020).

Agriculture and sustainable development are two interlinked concepts that are key to ensuring future global stability and prosperity. Agricultural sustainability involves practices and policies designed to meet the needs of the present without compromising the ability of future generations to meet their own needs (Nhemachena et al., 2018; Avakumović & Avakumović, 2025). Given the level of development that agriculture has reached in countries with a tradition in this sector, a final proposal on managing and minimizing the use of resources to achieve sustainable development refers to technological innovation, i.e. the use of modern technologies in agriculture, such as precision farming, the insertion of IoT in this sector and automation (Molina-Maturano et al., 2020).

Therefore, these considerations led to achieving the purpose of the present research, namely, to conduct both a literature review on smart agriculture, IoT, linking agriculture to sustainable development and a bibliometric analysis. The objective of this study is to highlight trends in international research on these topics and the significant impact of technology on agriculture. Finally, the results of the literature review and the bibliometric analysis are compared, and the overlaps are explored.

The hypothesis of the research starts from the assumption that technologies, such as precision farming, the use of drones and sensors, play a significant role in the sustainable development of agriculture, and this will result from both the literature review and the bibliometric analysis. The research hypothesis is based on previous studies showing that the use of modern technology and agricultural innovations can increase efficiency while reducing the environmental impact (Adenle et al., 2020).

The paper is structured as follows: after the introduction, the literature is reviewed, showing the progress in research on the topics of IoT, digitalization and smart farming.

The third part presents the methodology, and the fourth one presents the results using different criteria for analyzing the progress in literature: co-occurrence, link strength, country, year, type of paper, and language of origin of the manuscript. Then, the results of the inference between IoT, digitalization in agriculture, and smart farming are discussed in relations to their impact on sustainable agriculture, considering the three pillars of sustainability – economic, social and environmental. Finally, conclusions are drawn.

Literature Review

By adopting certain principles and promoting a balance between economic, social and environmental needs, agriculture can become a driver of sustainable development, while helping to protect the environment and ensure a sustainable future for generations to come (Bastan et al., 2017). This statement is sustained by several drivers and principles, explored in the following.

According to the literature, a first principle is considered the conservation of natural resources. Sustainable agriculture focuses on protecting soil, water and biodiversity. The use of farming practices such as conservation agriculture, crop rotation and organic farming helps maintain soil fertility, water quality and natural habitats (Kilcher, 2007; Rusu et al., 2015).

Attention should also be drawn to resource efficiency. Sustainable development involves the efficient use of available resources, such as water and energy, to maximize agricultural yields without having a negative impact on the environment (Kumar et al., 2020).

The literature also refers to climate change recovery. Agricultural practices such as regenerative agriculture, efficient management of agricultural waste and the use of renewable energy contribute to reducing greenhouse gas emissions and storing carbon in the soil (Shahzad et al., 2021).

Other key aspects of the relationship between agriculture and sustainable development include the promotion of food security, i.e. the involvement of small producers and local agriculture to ensure equitable access to food; and community engagement and education, which refers to educating farmers and consumers with the help of local communities about sustainable agricultural practices (Viana et al., 2022; Getman, 2025; Francis et al., 2017).

Moreover, new innovative technologies can also support food safety, i.e. the development of blockchain technology in supply chains. It can be used to ensure traceability and transparency in agricultural supply chains, tracking the origin and production process of food from farm to fork. This helps prevent food fraud and promotes sustainable farming practices (Chandan et al, 2023).

However, in the current context of technological development in agriculture and the need to go beyond the current level of sustainable development indicators, by far the most important key element in the relationship outlined above is that of technological innovation. According to the literature, there are several ways to implement innovative technologies in agriculture to improve challenges related to productivity (either labor or yield), efficiency and sustainability. The most common form is precision agriculture. This involves the use of technologies such as GPS navigation systems, drones, and sensors to collect and analyze precise data on soil, crop and weather conditions. This information allows farmers to make more informed decisions about fertilization, irrigation, and crop protection, while reducing resource use and environmental impact (Odara et al., 2015).

Agricultural biotechnology is more present at the global level, given that it is subject to limits and restrictions at the European level. Agricultural biotechnology includes techniques such as genetic modification and genome editing to improve plant quality and increase resistance to pests, diseases, and adverse climatic conditions. These innovations can increase crop yields and reduce reliance on pesticides and fertilizers (Moshelion and Altman, 2015).

The implications of smart irrigation systems are also included in the research. Their use refers to the application of sensors and automated control technologies to optimize the utilization of water in agriculture. At the same time, these systems monitor soil moisture and weather conditions to deliver precise amounts of water at the right time, leading to a reduction in water wastage (Obaideen et al., 2022).

Regarding the restrictions on the limitation of cultivated areas, in conjunction with global population growth, the concept of vertical agriculture and urban horticulture is also found in the literature. Modern technology allows plants to be grown in vertical systems and in confined urban spaces using artificial lighting, automatic irrigation systems and climate control. These systems can make food production more efficient and sustainable, while reducing transport distances and associated emissions (Chatterjee et al., 2020).

Another pervasive theme in research is robotics and automation. This topic is increasingly being addressed, given the situation facing rural areas today (at least in Europe), regarding depopulation of these areas and a shrinking workforce. The use of robots and automation in agriculture can reduce the reliance on human labor and improve the efficiency of agricultural operations. For example, robots can be used for crop harvesting, precision weeding or plant health monitoring (Yuan et al, 2023).

Thus, the main directions of research exploring the complex relationships between smart farming and sustainable agriculture are: conservation of natural resources, resource efficiency, climate change, food security and safety, vertical and urban agriculture, technological innovation, agriculture biotechnology, smart irrigation systems, robotics and automation.

Materials and methods

To confirm the directions of research present in the literature, exploring the relationships between smart farming and sustainable development of agriculture, a detailed bibliometric analysis is carried out. Bibliometric analysis is an essential tool in scientific research, used to assess the impact and evolution of a particular field of study (Donthu et al., 2021).

Research objectives and rationale

Having in mind that one of the main objectives of the research is to identify the positive impact of the emerging technologies on sustainability and efficiency in agriculture, the use of modern technologies, such as IoT, smart farming and digitization, which provide innovative solutions for real-time monitoring and management of crops, thereby reducing resource consumption and minimizing negative environmental impacts, is explored.

Another objective of the research is to highlight the importance of modernization in agriculture, arguing that modern technologies enable farmers to make informed decisions based on accurate data. This not only improves yields but also reduces the risks associated with traditional farming practices.

Finally, the research highlights the growing trends and interest in IoT, smart farming and digitization in agriculture, considering the adoption of these technologies as a necessity imposed by the current challenges of global agriculture. Emerging technologies are enabling a more sustainable and resilient agriculture, able to respond to current and future challenges.

These arguments explain the selection of the search phrase "IoT in agriculture" OR "Smart farming" OR "Digitalization in agriculture" AND "Sustainable Agriculture" for this particular inquiry.

The rationale behind this piece of research starts with database selection, SCOPUS, continues with the selection of search criteria, title, keywords and abstract. Then, the search phrase and criteria have been selected. After data extraction, the results have been analyzed, mapped and discussed.

Finally, the research highlights the growing trends and interest in IoT, smart farming and digitization in agriculture, considering the adoption of these technologies as a necessity imposed by the current challenges of global agriculture.

Data Collection Process

This analysis was carried out at the level of scientific studies written, according to the SCOPUS bibliometric database. The SCOPUS database has been selected for this research based on its broad coverage and disciplinary diversity, providing access to a wide range of relevant studies in areas such as agriculture, environmental sciences and technology. SCOPUS is recognized for its quality and rigor, with strict article selection criteria ensuring the credibility of sources. In addition, it provides advanced bibliometric analysis tools essential for assessing existing literature and identifying influential papers.

After choosing the database, the research continued by querying the bibliometric database, searching according to the criteria “Title, Keywords, Abstract”, and the search phrase mentioned before. Therefore, all scientific papers that contained either the term IoT in agriculture, Smart farming or Digitalization in agriculture, in conjunction with Sustainable agriculture, have been identified. These particular terms have been selected because they cover the main application areas of IoT and digitization in agriculture in the context of sustainability. The inquiry has been limited to the title, keywords and abstract because they provide a full and comprehensive picture of the focus and purpose of the papers and are essential for identifying their relevance in the context of the topics studied.

In order not to be limited from a time framing perspective, no restrictions have been made in terms of time period; the results identify scientific research from 1998 to the present for this theme. The timeframe has been chosen as a variable to capture the evolution and trends in IoT and digitization in agriculture over an extended period covering both the beginnings of these technologies and recent developments. The choice of a broad time span allows to observe progress and changes in the scientific approaches and technologies applied in this field.

Table 1. Centralization of bibliometric database query results

Database	**Search Terms**	**Results**	**Data format**
SCOPUS	“IoT in agriculture” OR “Smart farming” OR “Digitalization in agriculture” AND “Sustainable Agriculture”	Articles, books, book chapters, conference papers, reviews	Bibliography - Research Information Systems (.RIS)
Total Results	3113	Not in the English Language	50
		Eliminate Duplicates and Irrelevant	119
Final dataset	**2944**		

Source: authors’ contribution

A total of 2,944 valid scientific documents have been identified according to this inquiry phrase, all published from 1998 to the present. These data have been then analyzed in time and as occurrence, using VOSviewer software to identify the correlations between keywords, as well as the correlations between authors and countries of publication of these scientific materials.

The bibliometric analysis aimed to analyze collaborative networks and geographical influence on the development of research, as well as to examine the themes and topics of interest that have been addressed over time. Providing a comprehensive overview of the literature and its evolution, as well as helping researchers to identify gaps and opportunities for future research, are elements that contribute to the usefulness of bibliometric analysis. Through this methodology, the paper provides a detailed and grounded understanding of the interconnections between IoT, smart farming and digitization in the context of sustainable agriculture, highlighting major contributions and trends in this field.

Results

The results are presented in two separate sections. The first one presents general information about the papers selected, and the second one shows the keywords' co-occurrence and link strength.

Number, language and type of papers

The number of scientific papers published is increasing from year to year, from 1998 to 2025. However, this topic has shown little interest for researchers and academics for 17 years, since the first research was carried out, with 31 research papers being written until 2015. With the global acceptance of the concept of sustainable development through the 2030 Agenda (in 2015), the topic has grown exponentially, with more than 2,960 scientific papers produced in the last 9 years. Analyzing the average annual growth rate over the whole period, it can be estimated that each year the publications on this topic have increased by 29.6%, but when analyzing the period 2015-2024, since the topic has grown significantly, the average annual growth rate is approximately 43%.

Continuing the analysis of the results obtained from the database query, a structural analysis of the 2,994 scientific documents, regardless of language, was carried out according to their type: 1,539 articles (51.40%), 35 books (1.17%), 350 book chapters (11.69%), 543 conference papers (18.14%), 1 conference review (0.03%), 1 data paper (0.03%), 12 editorials (0.40%), 3 letters (0.10%), 14 notes (0.47%), 490 reviews (16.37%) and 6 short surveys (0.20%).

A classification of scientific documents has been made according to the language in which they have been written: 19 Chinese (0.63%), 2,944 English (98.33%), 2 French (0.07%), 19 German (0.63%), 1 Portuguese (0.03%), 1 Russian (0.03%), 8 Spanish (0.27%). As can be seen, out of the total number of scientific documents, more than 98% them have been written in English.

Analysis of keyword co-occurrence and link strength

Using the VOSviewer software, the co-occurrences between keywords for the 2,944 scientific documents have been analyzed and given the multiplicity of keywords in all these documents, the criterion was chosen that these keywords should record a minimum of 20 co-occurrences to make the results as conclusive as possible. A total of 254 keywords were recorded that met this requirement, and the analysis and creation of neural maps were performed with this volume of keywords.

In Table 2, there are extracted the top 25 keywords with the minimum number of co-occurrences are extracted as required by the total link strength. From these results, it can be determined that the searched phrases are in this top 25-word ranking, with phrases such as "IoT" being the second keyword in terms of total link strength, but also in terms of number of co-occurrences. The phrase "smart farming" used in document search ranks 9th with 272 co-occurrences. The phrase "sustainable agriculture" ranks 10th with 248 co-occurrences.

The most frequently encountered word is agriculture, with a total of 637 co-occurrences, and in the third position is the word "crops". It can also be highlighted that phrases such as "precision agriculture", "agricultural robots", "artificial intelligence", and "machine learning", all of which lead to the technological innovation discussed at the beginning of the research, are also shown in the literature as drivers for the sustainable development of agriculture.

Table 2. Top 25 keywords by total link strength

No	Label	Occurrences	Total link strength
1	agriculture	637	4245
2	internet of things	450	3325
3	crops	270	2311
4	precision agriculture	329	2202
5	agricultural robots	247	1948
6	machine learning	234	1811
7	sustainable development	223	1804
8	farms	196	1772
9	smart farming	272	1691
10	sustainable agriculture	248	1676
11	agricultural technology	182	1574
12	artificial intelligence	202	1364
13	food supply	156	1354
14	climate change	203	1339
15	cultivation	150	1249
16	sustainability	214	1224
17	smart agricultures	140	1212
18	Article	108	1159
19	smart agriculture	159	1096
20	Iot	167	1086
21	decision making	139	1085
22	Nonhuman	96	1039
23	remote sensing	149	989
24	machine-learning	95	966
25	antennas	114	962

Source: own processing based on Scopus data using VOSviewer

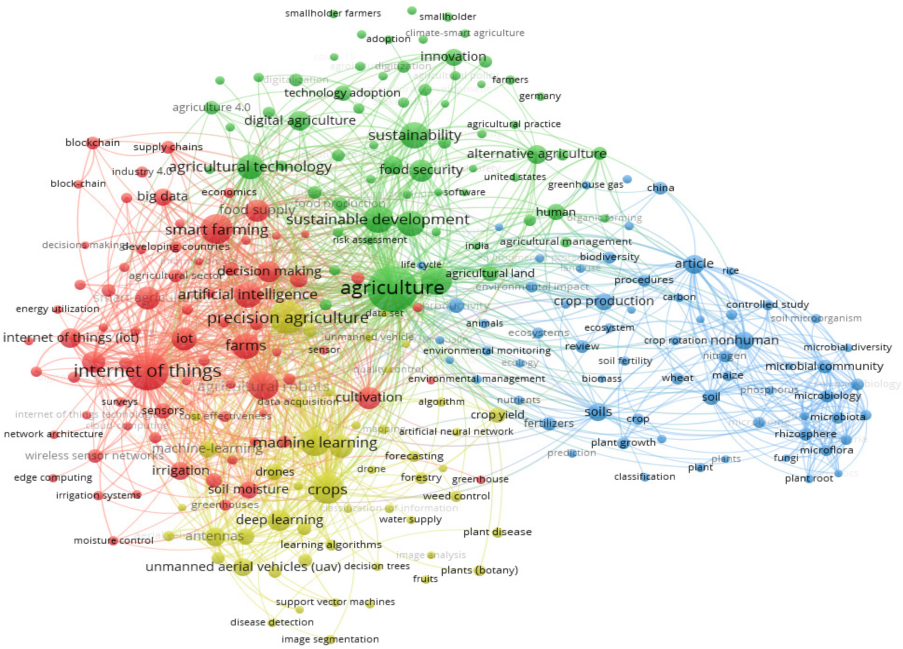
The 254 identified keywords have been classified into 4 clusters according to their relatedness and strength of linkages and co-occurrences. Of the total keywords identified, 29.1% (74 words) are grouped in cluster 1 (red), 26% of the words (66 words) are grouped in cluster 2 (green), 25.6% of the words (65 words) are grouped in cluster 3 (blue), and 19.3% of the words (49 words) are grouped in cluster 4 (yellow). Figure 1 shows the neural map of the 4 clusters according to the 254 keywords and their interconnections.

According to the map of the totality of keywords according to occurrences, it can be seen that the term agriculture is in the center of the map, having also the most occurrences, as mentioned above. Then, the phrase “internet of things” has been identified in cluster 1 and “precision agriculture” in cluster 4, but it can be seen that in cluster 3, there is no item with such a high significance as those presented above.

In cluster 1, keywords such as Internet of Things, smart farming, artificial intelligence, decision making, big data, blockchain, and network architecture have been identified. Thus, it can be appreciated that the publications whose keywords have been classified in this cluster have focused on research in the field of IoT and smart farming, with a vision of decision making based on this data and the creation of a network architecture based on big data and blockchain.

This exposure leads to the hypothesis that the integration of emerging technologies can lead to improved decision-making in agriculture. By integrating these technologies, an advanced network infrastructure can be created to efficiently collect, analyze and use agricultural data to make smarter decisions and optimize agricultural processes, resulting in higher yields and reduced environmental impact.

Figure 1. Map of interconnections between keywords and clusters.



Source: own processing based on Scopus data using VOSviewer

In Cluster 2, interconnections between words such as agriculture, sustainable development, sustainability, food security and safety, alternative agriculture and technologies and digital agriculture can be observed. Therefore, this cluster contains keywords from the research that focused on these concepts whereby alternative agriculture, respectively digital agriculture, leads to sustainability and sustainable development, and the first objective of this development is to ensure food for the population, thus ensuring food security and safety.

It can be noted that this set of keywords highlights the researchers' focus on the following main issues: developing alternative and digital agriculture to promote sustainability and sustainable development, with a focus on feeding the population and ensuring food security and safety. This demonstrates the growing recognition of the importance of adopting innovative agricultural practices and digital technologies to meet society's food needs in a sustainable and environmentally responsible way.

In cluster 3, there are keywords such as: crop production, productivity, environmental impact, soils, fertilizers, non-human, microbacterial and other words that make this cluster a more technological one in terms of research, i.e. through these researches we have pursued the impact of the questioned theme on the production sector, on productivity, yields, non-human intervention in the soil and the fight against all microbacterial aspects.

Therefore, it can be stated that the research in this cluster aims to explore and understand the impact of technical and agronomic factors on agricultural production, productivity and sustainability in an environmental context. Through these studies, the aim is to evaluate and optimize agricultural practices, to minimize environmental impacts and improve the performance of the agricultural production sector.

Cluster 4 contains keywords such as: precision agriculture, robotics, machine learning, crops, algorithms, and drones. Thus, in this cluster, keywords from research that can support the theme under investigation, namely IoT and smart farming for sustainable agricultural development, have been included. This research creates better links between technical (digital) and technological (agricultural) sides. These keywords reflect interest in areas such as automation, data analysis and the use of artificial intelligence in agriculture to optimize farming processes, make smarter decisions and maximize crop yields.

Therefore, it can be stated that the research in this cluster explores and assesses the potential and benefits of advanced agricultural technologies to support the development and implementation of more efficient and sustainable agricultural practices.

Discussions

The results prove that the interest of researchers in smart and sustainable agriculture has increased in the last ten years. These findings, made on the scale of the research, are also confirmed by statistical forecasts of the market value of smart agriculture worldwide between 2021-2027. In the period 2021-2023, this value has increased from \$12.8 billion to \$17.6 billion, and the report forecasts that it will reach \$33 billion in 2027 and then exceed the \$50 billion threshold in 2030 (Statista, 2025).

The inferences between smart farming and sustainable agriculture are confirmed, also in the literature. Barroso-Barroso (et al., 2025) argued that smart agriculture is an engine of sustainability and innovation, because it integrates science and technology to cope the global issues of climate change, food security, and sustainable development. Pentoś (et al., 2025) claimed that the growth of precision agriculture and AI technologies can contribute to the further development of sustainable agriculture. Rađenović (et al., 2025) highlighted the main benefits of digitalization in agriculture and stressed its importance for sustainable development in rural areas.

The main directions of research found in the literature, which overlapped with the results of the bibliometric analysis, confirm the interest of scientists in exploring the links between smart farming and sustainable agriculture.

Coming back to the main directions of research found in literature and listed in the final part of the section literature review, they can be found in different clusters of the bibliometric analysis, as follows: conservation of natural resources, resource efficiency and climate change in cluster 3, food security and safety and vertical and urban agriculture in cluster 2, technological innovation, agriculture biotechnology, smart irrigation systems in cluster 1 and robotics and automation in cluster 4.

Emerging technologies in agriculture and their economic impact

Integrating emerging technologies in agriculture can significantly improve process efficiency and resource use. To sustain this statement, some drivers are explored. Firstly, the integration of innovative technologies has a direct impact on agricultural yields, leading to higher yields by optimizing production processes, as argued by Kumar (et al., 2020). Farmers could thus achieve a higher agricultural output with the same level of resource consumption, or even a lower one, thus directly influencing the profitability of the farmer's activity.

Digital farming and technological innovation can also make farmers more competitive in the market. By adopting digital and innovative technologies, farmers can develop higher quality and sustainable products, as stated by Moshelion and Altman (2015), which could attract more customers and open up new business opportunities. Using these emerging technologies to optimize agricultural production processes can reduce the use of certain resources such as water and energy, while contributing to significant long-term savings for farmers, as demonstrated by Rusu (et al., 2015). Optimizing resources can also lead to lower environmental impacts, so we can also talk about reducing environmental costs.

Thus, the integration of emerging technologies in agriculture can have a significant positive impact on the economy, making the agricultural sector more efficient, competitive and sustainable.

Emerging technologies in agriculture and their social impact

Increasing agricultural yields not only influences producers, but also consumers. This intensive agricultural development with emerging technologies can increase access to quality food for the whole population, especially for less privileged communities, as argued by Chandan (et al, 2023). Subsequently, this could reduce food insecurity and improve the health and well-being of communities. Food security cannot be achieved without considering food safety. The use of emerging technologies in agriculture can help improve production practices and reduce the risks associated with food contamination or other food safety issues. As a result, consumers can feel more confident in the food they eat, contributing to a healthier and happier society.

Last but not least, the integration of emerging technologies in agriculture can help increase access to agricultural education and training, as explored by Francis (et al., 2017). As a result, young people and farm workers can acquire relevant skills and knowledge to take advantage of new technologies and innovative farming practices.

Thus, the integration of emerging technologies in agriculture can have a significant positive social impact, helping to improve access to quality food, increase food security, create jobs, and promote education and training in agriculture.

Emerging technologies in agriculture and their environmental impact

In relation to reducing environmental costs, this results from decreasing the use of resources, mainly water and energy. One impact of the emerging technologies in the environmental pillar vision relates to the reduction of natural resource use. These technologies can contribute to the conservation of water resources as well as to the reduction of water and groundwater pollution, as stated by Adegbeye (et al., 2020).

Continuing with the idea of optimizing production processes, smart and precision farming can reduce the use of chemical pesticides and fertilizers, as demonstrated by Moshelion and Altman (2015). Farmers can identify areas that need special treatment, reducing inefficient use of pesticides and fertilizers. This reduces soil and groundwater contamination and protects biodiversity.

Advanced farming techniques can contribute to reducing carbon emissions through the use of soil management practices such as conservation and organic farming, as shown by Shahzad (et al., 2021). These practices can help store carbon in the soil and reduce greenhouse gas emissions associated with deforestation and the burning of agricultural land. Moreover, the use of sustainable farming practices, supported by technologies such as soil and crop monitoring systems, can help protect soils from erosion and degradation (Li et al., 2014). This helps protect soil fertility and biodiversity, with a positive impact on agriculture and natural ecosystems.

The complexity of the effects of emerging technology on the economy, society and environment, described above, confirms the hypothesis formulated at the beginning of the research that technologies, such as precision farming, the use of drones and sensors, play a significant role in the sustainable development of agriculture.

Conclusions

This paper sought to highlight all research in the areas of “IoT in agriculture”, “Smart farming”, “Digitalization in agriculture”, with influences on “Sustainability in agriculture”. A final answer to the research question is that smart farming is strongly related to sustainable agriculture, contributing to its development, as demonstrated by both literature review and the bibliometric analysis.

This conclusion is sustained by the growing interest of scientists in exploring the topics mentioned above and by the links and co-occurrences between the keywords. The number of papers published in the field of smart farming and sustainable agriculture reached a peak in 2015, with the implementation of the Sustainable Development Strategy (Agenda 2030) by the United Nations. While 31 research papers have been written in the period 1998-2015, more than 2,960 papers have been published, after 2015, demonstrating an increasing interest in these topics.

At the same time, this scale of research comes against the backdrop of limited natural resources and the totality of strategies to protect the environment. At present, in developed countries, performance in the agricultural sector has reached a peak, and the only optimal option for sustainable agricultural development is considered to be smart farming, in all its forms.

Whereas the importance of smart farming and its effects on sustainable development has been demonstrated in literature, as proven in this paper, practical actions for digitalization implementation in farms and measures of agricultural policy for supporting it should be investigated in future scientific papers.

The research has its limitations, since only the SCOPUS database has been inquired, leaving out papers from other databases, and, like this, some inferences and co-occurrences may have been missed.

Conflict of interests
The authors declare no conflict of interest.

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RISK MANAGEMENT IN THE AGRICULTURAL PRODUCTION IN SERBIA

Zdravko Petrovic[1], Ilija Smiljanic[2], Gruja Kostadinović[3]

**Corresponding author E-mail: ilijadsmiljanic@gmail.com*

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A B S T R A C T

The subject of consideration in this paper is the analysis of the structure and state of agriculture in Serbia, as well as the impact of climate change and the accompanying risks in the production. The facts that will be considered include the structure of agricultural areas, means of work, methods of processing and protection against natural disasters during the process of production. A special consideration is given to the protection of agricultural production from natural disasters. Although there are several ways of protection, it is still at a low level. The causes and consequences of the low level of protection of the agricultural production will be pointed out . At the end of the paper, the proposals for measures how to improve the insurance of agricultural production in Serbia will be presented.

Introduction

The effects of climate change are becoming increasingly evident in agricultural production and they additionally affect the intensity of the realization of risks in agricultural production in Serbia. Certain risks, such as - hail, spring frost, spring snow, flood, drought, which in the previous the period was followed by a certain period of time terms and frequencies , have now become frequent and unpredictable , both in terms of time of occurrence and intensity. The consequences are great damage to agricultural production (Šušljik, 2025).

Workers in agriculture, both in our country and in the world, cannot deal with this problem by themselves, which means that these types of damage regularly fall on the

1 Zdravko Petrović, PhD, Full Professor and lawyer in Belgrade, Bulevar oslobođenja no. 152, 11000 Belgrade, Serbia, Phone: +381 63 575 880; E-mail: petrovicmzdravko@gmail.com, ORCID ID (https://orcid.org0009-0002-9401-2725/)

2 Ilija Smiljanic, PhD, Company for mediation in insurance “NORDAL DIV”, Belgrade, Bosanska 71a, 11000 Belgrade, Serbia, Phone: +381 64 834 55 09; E-mail: nordaldiv@gmail.com, ilijadsmoljanic@gmail.com, ORCID ID (https://orcid.org/0009-0007-1083-4577)

3 Gruja Kostadinović, PhD, Full Professor, MB University, Faculty of Business and Law, Teodora Drajzera no. 27, 11000 Belgrade, Serbia, Phone: +381 18 423 82 88; E-mail: gruja.kostadinovic@konstantinveliki.edu.rs, ORCID ID (https://orcid.org/0000-0002-6049-0916)

state budget (Milojević et al., 2025). Therefore, the state of Serbia must first of all, with incentive and preventive measures, and then with repressive measures of this type of risk in agricultural production, transfer from the budget to other factors, such as individual protection methods, collective protection or risk transfer to insurance companies (Radovanović, 2025).

The analysis of the current situation in agricultural production, as well as the situation in other countries, will indicate the directions and methods in order to resolve the problem of damages in agriculture.

Agricultural resources in Serbia

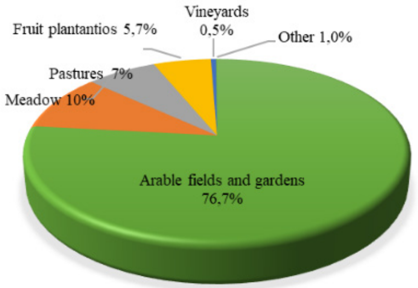
Economic and social importance ranks the activity of agricultural production as one of the most important economic branches in Serbia and it also represents an essential element of rural development, which are typical for other countries of similar level of development (Rosić & Vilma Getman, 2025). The share of agricultural production in the gross domestic product (GDP) of Serbia in the year of 2023 was 3.8 %, and compared to 2017, there was a decrease, as it was 4% at that time. The share of directly employed or owners of farms in 2023 was 3.4% (Republic Institute of Statistics, Census of Agriculture in 2023 in Serbia, brochure for EU needs, Belgrade, 2024). However, when the number of seasonal workers is taken into account, where most of them work illegaly, then it is around 20%.

This situation can be explained in the high share of seasonal workers, as well as in the low level of of mechanization, that is quite old. If the low level of subsidy from the state is taken into account, as well as the way it is implemented, the non-competitiveness of our agricultural products in the world market is not surprising. The situation is similar in the countries of the region, too. Nobel laureate Teodor Schulz, an agroeconomist, in his ideas about the importance of agriculture, says: “Poverty is an indicator of ignorance of the economics of agriculture (Marović, 2017).

Structure and situation in the agricultural sector

The Republic of Serbia has 5.077 million hectares of agricultural land, of which 67% is agricultural and 33% are areas under the forest. 3.4 million hectares that are agricultural land, 67% of the land is used intensively (in the form of arable land, orchards and vineyards), while 33% of agricultural land is natural grassland (meadows and pastures).

Figure 1. The structure of used agricultural land in Serbia in 2023.



Source: Republic Statistical Office of Serbia, Statistical Yearbook, for 2024.

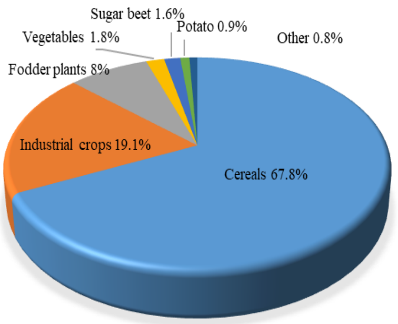
In the total value of agricultural production in 2023, crop production covers 69.8%, and livestock production is 30.2%.

The area of land under forest in the amount of 2,855 million hectares is distributed in the state sector, 1,191 million hectares, which is about 42%, and 58% of the area, ie 1,664 million hectares, is in the private sector (Republic Institute of Statistics, (2024) Statistical Yearbook of the Republic of Serbia for 2023.

The predominant part of about 3.4 million hectares, i.e. 67 %, which is agricultural, is used in the form of: arable land and garden 76 , 7 %, meadow 10 %, pasture 7 %, orchard 5.7 % and vineyards 0.5. (Slika1).

The predominant part of the agricultural land, about 3.3 million hectares or 67 % , is used as arable land, but about 7% is not used annually (it remains in the form of uncultivated land). In addition to the areas left for fallow, a significant part of the areas under meadows and pastures is not used due to inaccessibility, weeds or due to economic unprofitability. It is estimated that every year between 200 and 350 thousand hectares of arable land and meadows remain uncultivated, while the area of unused agricultural land with pastures is significantly larger.

Figure 2. Structure of sown arable land in Serbia in 2023. year .



Source: Republic Institute of Statistics of Serbia, Statistical Yearbook, for 2024.

According to planted crops, the structure of agricultural land in 2023 in Serbia includes: cereals 67.8%, industrial plants 19.1%, fodder plants 8%, sugar beets 1.6%, vegetables 1.8% and potatoes 0.9%, (Slika 2) .

Looking at the structure of the created values in Serbia : 70% comes from the crop production, and 30% from livestock production, with the share of crop production increasing and the share of livestock decreasing. In the EU countries, 70% of the value in agriculture comes from livestosck production and 30% from crop production.

The average economic size of an agricultural farm in Serbia is about six times smaller than farms in the European Union. This can be explained as the result of:

- the out-of- dateness of machinery and the inability of renewing it due to weak economic opportunities;
- low level of well-skilled workers and education;
- minimal application of agrotechnical measures, due to lack of funds;
- a large share of mixed farms;
- a small share of areas under the irrigation system;
- low share of areas under greenhouses and greenhouses;
- low level of subsidy from the state;
- low level of cooperatives.

It is not possible to expect a significant increase in the economic size of farms or for our agricultural products to be competitive on the world market, while there are the above mentioned problems.

Labor and labor resources

The lack of labor force and outdated means of work are the two key factors that burden the agricultural activity and make it uneconomical and uncompetitive. The mutual correlation of the mentioned factors additionally intensifies the problem in agriculture. The outdated mechanization requires greater engagement of workers and therefore the labor cost is higher.

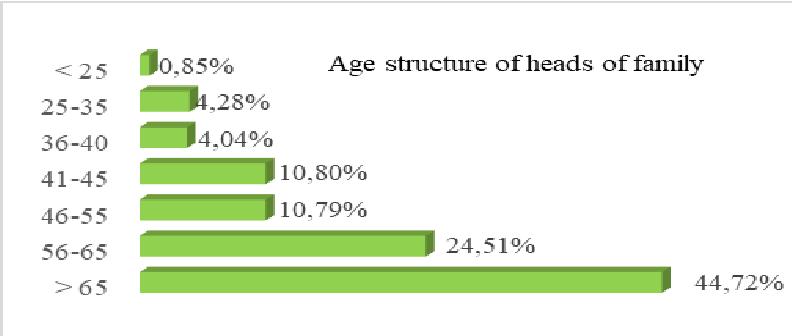
The Employment in agriculture in Serbia can be classified into five categories :

- Permanently employed on the farms of legal entities and entrepreneurs
- Permanently employed on family farms
- Seasonal workforce on agricultural farms
- Members of family farms who do part of the agricultural work and are not employed (housewives, pensioners, children and other unemployed people)
- Members of family farms who are employed and work on family farms in their free time

It is estimated that about 1,157,319 people are engaged in agriculture in this way, working on 502,318 farms, where 506,323 are family farms, 1,589 legal entities and 413 entrepreneurial farms. It means that about 20% of the workforce is employed in the agricultural sector, and its income contributes 3.8% to the GDP (Census of Agriculture in 2023 in Serbia).

The age structure of heads of family households is also unfavorable. According to data from the Federal Bureau of Statistics, from agricultural census in 2023 , 44.72% household owners are over 65 years old and only 0.85% are under 25 years old (Slika 3).

Figure 3 . Age structure of heads of family households in Serbia 2023.



Source: Republic Institute of Statistics of Serbia, Statistical yearbook for 2024.

Working tools are a chronic problem in agriculture. In most cases, it is outdated mechanization, especially in small farms. In fact, something has been improved, but considering the material possibilities and the amount of subsidy, it is not sufficient. In Serbia, an avertage of 2.000 new tractors and 60 combineharvesters. In Serbia these days, 168,353 single-axle tractors are used, there are 482,498 two-axle tractors and 46,322 combine harvesters. There are 7 out of 10 households which use their own tractors and one tractor is used for about 6.7 hectares. Farmers in Serbia own about a million attachment machines, and only every fifth machine is the new one. The average age of tractors is about 30 years (Statistical Yearbook of the Republic of Serbia for 2023).

Table 1. Overview of mechanization in Serbian agriculture by age

years of age	tractors		combine harvesters	
	pieces	%	pieces	%
< 1	7.088	1,5%	5.322	11,5%
1-5	13.660	2,8%	1.896	4,1%
6-10	24.499	5,1%	3.113	6,7%
11-15	37.694	7,8%	3.177	6,9%
16-20	43.311	9,0%	2.909	6,3%
> 20	356.246	73,8%	29.905	64,6%

Source: Republic Institute of Statistics, Statistical Yearbook of Serbia for 2023.

Risks in agricultural production

In the modern process of agricultural production, there is a basic group of risks which can be defined as: production, operational, market, financial, technological, institutional and regulatory, infrastructural, as well as the risk of disorganization.

A production risk is particularly important for this paper, as it affects the reduction of the quality and quantity of the product, or one of the above, and it is realized through:

Natural disasters*:* floods, torrents and high water that happen as a result of a large amount of precipitation in a short period of time, as well as the impurity of drainage channels, stormy weather, snowing at the beginning of the growing season, hail, fire due to negligence or negligent burning.

Lack or excess of water: it is undeniable that the problem of climate change is negatively reflected on agricultural production, either as drought or excessive rainfall in a period unsuitable for vegetation. The measures that were implemented to reduce the consequences of the drought in 2017 were almost invisible, as the irrigation systems covered less than 2% of arable land. On the other hand, the drainage canals are full of silt, overgrown with weeds and cannot be used. In 2023, the situation was more favorable, and it is around 3%. The individual farms contributed to this slight increase, as their share of 27.5% farms irrigated 8.3% of arable land. The largest part involves arable land and gardens with 72%, orchards 7% and vineyards 2% (Census of Agriculture in 2023 in Serbia).

Urbanization inevitably takes its toll and turns a large part of agricultural land, especially those near roads and urban areas, turning them the construction land.

Operational risk is characterized by:
Lack of workforce: a problem that is generally typical for the developed part of the world and affects Serbia as well.

Recently, there has been a noticeable lack of interest in seasonal jobs in agriculture, regardless of the fact that they are well paid. Migration of young people to cities and foreign countries is an additional problem too.

Mechanization failure: it is estimated that the age of agricultural machinery in Serbia is around 30 years old. It means that we cultivate the land with outdated mechanization, which directly implies more work and a greater number of accidents and frequent breakdowns. Due to the lack of finances, farmers still choose to buy used machinery rather than new

Market risk: - the impact of price fluctuations on the market is quite high, both due to the movement of production in the world and due to the disorganization of producers. In fact, the other buyers and resellers , as well as the import lobby are those who take the opportunity. On the other hand, the state that has chosen the liberal capitalism, remains invisible, even though it has to be its strategic activity - the production of food for its own population.

Financial risk: - a serious lack of finances forces the producers to use loans with high interest rates, that cannot be paid back by agricultural production. Subsidy payments are made after the engagement of somenone's own capital, in the form of a return that people wait for too long, making the financial liquidity of farms/ agricultural holding more complex.

Technological risk: - it is necessary to follow modern technologies in order to preserve competitiveness, but it also implies professional and skilled workforce and financial solvency.

Institutional and regulatory risk: - taking into consideration that the import-export policy in Serbia is largely liberalized, i.e. exempted from protective customs rates, it causes damage to domestic agricultural production as it is not competitive with foreign ones, that in this way takes a significant share in the domestic market. Sales chains with foreign capital additionally favor foreign products too.

Infrastructure risk: - the risk of inadequate infrastructure for production, the impossibility of storage or storage in inappropriate conditions due to lack of adequate capacities (silos, cold stores, etc.), as well as the product distribution itself.

Risk management in agricultural production

Since the Middle Ages, spatial diversification has been used as an approach to risk management in agriculture (McCloskey, 1976). Economists began to pay attention to this form of risk management only in the 1950s, analyzing the possibilities of its application in agricultural production. It is essentially a diversification approach, which provides a reduction in standard deviation by replacing one with more unrelated, smaller risks.

Diversification of risk in agriculture can be realized spatially, which implies carrying out production in different locations, and productively, which implies growing several different crops. This approach is best illustrated by our host's famous saying " "don't keep all your money in one bag".

Nowadays, when agricultural production is exposed to climatic and weather turbulence , even farmers in Serbia have realized that they must take into consideration the risk control, in order to avoid or reduce the damage in agriculture. Recently, we can meet four types of protection of agricultural crops.

- The earliest designed method of protection is using hail-defense rocket, which is losing effectiveness due to subjective as well as objective circumstances, although technologically improved. The subjective circumstances are the lack of workforce to handle, and the incomplete organization as well, which at a certain moment shows poor efficiency, while the objective circumstances are caused by climate change.
- Recently, especially in fruit growing, wine-growing and vegetable growing, the installation of protective nets has been popularized. A hail protection sustem for orchards using pro-tective nets costs betmeen 26.000 and 29.000 euros per hectare. Their efficiency is quite good, but what makes them unaffordable are: the expensive installation, limited service life and the possibility of damage during the major storm.
- The most recent approach to the protection of agricultural crops is with anti-hail cannons. This is a method that many developed countries, such as the Netherlands, Belgium, Portugal, the Czech Republic and others, have been using for a long

time. Recently, thanks to the engagement of two mechanical engineers from the Faculty of Mechanical Engineering in Belgrade, we also have a domestic version of this device. It works in a way that it shoots hot air, created by igniting acetylene, between the hail clouds and thus prevents the formation of ice. Its basic characteristics: it protects all types of crops in a diameter of about 80 hectares, it is mobile and is transported as a tractor trailer, it has its own power supply through a solar panel, it can be controlled and activated using a mobile phone. The maintenance of this device costs about 500 euros per year, depending on the number of activation ,there is no special permission that is required for use, it is subsidized in the amount of 50% and it is cheaper than the imported ones (For more information, see TRALING doo).

- However, the most effective way to manage risk is through insurance. Insurance companies are organizations specialized in the protection of people and their property, as they are technically and financially equipped to manage risks successfully, i.e. provide the necessary protection of property and people.

  Most of the risks in agricultural production are covered by insurance companies. The basic risks that are offered are: fire, lightning strike and hail, while additional risks are: spring frost, flood, storm, drought, excessive precipitation, loss of income, winter frost, production in greenhouses, loss of seed quality due to winter frost, loss of quantity and quality , insurance of young plants and insurance of plants in the crop, insurance against winter freezing, e.g. oilseed rape. General and special conditions for insurance of crops and fruits of insurance companies: Dunav, DDOR, Triglav and Đenerali.

  In addition to these risks, today's economic conditions in agricultural production, which are partly changed due to climate change, also require some new offers on the insurance market. There are already the existing risks as well as the new ones that have been specially defined in the offer for a long time. It is possible to conclude: insurance against one risk specified in the policy (eg hail); insurance against multiple risks specified in the policy; insurance against all risks except those specified in the policy ; yield insurance – is activated in case of a yield that is lower than the average; parametric insurance - is activated in case that some pre-determined parameter (for example, the amount of precipitation or the number of dry days) reaches or exceeds a certain value, regardless of the actual loss.

The insured risks and damages in agricultural production

The low level of development of the insurance market in Serbia (For more information, see: Smiljanić, 2016) is also visible in the insurance system in agriculture, ant it is typical for all poor countries. Therefore, the fact that in Serbia in 2023 only about 13% of the total area of used agricultural land was insured is not surprising . The analyses of earlier years ranged below 10% indicate a certain increase in insurance, but it is still at a very low level (Author's analysis based on data from five leading crop and fruit insurance companies in Serbia).

A similar situation is in Croatian agriculture too. There were only 18% of insured areas in 2023, which puts Croatia at the very bottom of the EU member states. Similar situation is in all countries in the region. It is a fact that the subsidies in these countries are lower than in the countries of the European union, but still they are from 30 to 70 %, and it cannot be said that they are insignificant. Obviously, the reasons of these are more complex. Is it the fact that the smaller farmers are sometimes distrustful of the insurance policy, while for some of them it is too expensive.

On the other hand, the official statistics show that damages in Serbian agriculture really exist. In 2012 the fires raged, causing damage on an area of 4,922 hectares, which was approximately 111.5 million dollars (85.7 million euros) (Jančić, 2012). The total amount of damage includes: direct damage, damage from lost yield, environmental damage, costs of extinguishing the fire and costs of rehabilitating the area affected by the fire.

In 2014, 72 municipalities out of 155 in Serbia were affected by floods, and the damage was estimated at 1,711.2 million dollars (1,525 million euros) where 256 million dollars (228 million euros) or 15% was related to agriculture. The insurance companies paid out 29,413, 000 million dollars (26, 275, 000 euros) which is 3% (Samardžić, Smiljanić, 2014).

During the last five dry years, there were about five billion dollars in damage to agriculture, which is the value of one year's agricultural production in Serbia, says the member of the board for the village of the Serbian Academy of Science and Arts (SANU), Branislav Gulan (Gulan, 2017).

It seems that Serbia is not ready for such a challenge, as there is less than 3% of arable land that is effectively irrigated, which means that together with Albania, we are at the bottom of the Europe. In the world, on average, between 17% and 20% of land is irrigated. In Serbia, according to the data of JVP Voda Vojvodina, around 80,000 hectares are currently irrigated. The total capacity of the irrigation system is about 180,000 ha, but the capacities for about 100,000 ha are unusable due to neglect.The enormous project Danube - Tisa - Danube canal, that in 2022 celebrated 45 years of its construction and that was built for the irrigation of about 510,000 hectares and the drainage of about 1,060,000 hectares, does not do either of these two purposes now (Vode Vojvodine, 2018). The irrigation project has never been realized, and the drainage project, that initially used to work, has not been working since 2008, as the drainage channels are silted up and overgrown with bushes and weeds.

In the period from 2013 to 2017, the average annual damages in the forest fund, were a result of natural disasters (wind, rain, hail, snow) and fire, amounted to about 78,000 m3 of wood volume (Statistical Yearbook of the Republic of Serbia for 2017), which on the other hand was 4,366,000 dollars (Srbijašume, 2023). In 2018, there was an increase in the damage of the forest fund, which was about 102,000 m^3 of wood volume and it was about 5 709,000 dollars. The share of state forests amounts to 44,000 m^3, recalculated 2.4 63,000 dollars, and privately owned forests 58,000 m^3, recalculated 3.246,000 dollars. Damage from natural disasters and fires in 2023 amounted to about 186,727 m3 of wood volume, which, calculated, amounts to about 10,450,000 dollars (Statistical Yearbook of the Republic of Serbia, for 2023).

Crop insurance in the European Union is different from that in Serbia. In most countries, insurance is mandatory in order to acquire the right to a subsidy and there are several measures related to the development of elements for risk control, such as established public-private funds for compensation of damages.

In Austria, 78% of agricultural land is covered by insurance, Hungary insures 52% of land, while the EU average is 35%. Thanks to high state subsidies, the highest percentage of crop insurance is in Spain and Germany. It ranges from 60 to 70 percent of the total number of farms (Kovačević, 2018).

Subsidies and insurance premium share intotal cost of agricultural production

In 2023, Serbia subsidized agricultural production insurance with 40% - 45% of the paid insurance premium, with the maximum amount of incentives being :

- for crop insurance - 100,000 dinars
- for insurance of vegetable crops - 500,000 dinars
- for insurance of fruit crops, grapevine and hops - 1,000,000 dinars
- for the insurance of plant nurseries and/or young perennial plants before they go into production - 500,000 dinars
- for animal insurance – 2,000,000 dinars

In total, the maximum amount for all types of incentives is 2,500,000 dinars.

In addition to that, there are subsidized loans from the Ministry of Agriculture in cooperation with commercial banks and insurance companies.

Local self-governments have the option of additional subsidizing agricultural insurance, so there are cases where in some municipalities the total subvention amounts to 100% of the net premium. In a large number of cases, in addition to the incentives granted by the state of Serbia, local governments, depending on the material possibilities and the frequency of realization of certain types of risks in their areas, grant an additional incentive ranging from 20-60 percent, so that we have cases where the insurance of agricultural production, in municipalities such as Inđija, Kraljevo and some others that grant an incentive of 60%, insurance, almost free of charge, considering that the insured only pays tax on the premium, which is 5%.

According to the law on protection from hail, insurance companies set aside 10% of the collected crop and fruit insurance premium. The distribution refers exclusively to the collected insurance premium of registered plots, registered agricultural holdings (RPG). The funds are used for financing of the hail defense system, as a preventive action (Article 15, Law on City Defense, Official Gazette of the Republic of Serbia no. 54/2015).

In the world, there are different ways used for the promotion of agricultural production insurance. They range from mandatory to optional insurance and from high levels of incentives to those where there are no incentives. Each country has established a system that best suits its national agriculture and the conditions under which production takes place, (Table 2).

The price of agricultural production insurance in Serbia is for farmers as they say unprofitable. Is it really true and what do the facts and calculation say?

The cost of insurance is much lower than, for example, a harvester causing damage during harvesting, which is accepted as normal and is considered a technological loss.

When taking into account the incentives provided by the state directly and through local governments for the insurance of agricultural production, the insurance price does not exceed 1% of the value of the crop in relation to the damage caused by the harvester in the harvest, which ranges from 3-6%, depending on the age of the harvester.

Table 2 . The method of insurance and the amount of incentives in some countries in the world

Countru	Subsidy	Way of insursnce
Cyprus	50%	The state is the insurance carrier, through the state insurance company - insurance is obligatory
Bulgaria	-	Commercial insurance without state participation
Finland	-	
Denmark	-	
Sweden	-	
Belgium	-	
Greece	-	
Australia	-	
Spain	60-70%	State Agricultural Insurance Corporation - the provider of subsidy in the form of coinsurance
Portugal	45-85%	Commercial insurance with state control and subsidy
USA	50-75%	
Austria	50%	Commercial insurance with state subsidy
Italy	50-80%	
France	10-30%	
Czech Republic	30%	
Russia	50%	
Slovenia	30-50%	
Netherlands	75%	
Germany	60-70%	
Croatia	70%	
Federation of Bosna and Herzegovina	50%	
Republic of Srpska	50%	
Serbia	40-45%	

Source : Data from national laws, regulations and decisions
as and the magazine Sigma (Swiss Re) for 2023 . a year

The examples in (Table 3) should prove that the agricultural insurance is not expensive. If the producer chooses the insurance against the basic risk, such as hail, fire or lightning strike, the calculation is shown for the types of products that are most represented in agricultural production in Serbia.

There is an example of the calculation of the insurance premium for the insurance of wheat per one hectare at an average three-year yield of 4.1 tons per hectare (Statistical Yearbook of the Republic of Serbia for 2023) and a planned price of 23 dinars per kilogram is 2,700.00 dinars, and corn at a yield of 8 tons per hectare and a planned price of 18 dinars per kilogram is 3,642.00 dinars (Decision of the Government of the Republic of Serbia dated July 3, 2025. year, Source).

If the minimum incentive of 40% given by the state is taken, the price of the insurance policy for wheat per hectare would be 1,620.00 dinars, and for corn 2,185.00 dinars, which amounts to 70 kg of wheat, or 121 kg of corn (Author's calculation based on the offers of three insurance companies in Serbia and the average three-year yield). If the incentives of local self-governments are taken into account, the price is even lower.

Table 3. Calculation of the insurance premium for the most widespread agricultural crops in Serbia

Култура	Принос т/ха	План, цена (дин)	Сума осигурања	Премија /ха	Премија / тони	Премија - субвенц. 70%/ха	Субвен. Премија кг/тони
Пшеница	4,1	23,00	94.300,00	2.700,00	658,54	810,00	35
Кукуруз	8,0	18,00	144.000,00	3.642,00	455,25	1.092,60	61
Индуст. Биље	3,0	37,00	111.000,00	3.645,00	1.215,00	1.093,50	30
Крмно биље	14,0	9,00	100.000,00	28.520,00	2.037,14	8.556,00	951
Шећерна репа	50,8	5,00	254.000,00	4.156,00	81,81	1.246,80	249
Кромпир	16,2	23,00	372.600,00	6.515,00	402,16	1.954,50	85
Поврће	13,5	18,00	243.000,00	12.245,00	907,04	3.673,50	204
Јагода	4,4	120,00	528.000,00	31.256,00	7.103,64	9.376,80	78
Малина	5,5	140,00	770.000,00	33.950,00	6.172,73	10.185,00	73
Шљива	5,3	23,00	121.900,00	7.948,00	1.499,62	2.384,40	104
Јабука	16,5	32,00	528.000,00	35.205,00	2.133,64	10.561,50	330
Кајсија	17,0	60,00	1.020.000,00	43.120,00	2.536,47	12.936,00	216
Крушка	18,0	45,00	810.000,00	43.250,00	2.402,78	12.975,00	288
Вишња	5,8	32,00	185.600,00	13.050,00	2.250,00	3.915,00	122
Грожђе	8,0	44,00	352.000,00	35.980,00	4.497,50	10.794,00	245

Source: Author's calculation based on offers from three insurance companies in Serbia.

Regarding fruit insurance, for a yield of 1,000.00 kilos , and at purchase prices from this season, the premium amounts are as follows: for plums 1.500.00 dinars, for apples 2.133.00 dinars and for strawberries 7.104.00 dinars, without subsidies .

If only state subsidies are taken into account, then it amounts to: 900.00 dinars for plums, 1.280.00 dinars for apples, and 4.262.00 dinars for strawberries .

If the state assumes the obligation to insure agriculture, on the basis of insurability of 80%, area and land of 70% subsidy, the state would have to set aside about 115 million dollars (100 million euros) annually for subsidies. When the return is calculated from a total of 25%, the real costs of the subsidy would amount to about 86 million dollars (75 million euros). According to the current Law on Hail Protection, insurance companies are required to deduct 10% of the insurance premium from each policy sold in the name of preventive hail protection. If the insurance of agricultural products were to be introduced as mandatory for the majority, the state could oblige the insurance companies to pay a part of the insurance premium, e.g. 15% is set aside for scholarships for the education of young personnel in agriculture. If this amount is compared with the amount that the state gives from the budget every year, for damages in agriculture, it is clear that insurance in agriculture is profitable for both the state and the owners of farms.

Table 4 . Calculation of the insurance premium against basic risks for forests in Serbia

	Deciduods trees	Conifers
Yield in tones per hectare	161,0	161,0
Average price per heath per cubic meter	5.900,00	5.900,00
Insurance sum per hectare	949.900,00	949.900,00
Premium per hectare	1.576,83	2.650,22
Premium per hectare subsidized 70%	473,05	795,07
Premium share in the price of cubic meter of wood	27%	45%
A share of subsidized premium in the price of cubic meter of wood	8%	13%

Source: Author's calculation based on offers from three insurance companies in Serbia

The analysis of forest insurance in Serbia also shows the profitability of insurance. From the data in (Table 4), it is clear that the insurance premium per one hectare of forest is almost symbolic in relation to its value. In the average price of wood (Price list of basic forestry products - wood assortments for 2023. year), the insurance premium, without subsidy, participates: for lichens 27%, and for conifers 35%, which is quite high, but by applying the same subsidy methodology as for agricultural crops of 70% and 80% insurability, the share of the insurance premium in the price of 1 m^3 of wood becomes quite acceptable. For the sake of comparison, the total amount of fire damage in 2012 per hectare was 1,962,085 dinars, which is 207% in relation to the value of wood mass per hectare (949,900 dinars) (Jančić, 2012).

The previous, short analysis leads to the conclusion that it is unacceptable to say that the insurance policy in agricultural production is too expensive and that it is the reason why only a small part of it is protected by insurance.

A lack of information among farmers-one of the reasons for the low level of insurance

Although the experts have been recommending insurance to producers for years, farmers in Serbia are not used to the idea of insuring their crops. The data show that in 2023, only 12.3% of agricultural production was insured, which shows a decrease of 0.3% compared to 2017. (Census of Agriculture in 2023 in Serbia). As the negative impact of climate change is obvious, it is difficult to find an explanation for this. In contrast to domestic manufacturers, their colleagues in Europe have a completely different practice.

The analysis, in the previous chapter, showed that the price of the insurance policy should not be a limiting factor. The state cannot be blamed for being passive, since it carries out various activities, including this year's agricultural fair in Novi Sad, where special attention was paid just to this topic. It was pointed out that the state gives significant funds for insurance incentives in agriculture, but that they are generally used more by large systems and agro-entrepreneurs than by small farms. Unfortunately, it seems that the current incentive level of 40-45% is not enough to make farmers in Serbia more interested in crop insurance, so that the planned funds allocated by the Ministry of Agriculture every year in the agricultural budget remain partially used. In 2023, 1,952,000,000 dinars were paid for insurance subsidies (Radović 2024).

Smaller producers, however, do not insure their crops, because, as they say, insurance is expensive and unprofitable. The problem is that most of them are not informed about the subsidies offered by the state, which specifically apply to areas up to 20 hectares.

Municipalities throughout Serbia help agricultural producers, but due to the lack of information and lack of interest of farmers, a large number of insurance benefits have been reduced.

All analyses lead to the conclusion that agricultural producers are not sufficiently informed and do not have valid information about the benefits of an insurance policy and the possibility of collecting damages caused by hail, stormy winds, fires or the other weather events. Obviously, the information that farmers get are not clear enough and well-explained, in a satisfactory manner. It should be taken into account, that the professional language used in insurance terminology is specific and different in many ways from that in everyday use. It is necessary to explain to the agricultural producer what he insures, how much it will cost him, and in case of damage, what he will be get. The complete process of concluding an insurance contract and compensation for damage must go through with minimal administration.

The next problem is distrust of insurance companies. We should not forget the period during the nineties of the last century and the great disappointment in financial institutions that the people experienced. During that period, the banks stopped paying out foreign currency savings to citizens and dinar savings ,as well as life insurance policies , that were devalued by deliberately caused inflation.

On the other hand, there is certainly a part of those who took out insurance, and then, at the first damage, were disappointed in irresponsible treatment that was done by some insurance companies. To a certain extent, it is also the idea that the state will compensate for larger damages, as it is doing now.

Although legal instruments of insurance are the most dominant form of legal protection of it should be noted that all plant breeders also have mechanisms for the protection of intellectual property rights at their disposal. Given the specifics of the object of protection, legal mechanisms for the protection of new plant varieties belong to a multi-layered system of intellectual property rights (Ćemalović, Petrović, 2019).

The right of plant breeders in the Republic of Serbia is exercised through the Plant Protection Administration, which maintains a register of the title of the right and all necessary data on the newly created plant variety.

Possibilities of increasing the level of insurance in agriculture

The impact of climate change on the realization of some of the risks is obvious, but farmers in Serbia do not accept it as a reality and as a problem of the future. Leaving the fate of their effort to the power of nature, will not bring a good result in the end.

It would be desirable for the state to transfer all risks (fire, flood, storm, hail, snow, landslides, etc.) to the budget in the form of remediation of the consequences, or co-finance its own means of protection . Based on the experiences of other countries and their own conditions, it is necessary to determine measures that would include the necessary preparatory work as a precondition for their successful implementation, which would contain the following:

- Increase the incentive to around 70% and thus give priority to agricultural production;
- Leave the possibility of additional subsidies to local self-governments;
- Allow the right to incentives to all registered farms , regardless of the size of area
- Abolish the upper limit of the amount of subsidized funds;
- Abolish the insurance tax of 5% (in some countries it has been abolished);
- Simplify the procedure for obtaining funds for incentives, which means ;
    - that the incentive request can be submitted throughout the year,
    - that when concluding the insurance contract, the insured pays the part of the premium that is not covered by the subsidy, and the insurance company has to pay the difference directly to the appropriate ministry within a reasonable time,
- Conduct the education through local self-government in cooperation with the Insurance Association
- Introduce mandatory insurance for users of all types of incentives, loans, users of state land, as well as members of cooperatives;
- In addition to crop and fruit insurance, introduce mandatory farm liability insurance. Recently, especially on farms in Vojvodina, there have been cases of poisoning of game and birds. Unburied seed grains that have been treated with pesticides containing toxic substances are suspected;
- Develop a model of public-private partnership in insurance that has proven to be successful in some countries;
- Demand from insurance companies to enter the market with new products that would follow possible new risks;
- In cooperation with insurance companies, create a risk map with an overview of frequency and intensity;
- Form an independent state commission that would arbitrate in cases where the insured is not satisfied with the amount of damage ;

- Ensure the participation of insurance companies in co-financing the education of people in agriculture;
- Use preventive measures to find more modern and reliable defense measures against natural disasters
- In order to avoid moral risk, impose the obligation to plant only certified seed, to use mineral fertilizers, as well as the use of chemical protective agents that must be controlled, in order to realize the income insurance to function
- Provide licenses for parvo purchase and use of all types of protection;
- Abolish drainage and irrigation fees;
- Introduce special subsidies for the installation of irrigation systems;
- Introduce mandatory insurance of state and private forests on the basis of subsidies;
- Suspend all types of support from the state budget to agricultural production that suffered damage
- Introduce strict control over the cost of subsidy funds

The allocated funds from the budget for subsidies would be higher, but the effect would be highly positive, considering that a certain part of the funds would be returned. The funds spent on compensation for damages, which are greater than the amount of insurance incentives, would remain in the budget.

The experience of developed countries shows that these measures would produce good results. In most countries, insurance is mandatory for getting the right to receive subsidies, and there are several measures related to the development of instruments for risk control, such as established public-private funds for compensation of damages.

The conclusion

Agriculture as a key sector in the process of of rural development in Serbia , must have the support of the state, as it is in most developed countries, in order to achieve significant growth, development and competitiveness.

It is to be expected that the state, if it provides all types of support, gets the appropriate results. results. Securing the invested funds, as well as the agriculture generally, is possible by investing in preventive protection measures and by insurance of property.

Taking into account that the level of insurance in agriculture is quite low, and thus a large part of the damage belongs to the budget, the state must introduce mandatory insurance measures (at least for users of budget funds) in order to transfer these risks to insurance companies. These mandatory measures should be accompanied by a higher subsidy of insurance costs, as well as a simple implementation.

All the analyses carried out in this paper show that the insurance of agricultural products in Serbia is profitable both for the state and the owners of agricultural farms.

If the opportunities to protect agriculture, in the form of insurance and a significant increase in the areas that can be irrigated, do not raise to a significantly higher level, agricultural production in Serbia will suffer defeat in the fight with climate change and new challenges.

The question that appears is if we would be able to produce enough food for ourselves in the near future. It would be definitely a huge damage and our irresponsibility, having in mind that we have resources that many countries would like to have.

Conflict of interests

The authors declare no conflict of interest.

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INFLUENCER MARKETING, CULTURAL SENSITIVITY, AND ARTIFICIAL INTELLIGENCE AS DETERMINANTS OF GREEN AGRI-FOOD PRODUCT PURCHASE: THE MODERATING ROLE OF LEGAL NORM COMPLIANCE

Stefan Zdravković[1], Žaklina Spalević[2], Jelena Ignjatović[3], Jelena Živković[4]
**Corresponding author E-mail: szdravkovic034@yahoo.com*

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A B S T R A C T

Sustainable consumption and the transition toward green products, particularly in the agri-food sector, represent important challenges for contemporary agricultural economics. This study examines the influence of influencer marketing, cultural sensitivity, and artificial intelligence on consumers' purchase intentions toward green products, with compliance with legal norms as a moderating factor. The research was conducted in the Republic of Serbia using a survey-based methodology on a sample of 418 respondents. The results show that all examined factors have a statistically significant positive effect on green product purchase, while compliance with legal norms strengthens these relationships. The findings indicate that sustainable consumption is driven by the interaction of digital communication, cultural alignment, technological support, and regulatory trust. It is recommended that agricultural producers and food marketers combine digital marketing tools with culturally adapted communication while ensuring adherence to legal standards. The study provides insights for policymakers supporting sustainable agri-food market development.

1 Stefan Zdravković, Assistant Professor, MB University, Faculty of Business and Law, Teodora Drajzera 27, 11 000 Belgrade, Serbia, Phone: +381693808004, E-mail: stefan.zdravkovic@ppf.edu.rs, ORCID ID (https://orcid.org/0000-0002-0047-3356)

2 Žaklina Spalević, Full Professor, Singidunum University, Faculty of Tourism and Hospitality Management, Danijelova 32, 11 000 Belgrade, Serbia, Phone: +381691233797, E-mail: zspalevic@singidunum.ac.rs, ORCID ID (https://orcid.org/0000-0001-8502-2038)

3 Jelena Ignjatović, Assistant Professor, MB University, Faculty of Business and Law, Teodora Drajzera 27, 11 000 Belgrade, Serbia, Phone: +38166300007 , E-mail: jelenaignjatovicjeka@gmail.com, ORCID ID (https://orcid.org/0009-0007-1851-9328)

4 Jelena Živković, Research Associate, Univeristy in Kragujevac, Institute for Information Technologies, Liceja Kneževine Srbije 1A, 34000 Kragujevac, Serbia, Phone: +381612699038, E-mail: jelenazivkovic@uni.kg.ac.rs, ORCID ID (https://orcid.org/0000-0002-8670-4249)

Introduction

Global pressures related to environmental protection, climate change, and the sustainable use of natural resources have positioned green products—particularly those originating from the agri-food sector—as a strategic priority in contemporary marketing and agricultural economics (Klabi, 2025). Rising consumer awareness of environmental and health-related issues has increased demand for products that are not only environmentally friendly but also associated with organic production, food safety, and responsible agricultural practices (Sun et al., 2025). In this context, understanding the determinants of consumers' purchase intentions toward green products is of critical importance for researchers, policymakers, and agri-food market participants (Long et al., 2024; Radomirović et al., 2025; Testa et al., 2024).

In recent years, influencer marketing has emerged as a powerful communication tool capable of shaping consumer attitudes and behaviors, particularly in markets characterized by information asymmetry, such as those related to organic food, sustainable agriculture, and green agri-food products. Influencers, as contemporary opinion leaders, can affect consumer trust and perceptions through personalized content, experiential narratives, and perceived authenticity, thereby influencing purchase decisions related to sustainable and healthy products (Cai et al., 2025). Alongside influencer marketing, cultural sensitivity—the ability to recognize, understand, and respect cultural norms, values, and consumption habits—plays a crucial role in tailoring marketing messages to diverse consumer segments, especially in the context of food consumption and traditional dietary practices (Bhardwaj et al., 2023).

The third pillar of this research, artificial intelligence (AI), has gained increasing relevance in both marketing and the agri-food sector. AI-driven tools enable more efficient market segmentation, personalized product recommendations, and predictive analysis of consumer behavior, thereby enhancing the effectiveness of marketing strategies aimed at promoting green and sustainable products (Wang et al., 2025). In the context of agricultural markets, AI contributes to improved transparency, traceability, and communication of product attributes, which are particularly important for green and organic products.

In addition to these market-oriented factors, compliance with legal norms has become an indispensable element of sustainable consumption and agricultural development. Regulatory frameworks governing food safety, organic certification, environmental protection, and consumer rights play a critical role in shaping consumer trust and market dynamics. Legal norm compliance not only ensures transparency and accountability within the agri-food sector but may also moderate the effectiveness of marketing and communication strategies in influencing consumer behavior. Although prior studies acknowledge the importance of legal regulations in sustainable consumption, an integrated analytical approach that simultaneously examines influencer marketing, cultural sensitivity, and artificial intelligence—while explicitly considering the moderating role of legal norms—remains insufficiently explored (Fan & Liu, 2025; Životić et al., 2025; Huang et al., 2025).

This study addresses the identified research gap through an empirical analysis conducted on a sample of consumers in the Republic of Serbia, employing Partial Least Squares Structural Equation Modeling (PLS-SEM) using the SmartPLS 4 software package. The theoretical contribution of this paper lies in the development of an integrative framework that links key contemporary digital marketing determinants with sustainable consumption in the agri-food context, while explicitly incorporating legal norm compliance as a moderating variable. From a practical perspective, the study provides actionable insights for agricultural producers, food marketers, and policymakers by offering guidelines for designing integrated marketing strategies that combine digital communication, cultural adaptation, and regulatory compliance to stimulate the purchase of green products.

The remainder of the paper is structured as follows. The next section presents a review of the relevant literature and the development of research hypotheses, followed by a description of the research methodology. The subsequent section reports and discusses the empirical results, while the final section outlines the main conclusions, theoretical contributions, practical implications, and directions for future research.

Literature review

Green Product Purchase

Green product purchase refers to consumers' intentions and behaviors related to selecting products with environmentally beneficial attributes, such as reduced environmental impact, recyclable packaging, and sustainable production practices (Filipović et al., 2024). Within the agri-food sector, green products are closely associated with organic food, environmentally responsible agricultural production, food safety, and healthy nutrition, making purchase decisions particularly sensitive to trust, information transparency, and perceived risk (Nitzko, 2024; Wan et al., 2026).

From the stimulus–organism–response (S-O-R) perspective, environmental messages, eco-labels, and sustainability cues act as stimuli that shape internal consumer states—such as attitudes, trust, and perceived value—which ultimately influence purchasing behavior. Similarly, the Theory of Planned Behavior (TPB) explains green product purchase through the joint effects of attitudes toward green products, subjective norms, and perceived behavioral control. Across these theoretical perspectives, credible information, social influence, cultural congruence, and risk reduction consistently emerge as key drivers of green purchase behavior, especially in markets for agri-food products characterized by credence attributes (Li et al., 2025; Pratama, 2020). These mechanisms directly correspond to the effects generated by influencer marketing, cultural sensitivity, and AI-driven personalization.

2.2. Influencer Marketing and Green Product Purchase

Influencer marketing relies on para-social interactions and perceived source credibility, including expertise, trustworthiness, and attractiveness, to shape consumer attitudes and behavioral norms. Within the Elaboration Likelihood Model (ELM), influencers may operate through both the central route—by providing diagnostic information, product demonstrations, and comparative arguments—and the peripheral route, by leveraging heuristics such as social proof and perceived authenticity. In the context of green and agri-food products, which often involve complex quality attributes and certification-based claims, trust in the information source becomes particularly salient. Influencers who communicate transparent environmental information, disclose sponsorships, and demonstrate personal engagement with green or organic food products can significantly reduce perceived risk and enhance perceived value, thereby strengthening purchase intentions (Rehman et al., 2025). Empirical evidence suggests that influencer credibility and identification play a decisive role in translating sustainability-related messages into green product purchase behavior (Meet et al., 2024; Zhou & Jiang, 2025).

H1: Influencer marketing has a positive effect on green product purchase.

Cultural Sensitivity and Green Product Purchase

Cultural sensitivity refers to the ability to recognize, understand, and adapt marketing communication to the cultural norms, values, and symbolic meanings of target consumer groups (Liao et al., 2023). In agri-food markets, consumption patterns are deeply embedded in cultural traditions, dietary habits, and social norms, which makes culturally sensitive communication especially important when promoting green and organic food products. Messages that align with local values—such as collective responsibility, environmental stewardship, or health consciousness—enhance message relevance, reduce psychological distance, and foster perceived respect for consumers' cultural identities. Prior research indicates that such alignment positively influences attitudes and behavioral intentions by increasing trust and perceived authenticity (Liang et al., 2024; Dobričanin & Aleksić, 2025; Shuilong et al., 2024). From an S-O-R perspective, cultural sensitivity enhances the diagnosticity and comfort associated with green claims, thereby facilitating approach behavior and green product purchase.

H2: Cultural sensitivity has a positive effect on green product purchase.

Artificial Intelligence and Green Product Purchase

Artificial intelligence (AI) has become an increasingly important tool in marketing and agri-food supply chains, enabling predictive targeting, personalized content delivery, optimized communication timing, and interactive decision support through recommender systems and chatbots. By tailoring green product information to consumers' preferences, dietary needs, and stages of the decision-making process, AI increases perceived relevance while simultaneously reducing search and decision costs. Within the TPB framework, AI-driven personalization strengthens favorable attitudes and perceived behavioral control by enhancing clarity, convenience, and informational accessibility. In addition, algorithmic recommendations may serve as normative cues, reinforcing social approval for sustainable consumption choices (Mijit et al., 2025).

Given the credence nature of many green agri-food products, AI systems can also provide timely access to certifications, labels, and traceability information, thereby reducing perceived risk and supporting green purchase decisions (Xu, 2025).

H3: Artificial intelligence has a positive effect on green product purchase.

Compliance with Legal Norms as a Moderator

Compliance with legal norms (hereafter: legal compliance) reflects firms' adherence to relevant laws, standards, and disclosure requirements, including truthful environmental claims, transparent advertising, data protection, and consumer rights. In the context of agri-food markets, legal compliance is closely linked to food safety regulations, organic certification schemes, and environmental standards. From institutional and legitimacy perspectives, visible legal compliance signals accountability and procedural fairness, thereby enhancing consumer trust and perceived credibility. Moreover, compliance reduces perceived legal and ethical risks related to greenwashing, misleading claims, or misuse of consumer data—risks that may otherwise weaken the effectiveness of marketing communication (Fan & Liu, 2025; Huang et al., 2025; Orset, 2024). Legal compliance can strengthen the impact of influencer marketing by ensuring transparent sponsorship disclosure and truthful environmental messaging, which increases influencer credibility and reduces consumer skepticism (Orset, 2024; Rojas & Yasin, 2025).

H4a: Legal compliance positively moderates the relationship between influencer marketing and green product purchase.

Similarly, culturally adapted marketing messages that comply with local advertising and consumer-protection regulations avoid misrepresentation and ethical pitfalls. Such compliance ensures that culturally resonant claims remain accurate and trustworthy, thereby amplifying their persuasive effect (Dlamini & Mahowa, 2024; Najafabadiha et al., 2025; Zhang et al., 2025).

H4b: Legal compliance positively moderates the relationship between cultural sensitivity and green product purchase.

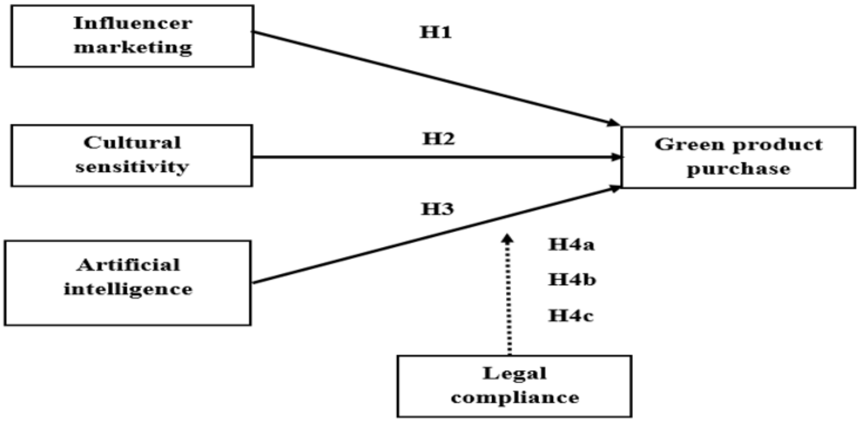
Finally, the effectiveness of AI-driven marketing may be undermined by concerns related to privacy, data misuse, and algorithmic opacity. Compliance with data-protection regulations and AI transparency requirements—such as informed consent and explainability—reduces these concerns and increases consumers' willingness to rely on AI-generated recommendations for green products (Srisathan et al., 2024; Wei et al., 2024).

H4c: Legal compliance positively moderates the relationship between artificial intelligence and green product purchase.

Conceptual Model

The conceptual model (Figure 1) specifies three direct effects on green product purchase—namely influencer marketing, cultural sensitivity, and artificial intelligence—as well as three interaction effects, with legal norm compliance moderating each relationship. The model is grounded in the stimulus–organism–response (S-O-R) and Theory of Planned Behavior (TPB) frameworks, whereby persuasive and relevance-enhancing stimuli—such as influencer communication, cultural congruence, and AI-driven personalization—shape consumers' internal evaluations and behavioral intentions. Within the context of green and agri-food products, legal norm compliance functions as a contextual mechanism that reduces perceived risk and enhances credibility by ensuring transparency, regulatory alignment, and trustworthiness of marketing messages. As a result, legal compliance strengthens the effectiveness of marketing-related stimuli in translating positive attitudes and perceptions into green product purchase behavior.

Figure 1. Conceptual model



Soruce: Authors

Research methodology

This study was conducted in the Republic of Serbia to empirically examine the effects of influencer marketing, cultural sensitivity, and artificial intelligence on green product purchase, with compliance with legal norms serving as a moderating variable. Given the relevance of green products—particularly green and agri-food products—in the context of sustainable consumption and agricultural markets, a survey-based research design was adopted to capture consumers' perceptions and attitudes. The sample comprised 418 respondents (Table 1), selected using a convenience sampling approach, which enabled efficient data collection within the defined research framework. The collected data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) implemented in the SmartPLS 4 software package. This method is particularly suitable for examining complex relationships among latent constructs, including moderation effects, and is widely applied in studies related to marketing, sustainability, and consumer behavior in agri-food markets. All research variables were measured using previously validated measurement scales adapted from the existing literature (Li et al., 2025; Meet et al., 2024; Orset, 2024; Wei et al., 2024; Xu, 2025) and assessed on a seven-point Likert scale, where 1 represents "strongly disagree" and 7 represents "strongly agree" (Table 2).

Table 1. Demographic structure of respondents

		Number of respondents	**% respondents**
Gender	Female	211	50.1%
	Male	207	49.9%
	Total	**418**	**100%**
Age	Up to 20 years	11	2.6%
	21-30 years	114	27.3%
	31-40 years	106	25.4%
	41-50 years	88	21.0%
	51-60 years	55	13.2%
	61 years and over	44	10.5%
	Total	**418**	**100%**
Education	Primary school	6	1.4%
	High school	219	52.4%
	Faculty	193	46.2%
	Total	**418**	**100%**

Source: Authors

Table 1 summarizes the demographic characteristics of the 418 respondents. The gender structure is well balanced, with 50.1% female and 49.9% male participants. In terms of age, the largest share of respondents belongs to the 21–40 age group (52.7%), a cohort typically characterized by high exposure to digital communication channels and growing awareness of sustainable and healthy consumption. Respondents aged up to 20 years account for 2.6% of the sample, while those aged 51 years and above represent 23.7%. With respect to educational attainment, the majority of respondents have completed secondary education (52.4%), followed by those holding a university degree (46.2%), whereas respondents with primary education constitute only a marginal proportion of the sample (1.4%).

Table 2. Measurement items, Cronbach's alpha, and Composite reliability

Variables	Statements	Cronbach's alpha	Composite Reliability
Influencer marketing	**IM1:** Influencers I follow provide useful and reliable information about green products, particularly those related to sustainable and healthy consumption. **IM2:** Influencers I trust influence my decision to purchase green products. **IM3:** Influencer messages are perceived as authentic and relevant to my choice of green products. **IM4:** Recommendations provided by influencers increase my willingness to purchase green products.	**0.895**	**0.889**
Cultural sensitivity	**CS1:** Marketing messages for green products reflect local cultural values and consumption traditions. **CS2:** Marketing communication is adapted to the language and symbols that are familiar and meaningful to me. **CS3:** Communication about green products demonstrates respect for diverse cultural perspectives. **CS4:** Culturally adapted content increases my motivation to purchase green products.	**0.847**	**0.866**
Artificial intelligence	**AI1:** AI-based tools (e.g., recommender systems and chatbots) help me easily identify green products. **AI2:** AI-driven personalization increases the relevance of information about green products. **AI3:** AI facilitates my decision-making process when purchasing green products. **AI4:** Recommendations provided by AI increase my willingness to purchase green products.	**0.915**	**0.896**
Legal compliance	**LC1:** Companies offering green products comply with applicable laws, regulations, and standards. **LC2:** The transparency and truthfulness of information about green products positively influence my trust. **LC3:** Compliance with legal norms increases my willingness to purchase green products. **LC4:** Adherence to legal and regulatory requirements strengthens the effects of influencer marketing, cultural sensitivity, and artificial intelligence on my purchase decisions.	**0.887**	**0.896**
Green product purchase	**GP1:** I frequently choose green or eco-friendly products, particularly food and agri-food products produced in an environmentally responsible manner. **GP2:** My purchase decisions, especially regarding food and agricultural products, depend on their environmental attributes. **GP3:** I am willing to pay a higher price for green products, particularly agri-food products, due to their ecological and health-related value. **GP4:** Purchasing green and sustainably produced agri-food products is an integral part of my everyday consumer decisions.	**0.929**	**0.918**

Source: Authors

Table 2 presents the measurement items, Cronbach's alpha, and Composite Reliability (CR) for all latent constructs used in this study. The results indicate strong internal consistency across all variables. Specifically, Cronbach's alpha values range from 0.847 (Cultural Sensitivity) to 0.929 (Green Product Purchase), exceeding the commonly accepted threshold of 0.70, which confirms the reliability of the scales. Similarly, Composite Reliability values are all above 0.85, further supporting the internal consistency and robustness of the measurement model. The high reliability coefficients for Influencer Marketing ($\alpha = 0.895$; CR = 0.889), Cultural Sensitivity ($\alpha = 0.847$; CR = 0.866), Artificial Intelligence ($\alpha = 0.915$; CR = 0.896), Legal Compliance ($\alpha = 0.887$; CR = 0.896), and Green Product Purchase ($\alpha = 0.929$; CR = 0.918) indicate that the items consistently capture their respective latent constructs (Hair et al., 2006; Nunnally, 1978). Results provide confidence that the subsequent PLS-SEM analysis is based on valid and reliable measures.

Research results

Table 3 presents the Average Variance Extracted (AVE) for all research variables, which indicates the proportion of variance captured by each construct relative to the variance due to measurement error.

Table 3. Average variance extracted (AVE) for research variables

Research variables	Average Variance Extracted (AVE)
Influencer marketing	0.763
Cultural sensitivity	0.712
Artificial intelligence	0.698
Legal compliance	0.681
Green product purchase	0.769

Source: Authors

These results confirm adequate convergent validity of the measurement model, demonstrating that the indicators of each latent construct effectively represent the underlying theoretical concept. The high AVE values for Influencer Marketing (0.763), Cultural Sensitivity (0.712), Artificial Intelligence (0.698), Legal Compliance (0.681), and Green Product Purchase (0.769) provide strong evidence that the constructs reliably capture the intended dimensions of the model, all exceeding the recommended threshold of 0.50 (Fornell and Larcker, 1981).

To assess the overall fit of the proposed model, key model fit indicators are presented in Table 4.

Table 4. Model fit indicators for the green product research model

Indicators of model validity	Research model – Green product	Recommended value
$\chi2$/df	1.892	<3
GFI	0.914	>0.9
IFI	0.933	>0.9
TLI	0.911	>0.9
CFI	0.957	>0.9
RMSEA	0.030	<0.08

Source: Authors

The reported values demonstrate an excellent fit between the proposed model and the observed data. Specifically, the χ^2/df ratio is 1.892, which is below the recommended threshold of 3, indicating a good fit (Bagozzi and Yi, 1988). Other fit indices further confirm the adequacy of the model: the Goodness-of-Fit Index (GFI = 0.914), Incremental Fit Index (IFI = 0.933), Tucker-Lewis Index (TLI = 0.911), and Comparative Fit Index (CFI = 0.957) all exceed the recommended value of 0.9 (Byrne, 1998). Additionally, the Root Mean Square Error of Approximation (RMSEA = 0.030) is well below the threshold of 0.08, suggesting minimal approximation error (Hair et al., 2006). Overall, these results indicate that the proposed PLS-SEM model provides a robust and reliable representation of the relationships among influencer marketing, cultural sensitivity, artificial intelligence, legal compliance, and green product purchase.

To examine the direct effects of the independent variables on green product purchase, the PLS-SEM path coefficients are presented in Table 5.

Table 5. PLS-SEM results – Impact of independent variables on the Green product purchase

Independent variables	Path coefficient	Standard deviation	T statistics	P values
Influencer marketing	0.359	0.066	5.897	0.000**
Cultural sensitivity	0.338	0.053	5.336	0.000**
Artificial intelligence	0.412	0.081	6.478	0.000**

Notes: Level of statistical significance: **0.01
Source: Authors

Table 5 reports the PLS-SEM results for the impact of influencer marketing, cultural sensitivity, and artificial intelligence on green product purchase. All three independent variables exhibit significant positive effects. Specifically, influencer marketing shows a path coefficient of 0.359 ($t = 5.897$, $p < 0.01$), cultural sensitivity has a coefficient of 0.338 ($t = 5.336$, $p < 0.01$), and artificial intelligence demonstrates the strongest effect with a coefficient of 0.412 ($t = 6.478$, $p < 0.01$). These results ***confirm that all hypothesized direct relationships (H1, H2, H3) are statistically significant***, indicating that higher levels of influencer marketing, culturally sensitive messaging, and AI-supported personalization are associated with increased green product purchase among consumers.

To investigate the moderating role of legal compliance on the relationships between the independent variables and green product purchase, the PLS-SEM moderation results are presented in Table 6.

Table 6. Moderation of Legal compliance in the PLS-SEM model (dependent variable: Green product)

Relatinos	Path coefficient	Standard deviation	T statistics	P values
Influencer marketing X Legal compliance	0.224	0.055	4.398	0.003**
Cultural sensitivity X Legal compliance	0.298	0.071	5.277	0.001**
Artificial intelligence X Legal compliance	0.368	0.088	5.917	0.000**

Notes: Level of statistical significance: **0.01

Source: Authors

Table 6 presents the results of the moderation analysis, examining the influence of legal compliance on the relationships between influencer marketing, cultural sensitivity, artificial intelligence, and green product purchase. The interaction effects of legal compliance are all positive and statistically significant. Specifically, the interaction between influencer marketing and legal compliance has a path coefficient of 0.224 ($t = 4.398$, $p < 0.01$), cultural sensitivity × legal compliance shows 0.298 ($t = 5.277$, $p < 0.01$), and artificial intelligence × legal compliance demonstrates the strongest moderation effect with 0.368 ($t = 5.917$, $p < 0.01$). These findings indicate that legal compliance strengthens the impact of influencer marketing, cultural sensitivity, and AI on green product purchase. In other words, the effectiveness of these independent variables is enhanced when companies demonstrate high adherence to laws and regulations, ***confirming the hypothesized moderating roles (H4a, H4b, H4c).***

Discussion of Results

The findings of this study are largely consistent with prior research examining green product purchase, influencer marketing, cultural sensitivity, and AI-enabled personalization (Liang et al., 2024; Meet et al., 2024; Shuilong et al., 2024; Zhou & Jiang, 2025; Xu, 2025). The confirmation of all hypothesized direct and moderating effects indicates that these factors play a significant role in shaping consumers' intentions to purchase green products. From a broader perspective, the results reinforce the view that sustainable consumption is not driven by a single determinant but emerges from the interaction of marketing communication, cultural alignment, technological facilitation, and regulatory trust. In the context of the agri-food sector and agricultural economics, these findings are particularly relevant. Green products—especially organic and sustainably produced food—are typically characterized by credence attributes, meaning that consumers cannot easily verify their quality, environmental impact, or production methods prior to purchase. As a result, trust, information transparency, and perceived credibility become central to purchase decisions. The positive impact of influencer marketing observed in this study suggests that influencers function as important informational intermediaries who reduce information asymmetry between producers and consumers in agri-food markets. By communicating production practices, ecological benefits, and personal consumption experiences, influencers help consumers form favorable attitudes toward green and organic products, thereby supporting demand for sustainably produced agricultural goods.

Similarly, the confirmed effect of cultural sensitivity highlights the importance of aligning marketing messages with local consumption habits, food traditions, and culturally embedded perceptions of healthy and sustainable diets. In agricultural markets, food choices are deeply rooted in cultural norms and everyday practices, which explains why culturally adapted communication enhances the effectiveness of green product promotion. These results suggest that green marketing strategies in the agri-food sector should not rely solely on universal environmental arguments but should also incorporate culturally meaningful narratives related to local food heritage, traditional agricultural practices, and region-specific dietary values. The significant positive influence of artificial intelligence further underscores the growing role of digital technologies in modern agri-food markets. AI-driven personalization enhances consumers' decision-making by delivering relevant, timely, and tailored information about green products, including certifications, origin, and environmental attributes. From an economic perspective, AI reduces search and transaction costs, increases market efficiency, and facilitates better matching between consumer preferences and green product offerings. This is particularly important for organic and sustainable food markets, where consumers often face complex information environments and higher perceived risks.

A key contribution of this study lies in demonstrating the moderating role of legal norm compliance across all examined relationships. In the context of agricultural economics, regulatory frameworks related to food safety, organic certification, environmental standards, and consumer protection are fundamental for building market trust. The findings indicate that legal compliance amplifies the effectiveness of influencer marketing, cultural sensitivity, and AI-based communication by signaling transparency, accountability, and institutional reliability. This suggests that marketing and technological efforts to promote green agri-food products are most effective when embedded within a strong and visible regulatory environment.

By integrating marketing, cultural, technological, and legal dimensions into a single analytical framework, this study extends existing research that has predominantly examined these factors in isolation. The holistic approach adopted here offers a more comprehensive understanding of consumer behavior in green and agri-food markets and reflects the complex reality of sustainable consumption in contemporary agricultural economies. In doing so, the study moves beyond narrow, single-factor explanations and provides empirical evidence that sustainable consumption is shaped by the interplay of multiple, mutually reinforcing forces.

Overall, the results emphasize that the promotion of green products in the agri-food sector requires coordinated strategies that simultaneously address consumer trust, cultural relevance, technological innovation, and regulatory compliance. This integrative perspective not only enriches the theoretical literature on green marketing and sustainable consumption but also provides valuable insights for agricultural producers, food marketers, and policymakers seeking to stimulate demand for environmentally responsible and sustainably produced agricultural goods.

Conclusions

This study provides a comprehensive examination of the determinants of green product purchase in the Republic of Serbia, with particular relevance to green and agri-food products within the broader context of agricultural economics and sustainable food markets. By empirically confirming the statistically significant effects of influencer marketing, cultural sensitivity, and artificial intelligence—alongside the moderating role of legal norm compliance—the findings demonstrate that sustainable consumer behavior emerges from the interaction of marketing communication, cultural alignment, technological support, and institutional trust. The results indicate that these factors jointly shape consumers' willingness to engage in environmentally responsible consumption, especially in markets characterized by information asymmetry and credence attributes, such as organic and sustainably produced food.

The originality of this research lies in the development and empirical validation of a holistic conceptual model that integrates marketing, cultural, technological, and legal determinants of green product purchase within a single analytical framework. Unlike prior studies that have predominantly examined these factors in isolation, this study captures the complexity of consumer decision-making in sustainable and agri-food markets by explicitly modeling their joint and interactive effects. By incorporating legal norm compliance as a moderating variable, the research introduces an institutional dimension that is particularly relevant for agricultural economics, where regulatory frameworks related to food safety, organic certification, and environmental standards play a decisive role in shaping market outcomes.

From a theoretical perspective, the study advances the literature on green marketing and sustainable consumption by adopting an integrative approach that bridges marketing theory, cultural perspectives, technological innovation, and institutional frameworks. The findings extend existing models of green consumption by demonstrating that consumer responses to sustainability-oriented stimuli are significantly strengthened when embedded in a legally compliant environment. This contributes to a more nuanced understanding of how multiple stimuli interact to influence purchase behavior, particularly in agri-food markets where trust, credibility, and regulatory assurance are central. In this way, the study addresses an important gap in the literature and provides a more comprehensive explanation of green product consumption from an economic and institutional standpoint.

The results offer several important ***practical implications*** for agricultural producers, food marketers, and policymakers. Firms seeking to promote green and organic products should adopt a multidimensional strategy that simultaneously leverages credible influencer marketing, culturally adapted communication, and AI-supported personalization, while ensuring strict compliance with legal and regulatory requirements. Such an approach enhances consumer trust, reduces perceived risk, and increases purchase intention, thereby supporting demand for sustainably produced agricultural goods. For policymakers, the findings highlight the importance of transparent and well-enforced regulatory frameworks, as legal compliance amplifies the effectiveness of marketing and technological tools aimed at promoting sustainable consumption. These insights are particularly relevant for strengthening green agri-food markets and supporting sustainable agricultural development.

Despite its contributions, this study has ***certain limitations***. The use of a cross-sectional survey design and convenience sampling in Serbia limits the generalizability of the findings to other national and cultural contexts. ***Future research*** could address these limitations by employing longitudinal designs to capture changes in consumer behavior over time and by extending the proposed model to other countries and agri-food markets. Additionally, incorporating further explanatory or moderating variables—such as environmental awareness, social norms, trust in food institutions, or rural–urban differences—could provide an even deeper understanding of sustainable consumption patterns. Such extensions would further enhance the relevance of this research for the field of agricultural economics and the development of resilient and sustainable food systems.

Conflict of interests

The authors declare no conflict of interest.

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CONSUMER TRENDS IN BAKERY MARKET: UNDERSTANDING OF CONSUMER PERSPECTIVES AND PREFERENCES FOR FUNCTIONAL BAKERY PRODUCTS IN SLOVAKIA

Kristína Predanócyová[1], Peter Šedík[2], Cristina Bianca Pocol[3]
**Corresponding author E-mail: peter.sedik@uniag.sk*

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ABSTRACT

The aim of the paper is to identify key consumer attitudes towards functional bakery products and explore factors affecting consumer behavior. The study is based on questionnaire survey conducted on a sample of 775 functional bakery products consumers in Slovakia. The results showed that consumers prefer grain and whole wheat bread, while sweet pastries with low-calorie sweeteners are the least consumed. Furthermore, key factors influencing purchase are freshness, quality, taste, and health benefits. The results indicated that consumers are choosing products based on increased whole grain content, fiber, and minerals and key reasons for consumption are reducing obesity risk and supporting digestive health. The study also pointed out consumer awareness and interest in healthy eating as key drivers for future market development. Findings provide valuable information to food companies in the new bakery products development and marketing, as well as to policy makers in supporting the public health.

Introduction

Bakery products play an important role in human nutrition and are the basis of any daily diet. Their social importance is linked to cultural traditions, availability and diverse assortment (Mickiewicz, Britchenko, 2022). The global bread and bakery market

1 Kristína Predanócyová, researcher, Slovak University of Agriculture in Nitra, AgroBioTech Research Centre, Trieda A. Hlinku 2, 949 76 Nitra, Slovakia, Phone: +421 37 641 4908, E-mail: kristina.predanocyova@uniag.sk, ORCID ID (https://orcid.org/0000-0001-8867-1666)

2 Peter Šedík, associate professor, Slovak University of Agriculture in Nitra, Institute of Marketing, Trade and Social Studies, Faculty of Economics and Management, Trieda A. Hlinku 2, 949 76, Nitra, Slovakia, Phone: +421 37 641 4163, E-mail: peter.sedik@uniag.sk, ORCID ID (https://orcid.org/0000-0003-2495-5162)

3 Cristina Bianca Pocol, professor, University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Faculty of Veterinary Medicine, Department of Animal Production and Food Safety, Calea Mănăștur 3-5, Cluj-Napoca 400372, Romania, Phone: +40 740176785, E-mail: cristina.pocol@usamvcluj.ro, ORCID ID (https://orcid.org/0000-0001-5079-8004)

has evolved significantly over the past decade, driven by changing dietary patterns, increased competition from small-capacity bakeries and retail chains, the adoption of digital technologies, the COVID-19 pandemic, as well as broader economic and political developments (Kostyuchenko et al., 2024). In this context, functional bakery products have emerged to meet these new market trends and are defined as products that offer health benefits beyond their basic nutritional value, through the inclusion of functional ingredients or the optimization of their nutritional composition (Guiné, Florença, 2024; Karantonis et al., 2022). The increased demand for such products prompts companies to diversify and innovate, creating opportunities for market expansion and exports (Królak et al., 2022). It follows from the above that the current trend is the expansion of functional bakery products to meet the nutritional needs of consumers as well as the requirements for an active lifestyle and sustainable consumption (Kostyuchenko et al., 2024; Mickiewicz, Britchenko, 2022; Maiboroda, 2021).

Functional bakery products play an essential role in today's food context, particularly due to the increasing incidence of chronic diseases associated with unhealthy eating and modern lifestyles (Dossa, Rivis, 2024; Martirosyan et al., 2021). Given that bakery products are staple foods and are consumed frequently and in large quantities by the majority of the global population (Mickiewicz, Britchenko, 2022; Di Cairano et al., 2022), fortifying them with functional ingredients is an effective and affordable way to increase their nutritional value, reduce the risk of disease and support long-term health (Zupo et al., 2026; Guiné, Florença, 2024; Karantonis et al., 2022). The functionality of sweet or savory bakery products can result from their intrinsic properties or from the incorporation of beneficial ingredients such as fiber, protein and bioactive molecules (Di Cairano et al., 2022). The literature highlights a significant diversity of studies on functional bakery products, focusing either on sensory attributes or on health claims (Guiné, Florença, 2024; Pinto et al., 2014). However, there are few studies that analyze the purchasing and consumption behavior of functional bakery products (Han, Kim, 2015; Hwang et al., 2006), with most research focusing on conventional bakery products (Chatziharalambous, Koutelidakis, 2025; Choudhary et al., 2021). Current marketing strategies in the bakery sector are based on innovation and the use of technologies that enable the development of new products to meet several criteria simultaneously: they must be tasty, healthy and affordable (Guiné, Florença, 2024; Zarzycki et al., 2024). Improving the chemical composition of bakery products often involves replacing traditional ingredients with healthier ones and this is a challenge for manufacturers, who need to maintain product quality and stability in the long term, as well as consumer acceptance, due to possible changes in sensory characteristics (Zarzycki et al., 2024; Sajdakowska et al., 2020). Cristea et al. (2025) highlight that the success of marketing strategies depends on the integration of elements specific to sustainable development and the customization of functional bakery products (Zhang et al., 2022).

Consumer preferences regarding functional bakery products are influenced by numerous factors: cognitive, sensory, value-based and contextual. Nicolosi et al. (2023) highlight that buyers' choices are increasingly conscious, being determined both by taste pleasure and, above all, by the level of knowledge about the benefits of the products. The information on the label can play a decisive role in the choice and consumption of these products, especially among health-conscious consumers and athletes (Sajdakowska et al., 2020). Increased consumer awareness of labels and ingredients is driving a preference for functional bakery products with "clean labels," which are natural and free of synthetic additives (Polachini et al., 2023). Chatziharalambous and Koutelidakis (2025) recommend that stakeholders grant tax breaks to manufacturers of functional bakery products and take measures to ensure the correct labeling of these products, while also organizing public health campaigns to educate consumers on how to read and understand the information provided on labels. Freshness and minimal processing are among the most important attributes for consumers, as they are associated with safety and health benefits (Miolla et al., 2023).

According to Guiné and Florença (2024), awareness of the importance of healthy eating and the search for more nutritious food alternatives are determining factors in the choice and consumption of these products. Health-related motivations are also highlighted in the study by Sajdakowska et al. (2020), which analyses consumer behavior in the case of bread enriched with functional ingredients. Thus, the perception that fiber bread is more nutritious and helps prevent health problems significantly influences the consumption of this type of functional bakery product. However, functional benefits are not sufficient for product acceptance if the sensory experience, especially taste, does not match consumer preferences (Zhang et al., 2025). Other authors emphasize that taste has a greater influence on consumer preferences than health benefits, which requires greater attention to be paid to the sensory acceptability of innovative functional products (Miolla et al., 2023). Similarly, Mickiewicz and Britchenko (2022) consider taste to be a key factor in the success of demand for functional bakery products. Fortifying bakery products with functional ingredients can generate unpleasant flavors for consumers, but these effects can be prevented by protective techniques such as microencapsulation, which preserves both taste and nutritional benefits (Tolve et al., 2022). Sensory changes, including flavor and texture, influence consumer acceptance of the product; even though fortification with different functional ingredients can generate different tastes or sensations, acceptance remains sufficiently high if these changes are not extreme (Liu et al., 2022). In addition to sensory elements, consumer preferences for functional bakery products are also influenced by personal experiences, such as "green experiences," concerns about climate change, ecological orientation and marketing communication (Nicolosi et al., 2023).

Trust in functional products increases with income and household size, suggesting that economic stability and family responsibilities positively influence the acceptance of this type of product (Chatziharalambous, Koutelidakis, 2025). Other studies indicate that significant factors determining consumers' willingness to purchase bakery products enriched with functional ingredients include level of education, the presence of the mother in the household as the main decision-maker in food purchases, the perception that these products are healthy, and their taste (Bocog et al., 2023). The income of the population significantly influences the consumption of functional bakery products therefore the purchase of functional bakery products is influenced by price and consumers' financial availability. The shift from cheap, high-calorie products to local, healthy and innovative products suggests that those willing to pay more opt for higher quality and functional products (Lobanov et al., 2018). The acceptance of functional bakery products is influenced by a complex combination of sensory, cognitive, socio-demographic and economic factors, and the effect of each factor may vary depending on the cultural and economic context (Mickiewicz, Britchenko, 2022). In this sense, consumer perception and motivation for these products are not uniform and commercial success depends on adapting marketing to regional differences and the type of information presented about them (Bruschi et al., 2015). The main objective of the paper is to identify key consumer attitudes towards functional bakery products and explore factors influencing consumer behavior, with an emphasis on future market development in Slovakia. Several research questions were formulated:

RQ1: What factors influence consumers' purchasing decisions regarding functional bakery products?

RQ2: What are the main reasons for consuming functional bakery products?

RQ3: What are the main drivers of the future functional bakery products market?

Materials and methods

The study involves an investigation based on a consumer survey that examines consumer behavior in the functional bakery products market in Slovakia. Questionnaire survey was carried out in 2021 on a sample of 775 consumers of functional bakery products across Slovakia and the data were collected using the snowball sampling method. The research sample can be characterized as follow: 61.7% women, 57.9% living in rural areas, 79.9% secondary education, 16.9% university education and 3.2% primary education. In terms of age, the sample includes <25 years (45.8%), 25-49 years (35.1%) and >49 years (19.1%). Most respondents in the sample are economically active people (47.5%) or students (41.4%). The sample included respondents from all regions of Slovakia, although the Nitra Region was the most strongly represented.

The research design of the survey was focused on identifying the key factors, expectations, and motivations for functional bakery products consumption. Only consumers who regularly and occasionally consume functional bakery products participated in the research.. Consumption frequency of selected types of functional bakery products namelywhole grain bread, whole wheat bread, bakery products with increased protein value, bakery products with increased vitamin value, bakery products with increased mineral value, sweet pastries containing low-calorie sweeteners, sweet pastries enriched with functional ingredients were examined. Additionally, the study identified the factors influencing consumers' purchasing and consumption decisions. The respondents evaluated 19 factors using 7-point scale, where 1 represented no importance while 7 represented high importance. The scale exhibited good internal consistency reliability, as indicated by Cronbach's alpha (α = 0.886). Principal component analysis was applied to study relationships among variables. In addition, Kaiser–Meyer–Olkin Measure of Sampling Adequacy (KMO = 0.856) indicated very good sampling adequacy and Bartlett's Test of Sphericity (p=<0.001) indicated that data are highly suitable for factor analysis.

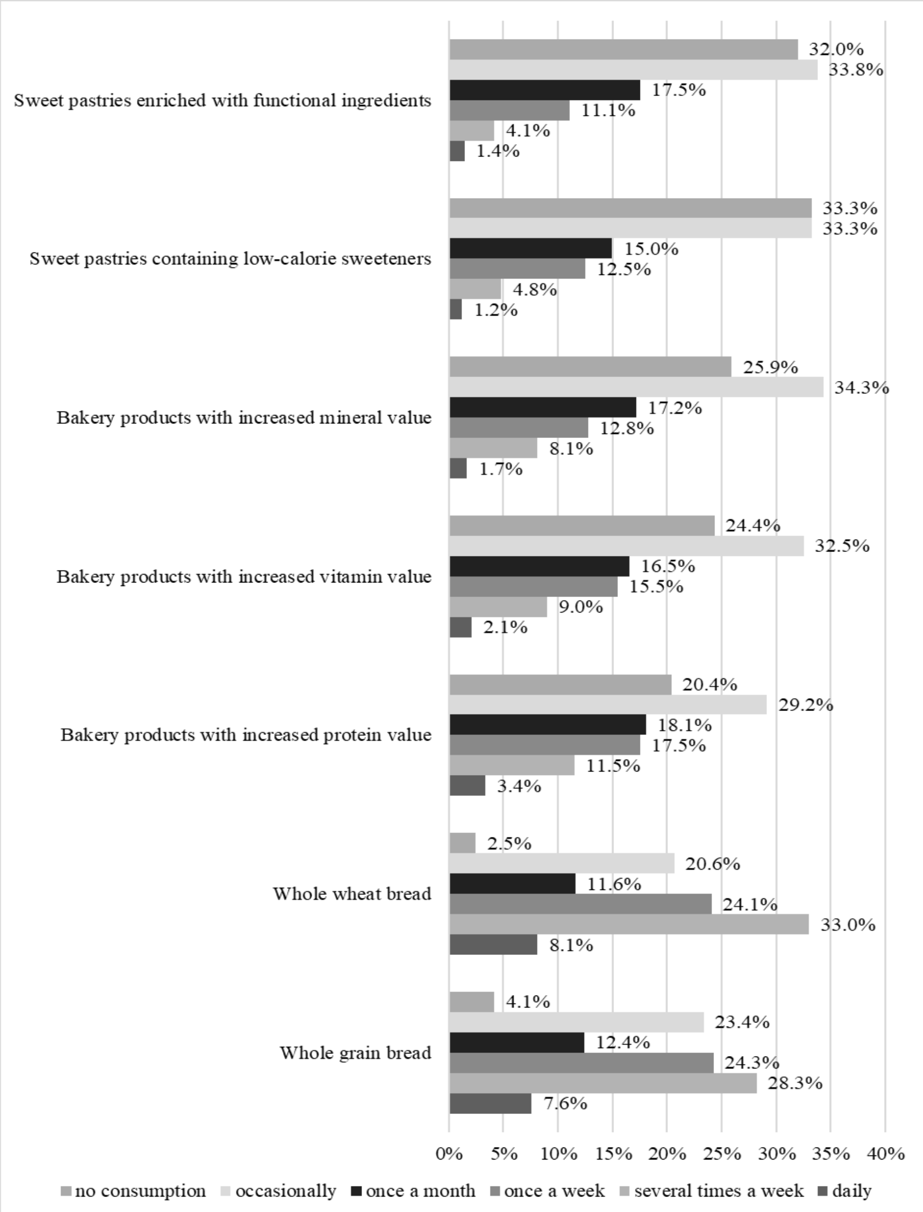
Furthermore, elements related to ingredients, such as reduced fat content, increased whole grain content, increased vitamin content, increased fruit and flaxseed content, increased fiber and mineral content, increased content of wheat, rye, and rice bran, reduced sugar content, increased content of low-calorie sweeteners, content of extruded flour from cereal crops, increased content of herbs and spices were also evaluated using a 5-point scale, where 1 representing no importance and 5 representing high importance. Statistical analysis using Friedman test and Nemenyi's procedure were applied to reveal differences in factor evaluation.

The survey also aimed to identify crucial aspects driving the consumption of functional bakery products. Respondents evaluated reasons for functional bakery products consumption on a 5-point scale, including reducing the risk of heart and cardiovascular disease, prevention of some cancers, especially colon cancer, reducing the risk of obesity due to a lower glycemic index and promoting the maintenance of a healthy weight, reducing the risk of gastrointestinal diseases and supporting the maintenance of a healthy digestive system, support the maintenance and stabilization of blood glucose levels, cholesterol lowering, support the maintenance of healthy bones and teeth, as well as healthy eyes, skin and nails, strengthening the immune system and supporting the central nervous system and mental health, reducing the risk of stroke. These consumption motives were evaluated on a 5-point scale, where 1 representing no expectation, and 5 representing high expectation. Friedman test and Nemenyi's procedure were applied to reveal differences in consumer evaluation of motives for consumption. Moreover, the survey also examined possible factors determining the future development of the functional bakery products market. Consumers identified one of the possible determinants that can influence future consumption: the expanding range of functional bakery products and the emergence of innovative functional bakery products, informing consumers about which bakery products are functional and about the health effects of consuming function bakery products, consumer interest in healthy eating, composition of functional bakery products, promotion of functional bakery products in groceries and labelling of functional bakery products on food packaging. The data collected from the survey were processed using Microsoft Excel and analyzed through statistical software XLSTAT 2022.4.1, with a significant level of 0.05.

Results

The research focused on evaluating the consumption frequency of selected functional bakery products and.based on the research results shown in *Figure 1*, it can be concluded that the most preferred for consumption among Slovak consumers were whole grain bread and whole wheat bread, and on the contrary, the least consumed were sweet pastries containing low-calorie sweeteners and sweet pastries enriched with functional ingredients.

Figure 1. Frequency of bakery products consumption



Source: Own research

The results of the study revealed that more than 60% of consumers were regular consumers (consumers at least once a week) of whole grain bread and whole wheat bread. Furthermore, it should be emphasized that fewer Slovak consumers regularly consume bakery products with increased protein content (32.6%), bakery products with increased vitamin content (26.6%), bakery products with increased mineral content

(22.6%), followed by sweet pastries containing low-calorie sweeteners (18.5%) and sweet pastries enriched with functional ingredients (16.6%). The results indicated that approximately half of the consumers of functional bakery products were occasional consumers of all selected products except bread. Regarding non-consumption, sweet pastries containing low-calorie sweeteners (33.3%) and sweet pastries enriched with functional ingredients (32.0%) were the most frequently reported as not consumed among the selected functional bakery products.

The purchase of individual functional bakery products can be determined by different factors. Consumers evaluated 19 selected factors, and based on the research results and average scores, it can be concluded that freshness (mean=6.25), quality (mean=6.21), and taste (mean=5.92) are key to the selection of functional bakery products. On the other hand, the least important factor for Slovak consumers in the process of purchasing functional bakery products was product advertisement (mean=3.89). In the context of identifying the factors determining the purchase of functional bakery products, the hidden relationships between the selected factors were examined (*Table 1.*).

Table 1. PCA factor loadings

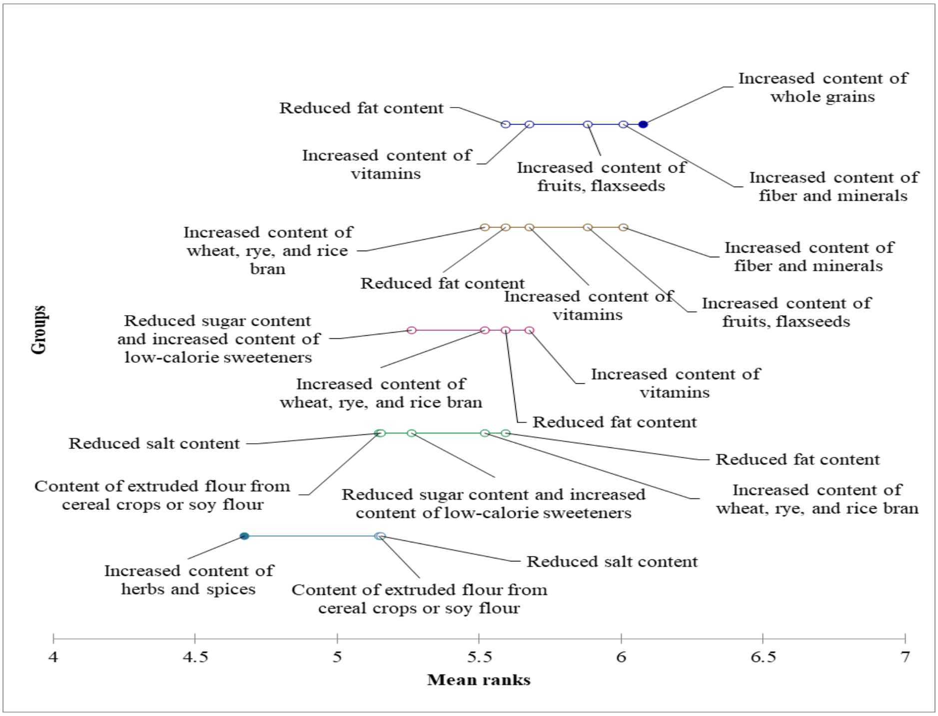
Indicators	Component			
	1	2	3	4
Product advertisement	0.788			
Sales Support	0.783			
Price discount	0.717			
Point of sale	0.662			
Price of an alternative product	0.610			
Recommendation	0.523			
Price	0.453			
Origin		0.855		
Producer		0.840		
Locality		0.830		
Brand		0.764		
Freshness			0.763	
Taste			0.762	
Quality			0.722	
Type/flavor			0.637	
Aroma			0.542	
Nutritional values				0.910
Energy value				0.896
Composition				0.819

Source: Own research

The acquired results revealed 4 latent factors. The first factor involves both marketing factors such as product advertisement, sales support, recommendations as well as price factors (prices, price discount and price of alternative product). The second latent factor comprises origin, producer, locality and brand. The third latent factor includes intrinsic factors such as taste, aroma, type/flavor, freshness and quality. The last factor consists of composition, nutritional and energy values.

In connection with the composition as one of the key determinants of the consumption of functional bakery products, it is possible to consider the content of individual components in the products as important in the selection of specific functional bakery products. For this reason, the survey was aimed at noticing selected factors related to the ingredients in functional bakery products. The research results and average scores showed that consumers most notice the increased content of whole grains (2.98), the increased content of fiber and minerals (2.91) and the increased content of fruit and flax seeds (2.91). On the other hand, they were least interested in the content of extruded flour from cereal crops or soy flour (2.64), reduced salt content (2.63) and increased content of herbs and spices (2.45). In the context of identifying the significance of individual components in functional bakery products, differences in consumer evaluation between components were also revealed by applying the Friedman test (p-value <0.001). These differences are graphically represented using a Demsar plot (*Figure 2.*).

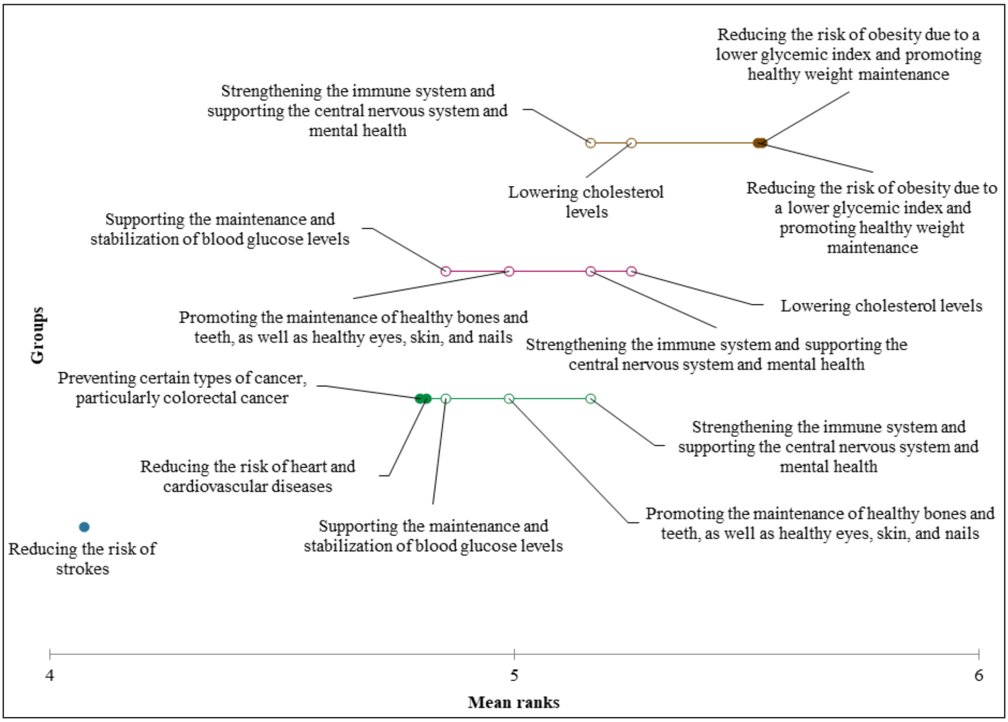
Figure 2. Composition attributes affecting functional bakery products consumption



Source: Own research, Lumivero, 2026

The results and average scores revealed that Slovak consumers consume functional bakery products mainly for the reasons of reducing the risk of obesity due to a lower glycemic index and supporting the maintenance of a healthy weight (3.49), reducing the risk of gastrointestinal diseases and supporting the maintenance of a healthy digestive system (3.48), lowering cholesterol levels (3.39), strengthening the immune system and supporting the central nervous system and mental health (3.34). Moreover, by applied the Friedman test ($p<0.001$) and subsequently using Nemenyi's post hoc procedure, statistically significant differences between reasons for functional bakery products consumption were identified. These differences are visually represented by the Demsar plot (*Figure 3.*).

Figure 3. Reasons for functional bakery products consumption



Source: Own research, Lumivero, 2026

The results of the survey indicated that almost 40% of Slovak consumers consider informing consumers about features and health benefits of functional bakery products as key market drivers for the market with functional bakery products. Consumers also considered other determinants to be important, namely the interest of consumers in healthy eating (27.4%), the expanding range of functional bakery products and the emergence of innovative functional bakery products (14.2%) and the promotion of functional bakery products in commercial establishments and the labelling of functional bakery products on food packaging (11.7%). On the other hand, only 7.4% of Slovak consumers thought that the composition of functional foods can significantly influence the market of functional bakery products and their consumption in the future.

Discussions

Our consumer study conducted in Slovakia revealed low consumer awareness regarding the functional bakery products and their consumption and the results indicate that Slovak consumers most prefer whole grain bread and whole wheat bread. Similar findings were found in a study conducted by Miolla et al. (2023), emphasizing that health-conscious consumers are willing to accept enriched bread as a healthier alternative to traditional products and due to the better nutritional properties. The results show that value-added bread is the most preferred among consumers, which can be justified by higher health benefits and price affordability, and therefore the bakery market should be oriented more towards expanding the range of breads with various additives, even with a future perspective.

In the context of factors affecting purchasing and consumption of functional bakery products, our findings showed that freshness, quality and taste are the most important. Our results are consistent with the study conducted by Bocog et al. (2023) who found that taste, price, appearance, and nutritional value are key factors in the process of buying bakery products Regarding composition factors, our study identified that consumers prefer to consume bakery products with high content of whole grains, fiber, and minerals. However, the results of the study conducted by Kušar et al. (2023) are slightly different and identified that a high protein content in bakery products is more desirable than a high fiber content. The above may indicate that consumers take into account not only sensory properties but also compounds that increase health benefits. In addition, consumers recognize environmental advantages as another reason for consuming enriched bakery products, such as those containing fiber (Królak et al., 2020) and insect flour (Amoah et al., 2023), which could be an important aspect for future choices of bakery products.

Our study further revealed that the future development of the functional bakery product market may be determined mainly by higher consumer awareness of health benefits and an overall interest in healthy eating, which is currently insufficient. This is confirmed by Miolla et al. (2023) who emphasized that lack of knowledge about enriched bread and according to Nilova and Malyutenkova (2020) consumers should be informed about health benefits through e-commerce. Furthermore, considering global trends and recommendations for healthy eating, consumers need to be informed about the beneficial properties of functional bakery products to gain awareness that bakery products are the most affordable healthy and nutritious foods (Mickiewicz, Britchenko, 2022). For the future positive development of functional bakery products, it is appropriate to educate consumers through various communication methods and offer new value-added bakery products that meet consumer requirements for sensory and health aspects.

Conclusions

The key findings of the study include insufficient consumer awareness regarding the consumption of functional bakery products, which appears to be associated with their low frequency of consuming bakery products enriched with health-beneficial substances or those with reduced levels of health-harmful compounds. Additionally, it was identified that functional bakery products selection is affected by product features, factors associated with consumer considerations, and marketing and packaging elements. For Slovak consumers, bakery products with added fiber, minerals, whole grains, fruits, and flaxseeds are particularly appealing. The study further identified the future perspectives of functional bakery products, as consumers recognize the health benefits of consumption, including immune system support, nervous system support, mental health, cholesterol reduction, and reducing the risk of obesity. Overall, the findings suggest that higher consumer awareness of the features and health benefits of functional bakery products may support more informed decision-making and contribute to the development of functional bakery market. The findings of the consumer study in Slovakia have significant implications for both science and practice. From a scientific perspective, the study helps to understand consumer preferences and behavior on the functional bakery market with an emphasis on factors, reasons, and perspectives related to the consumption of functional bakery products. These findings should be beneficial for researchers looking for novel approaches to enhance functional bakery goods and new ingredients that satisfy consumer demand. The study's findings are also beneficial for producers in the bakery industry, as they can utilize them for the development, production, and sale of functional bakery products that align with consumer preferences, thereby promoting positive market growth for bakery products. In addition, producers should focus on creating marketing strategies that emphasize the health benefits of consumption and transparent labelling of functional bakery products. The study results may also be valuable for policymakers who should implement educational campaigns to increase consumer awareness of functional bakery products to support public health.

Despite the valuable insights, consumer study has limitations. The findings are based on the survey conducted in Slovakia and may not be fully generalizable to other countries with different cultural and socio-economic conditions. Additionally, a limitation is the application of self-reported measures in the process of acquiring information from consumers. Following the study's findings, future research directions should consider expanding the scope of investigation, incorporating diverse cultural contexts. Conducting a more comprehensive study is essential to understand the differences in consumer behavior across various countries.

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Conflict of interests

The authors declare no conflict of interest.

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GLOBAL EXPERIENCE OF FINANCIAL REGULATIONS OF THE AGRO-INDUSTRIAL COMPLEX AND SERBIAN ENTREPRENEURIAL AGRICULTURE IN MODERN BUSINESS

Biljana Ilić[1], Slavica Anđelić[2], Nina Pavićević[3]

**Corresponding author E-mail: bilja0110@gmail.com*

A R T I C L E I N F O

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A B S T R A C T

The paper analyzes international practices in the financial regulation of the agro-industrial complex, with a special focus on the Republic of Serbia and the improvement of sustainable sector development under economic challenges. Particular attention is given to innovative financial instruments, including agrifintech, crowdfunding, and index insurance, as well as to the experiences of the United States, the European Union and China. The research applies a comparative analysis of financial regulatory models, institutional frameworks, and financing mechanisms. The findings highlight the importance of digitization and innovative financial models for improving access to capital and strengthening the competitiveness of small and medium-sized agricultural farms. The study also identifies key barriers, including inadequate infrastructure, low digital literacy, and regulatory limitations. The paper contributes to the literature by integrating traditional and modern financial instruments within the context of transition economies.

Introduction

The financial regulation of the agro-industrial complex (AIC) plays a key role in ensuring the stable and sustainable development of agriculture at the national and global levels. The focus of this topic is conditioned by the need to ensure food safety, stabilize the income of rural producers, and promote rural development. In the

1 Biljana Ilić, Full professor, Modern Business School (MBS), Terazije Street No. 27, 11000 Belgrade Serbia, Phone: +38162331077, E-mail: bilja0110@gmail.com, ORCID ID (https://orcid.org/0000-0001-6137-8478)

2 Slavica Anđelić, Associate professor, Faculty of Management, Njegoševa Street No. 1a, 21205 Sremski Karlovci, Phone: +381652471947, E-mail: slavica.andjelic@famns.edu.rs, ORCID ID (https://orcid.org/0000-0003-4021-0822)

3 Nina Pavićević, Assistant professor, Faculty of Social Sciences, Bulevar umetnosti Street No. 2a, 11070 New Belgrade, Phone: +381637682059, E-mail: nina.pavicevic007@gmail.com, ORCID ID (https://orcid.org/0000-0001-5231-3074)

conditions of globalization, financial instruments and regulatory mechanisms become important tools to support the agricultural sector, while entrepreneurship in agriculture is recognized as the driving force of innovation and economic growth. One of the main problems of financial regulation in agribusiness is inadequate financing and limited access to credit resources. Many farmers, especially in developing and transition countries, face difficulties in obtaining credit due to high risks and low profitability, which limits opportunities to modernize and increase productivity (Swinnen, 2018). Bogdanov, Božić, and Munćan (2008) state that the smallholder structure in Serbia is an additional challenge for the efficient use of financial instruments, while effective risk management requires the application of instruments such as crop insurance, forward contracts, and state subsidies. The topic of financial regulation includes various models of support (National Program of Agriculture of the Republic of Serbia, 2018–2021). Government support through subsidies, grants, and tax breaks reduces the financial burden of producers and enables investments in the modernization of production and the application of new technologies. International financial institutions, including the World Bank, provide loans and grants for agricultural development, which is especially important for countries with limited domestic investment and high business risks. Sedlak et al. (2016) point out that in transition conditions, it is necessary to adapt support mechanisms in order to stimulate entrepreneurial behavior, not just existential maintenance. The use of innovative financial instruments, such as microcredits, funds for startup projects, and financial derivatives, enables the reduction of uncertainty and encourages investment in new production technologies (Ferreira & Castro Junior, 2019). Accordingly, producers increasingly rely on crop insurance and index insurance, which provide better protection against financial losses caused by climate disasters (Abdi et al., 2022; Di Falco et al., 2014). Ferreira and Castro Junior (2019) show that forward and option contracts allow farmers to plan production and stabilize income in volatile market conditions. The integration of modern financial technologies in Serbia, including digitization and blockchain technologies, enables more transparent monitoring of supply chains, reduces the risk of fraud, and facilitates access to loans and subsidies (Aničić et al., 2023; Yadav & Singh, 2019; Li et al., 2020). Financial management software solutions further assist farmers in accurately tracking costs, planning investments, and estimating return on capital. The main goal of the research was to identify and analyze aspects of financial regulation of agribusiness with a focus on entrepreneurial initiatives in Serbia. The research included the analysis of innovative financial instruments, the assessment of the potential of financial technologies, and the study of the impact of environmental standards on financial regulation in the domestic context. Special attention was paid to the identification of obstacles to access to finance, including insufficient information for producers, complex administrative procedures, and high risk of losses. It also analyzed the role of the private sector and financial institutions in strengthening the capacity of farmers through microcredits, credit lines with reduced interest rates, and various types of insurance. The effectiveness of state support programs in increasing productivity and competitiveness was also evaluated, as well as areas in which legislative regulation can be improved. Taking into account global trends, especially the impact of climate change, market volatility, and environmental regulations, effective financial regulation must combine government policies, international support, and innovative financial technologies to ensure sector stability, encourage entrepreneurship, and increase risk resilience. Continuous monitoring and evaluation of the effects of financial instruments are crucial for adapting to changes in market and climate conditions. The paper uses a combined methodological approach that includes qualitative and quantitative analysis of secondary data. The methods of comparative analysis, descriptive statistics, and inductive-deductive reasoning were used, with the aim of identifying key patterns in the financial regulation of the agro-industrial complex. The quantitative part of the research is based on the analysis of time series of selected indicators in the period 2018–2025, while the qualitative part includes the interpretation of regulatory models and institutional frameworks in the observed economies.

Literature review

Financial regulation of the agro-industrial complex is a key instrument for ensuring the stability of production, managing risks, and encouraging investments in agriculture. Contemporary literature by previously mentioned authors and researchers indicates a gradual transition from traditional forms of financial support, such as subsidies and credit lines, to integrated models that combine market mechanisms, institutional support, and digital innovations. One of the main challenges in the agricultural sector is limited access to financial resources, especially for small and medium-sized farms (Polukhin & Panarina, 2022; Bornhofen et al., 2019). Previous research results show that the insufficient availability of financing represents a significant limitation to the growth and development of entrepreneurship in agriculture, especially in developing and transition countries (Beck & Demirgüç-Kunt, 2006). This problem is further expressed in rural areas, where the financial infrastructure is less developed, which limits investment activities and modernization of production (Ilić, Stanković, & Ostojić, 2024). Risk management occupies a central place in modern approaches to financial regulation. Agricultural production is exposed to numerous threats to its business, including climate change, price volatility, and yield uncertainty. According to Garrido et al. (2017), the combination of public and market instruments, such as insurance, stabilization funds, and diversification of funding sources, significantly contributes to risk reduction. In this context, the institutional framework and the quality of public policies, according to Acemoglu et al. (2001), have for many years played a key role in shaping effective systems of financial support. The development of digital technologies significantly affects the transformation of financial flows in agribusiness. According to Aker & Mbita (2010), the application of mobile technologies and digital financial services enables easier access to financial services, especially in areas with limited banking infrastructure. Digitization contributes to the reduction of information asymmetries, increases transparency, and facilitates the making of investment decisions. Alternative sources of financing, such as crowdfunding and crowdlending, are gaining more and more importance in the modern agricultural sector. These models enable raising capital without the mediation of traditional financial institutions, which is particularly important for small producers and startup projects (Belleflamme et al., 2014). This increases financial inclusion and encourages the development of entrepreneurial initiatives in rural areas. Contemporary research indicates that tourism demand is becoming increasingly dynamic and unpredictable, which requires flexible management models and continuous adaptation of the offer to changing market conditions (Ilić & Anđelić, 2022). At the level of agricultural policy, the importance of an integrated approach to risk management and financial support is emphasized. Analyses show that successful systems combine various policy instruments, including subsidies, insurance, and investment incentives, to increase the sector's resilience to external shocks (OECD, 2020). In this sense, the development of competitiveness of the agricultural sector is directly related to the efficiency of financial and institutional mechanisms. In the context of transitional economies, special attention is paid to improving the competitiveness and efficiency of agribusiness. According to Matkovski and colleagues (2020), institutional reforms and the development of market-oriented financing models are key to increasing productivity and integrating into the international market. Additionally, contemporary literature emphasizes the importance of financial inclusion as a key factor in the development of the agricultural sector. Financial inclusion means the availability and use of financial services by all categories of producers, including small farms and vulnerable groups. According to Demirgüç-Kunt et al. (2018), previous research shows that increased availability of financial services directly affects productivity growth, income growth, and poverty reduction in rural areas. In addition, the development of agribusiness value chains has a significant impact on financing models. The integration of producers into organized supply chains enables better access to credit, safer placement of products, and reduction of market risks. According to Miller & Jones (2010), financing based on value chains is an effective model for improving the competitiveness and sustainability of the agricultural sector. Based on the review of the relevant literature, it can be concluded that modern systems of financial regulation in agribusiness tend towards the integration of traditional and innovative instruments. However, the successful implementation of these models depends on the level of institutional development, the availability of financial resources, as well as the degree of digitization and education of producers (Pavićević & Ilić, 2026). These factors represent the key determinants of the further development of the agricultural sector in countries such as the Republic of Serbia.

Methodology

The research used various data sources, including statistics from the Republic Statistical Office (RSO), reports and annual publications from the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia (2024), as well as international databases such as Statista (2024). These data enabled the monitoring of key economic and production indicators in agribusiness in the period from 2018 to 2025, including the value of production, investments in infrastructure, credit exposure, and the participation of small and medium-sized agricultural holdings in the financial system. Academic publications used in the research included papers on innovative financial instruments, analyses of agrarian policy in Serbia, as well as studies on global trends in agricultural financing (Ferreira & Castro Junior, 2019; Heyl et al., 2021; Abdi et al., 2022; Bogdanov et al., 2008). The research provided a systematic analysis of existing financial regulations in the agribusiness sector, with the aim of identifying key trends, problems, and areas for improvement. The comparison of international experience included an analysis of support systems in the United States, the European Union, China, and Serbia, with a particular focus on measures that encourage entrepreneurship, stabilize producer incomes, and increase the sector's resilience to risks (Heyl et al., 2021; Aničić et al., 2023; Polukhin & Panarina, 2022). The paper examines how different countries combine subsidies, tax breaks, loans, and insurance as tools for financial stabilization and innovation. The research also included a critical assessment of the effectiveness of national and international support programs. Key indicators such as access to financial resources, the efficiency of subsidy programs, the degree of use of innovative instruments such as financial derivatives and crop insurance, as well as the implementation of modern financial technologies in agribusiness were analyzed (Ferreira & Castro Junior, 2019; Abdi et al., 2022; Kovačević et al., 2022; Stojanović et al., 2019).

Based on these data sources, the paper allowed the identification of the main challenges in domestic agribusiness, including insufficient financing, limited access to credit lines, high costs of adaptation to sustainable production standards, and limited application of digital technologies in financial management. It also pointed out the need to integrate international experiences into national policies in order to ensure better coordination between state institutions, financial organizations, and farmers. This multidimensional approach enabled the formulation of recommendations for improving financial regulation, as well as the identification of the potential for innovative financing instruments and technological tools that can contribute to the sustainability and competitiveness of agribusiness in Serbia.

Results

Agribusiness financial regulation plays a key role in ensuring the sustainable development of the sector. In recent years, there has been a growing interest in innovative financial instruments, such as agrifintech (Assa et al., 2025). Crowdfunding and crowdlending have become increasingly popular instruments, especially for small and medium-sized enterprises, as they provide access to capital independent of traditional bank loans. These tools reduce financial risk and enable faster start-up of investment projects, which is crucial for the development of entrepreneurial agriculture (Sedlak et al., 2016). Blockchain technology and the application of smart contracts ensure a high level of transparency and security of transactions, which is particularly important for tracking the origin of products and verifying quality standards (Mollick, 2014). These instruments can increase trust between producers, processors, and end consumers, as well as facilitate access to financial services such as loans and subsidies (Polukhin & Panarina, 2022). Index insurance is an innovative approach based on objective indicators such as weather conditions, yields, or market prices. It allows for faster payments and reduces administrative costs, thereby promoting the financial stability of producers (Abdi et al., 2022; Stojanović et al., 2019). In addition, index insurance contributes to greater resilience of agribusiness to climate risks and price volatility, enabling long-term production planning (Di Falco et al., 2014; Moritz et al., 2025). The development of agrifintech platforms enables better access to financial services, as well as the integration of tools for risk management, supply chain monitoring, and financial planning (Assa et al., 2025; Kovačević et al., 2022). The integration of digital solutions also encourages greater efficiency, transparency, and sustainability in the entire agribusiness sector (Bornhofen et al., 2019). Although the application of these instruments in Serbia is still in its infancy, there is significant potential for development, especially in the context of climate risks and the need to modernize and improve access to financial services (Aničić et al., 2023; Lutovac et al., 2024). The introduction of agrifintech solutions can be key to stimulating innovation, strengthening entrepreneurial behavior, and increasing the competitiveness of domestic agribusiness in the European market (Glavonjić & Golubović, 2021). The results obtained indicate a positive correlation between the application of innovative financial instruments and the level of investment activity in the agricultural sector (Bornhofen et al., 2019; Assa et al., 2025). The role of digital platforms in reducing information asymmetries and transaction costs is particularly highlighted, which directly affects the increase in the availability of capital for small and medium-sized agricultural holdings (Lutovac et al., 2024). This finding confirms that the integration of financial technologies is a key factor in the transformation of traditional financing models in modern agribusiness.

The United States experience

The USA is one of the leading agricultural powers in the world, with a developed system of regulations and mechanisms for supporting agriculture. In the USA, the agricultural sector records a significant production value and a high export value of manufactured products, which makes it one of the most important participants in the global agricultural market (Coble & Barnett, 2012). According to Statista, in 2023, the value of US agricultural exports amounted to over 170 billion USD, which reflects the significant volume of trade activity of the country in the agricultural sector. The agricultural support system in the USA includes direct subsidies to producers, developed insurance mechanisms, risk management programs, and a comprehensive legislative framework, such as the "Farm Bill", which includes credit support measures, modernization incentives, environmental programs, and other forms of financial assistance. These measures contribute to the stabilization of enterprise income, reduction of risks associated with price changes and climate conditions, as well as stimulation of innovation in agribusiness. Data on the total value of agricultural production in the United States are not readily available in a single public reporting table like exports, but estimates show that the value of agricultural production and the contribution of agriculture to the overall economy remain high, with increasing values over the past decade. For example, USDA data indicate that the value of agricultural exports continued to grow in 2024, reaching one of the highest values at around $176 billion, which testifies to the strong foreign trade position of American agriculture. These support mechanisms and the high value of exports are indicators of the effectiveness of the American system of regulations and incentive policies, which allow the stable functioning of the agricultural sector in the face of global economic challenges. Table 1 shows the growth trends in gross production value and export value in the period from 2018 to 2023.

Table 1. US agricultural output from 2018 to 2023, in billions of USD

Years	Gross production value	Export value
2018	≈ 375	≈ 83
2019	≈ 373	≈ 82
2020	≈ 391	≈ 90
2021	≈ 458	≈ 177
2022	≈ 543	≈ 196
2023	≈ 491	≈ 178

Source: Data processing based on Statista (2024)

Table 1 shows the trend in the gross value of agricultural production and exports in the United States from 2018 to 2023. Significant production growth is observed, especially in 2021 and 2022, which is a consequence of rising agricultural prices and increased global demand. The value of exports increases sharply from 2020 and reaches a peak in 2022. After that, in 2023, there is a slight decline, but exports remain at a high level. These data show that US agriculture is very competitive and has a strong impact on the global food market.

The European Union's experience

Agricultural production in the European Union is supported by the Common Agricultural Policy (CAP), which promotes environmental sustainability, competitiveness, and balanced rural development (Heyl et al., 2021; Bornhofen et al., 2019). Table 2 shows the value of agricultural production in the EU in the period 2018–2023.

Table 2. Value of EU agricultural production (total), in billions of EUR

Years	Value (billion EUR)
2018	≈ 435
2019	≈ 446
2020	≈ 417
2021	≈ 449
2022	≈ 537
2023	≈ 524

Source: Eurostat (2024)

Table 2 shows the total value of agricultural production in the European Union from 2018 to 2023. A decline is observed in 2020, which is a consequence of the disruption caused by the pandemic. This is followed by a recovery and significant growth, which reaches a peak in 2022 (Aničić et al., 2023). The high value in 2022 is the result of rising agricultural prices and production costs. In 2023, there is a slight decline, but the value of production remains at a high level. The CAP focuses on direct payments to producers and the development of rural areas, to encourage sustainable production and increase competitiveness in the market. France and Germany are the largest beneficiaries of the funds, reflecting their significant participation in EU agribusiness. In addition to financial incentives, the CAP also includes measures to preserve the environment, certify organic products, and support innovation in agriculture (Heyl et al., 2021). The data shows that the total value of production in the EU is stable with a growth trend after 2020, indicating a positive impact of policy and support on the development of the sector.

China's experience

China has a dynamic agricultural support system, which includes subsidies for mechanization, modernization, the application of new technologies, and incentives for environmentally friendly production (Bornhofen et al., 2019). Table 3 shows the results of the gross value of agricultural production in the period from 2018 to 2023. Table 3 shows the growth of the gross value of agricultural production in China from 2018 to 2023. Continuous growth is observed year after year, without significant declines. This trend is the result of strong state support, modernization of production, and a large domestic market (Assa et al., 2025).

Table 3. Results of China's agriculture from 2018 to 2023

Year	Gross value (RMB billion)
2018	≈ 6145
2019	≈ 6635
2020	≈ 7775
2021	≈ 8300
2022	≈ 8835
2023	≈ 8970

Source: National Bureau of Statistics of China

The growth is particularly significant after 2020, when the agricultural sector is experiencing accelerated development (Abdi et al., 2022). China's agricultural policy emphasizes the strategic importance of supporting small and medium-sized producers, as well as the development of technologically innovative solutions to increase productivity. The subsidy system allows for the purchase of modern mechanization and the improvement of infrastructure for the storage and transportation of products. In addition, the government provides incentives for the application of digital tools, such as crop monitoring sensors and agrifintech platforms. The results show a continuous growth in gross production value, which indicates the effectiveness of these measures and their positive impact on the economic stability of the sector (Bornhofen et al., 2019). By implementing integrated policies, China manages to ensure a more balanced development of rural areas and increase the competitiveness of its products in the global market. An additional effect is the encouragement of innovation in agribusiness and greater resilience to climate change and price volatility (Abdi et al., 2022). The government is also integrating crop insurance mechanisms and low-interest credit lines to reduce producer risks. Research shows that this support system is relatively flexible and adaptable to changing economic and environmental conditions. In addition, the support policy is also aimed at educating farmers and training them in the application of modern resource management techniques (Munćan & Živković, 2012).

Financial regulation and entrepreneurship in agriculture in the Republic of Serbia

Agriculture in Serbia is a strategic sector, but it faces problems of fragmentation, small scale of individual farms, and a lack of capital. Entrepreneurship in agriculture involves a transformation from subsistence to market production, which requires a different and more innovative approach to financing. Access to favorable sources of financing is key to the development of entrepreneurship, primarily through credit lines supported by state interest rate subsidies (Ljubičić et al., 2019). In Serbia, the support system includes direct incentives per hectare, subsidies for fuel and fertilizer, as well as special credit lines developed by the Ministry of Agriculture in cooperation with commercial banks (Ferreira & Castro Junior, 2019). The main challenge remains the high level of indebtedness of agricultural farms and difficulties in meeting banking requirements, including providing collateral.

Table 4. Basic indicators of agriculture in the Republic of Serbia (2018-2023)

Year	Agriculture's share in GDP (%)	Export of agricultural and food products (million USD)
2018	6,1	≈ 3.300
2019	6,2	≈ 3.620
2020	6,3	≈ 4.150
2021	6,7	≈ 4.900
2022	5,9	≈ 5.000
2023	6,0	≈ 5.400
2024*	6,1	≈ 5.600
2025*	≈ 6,0	≈ 5.800

Source: Republic Statistical Office of Serbia (RSO, 2024); Ministry of Agriculture, Forestry and Water Management of the RS (2024). (*estimate based on available trends)*

Table 4 shows the trend in the share of agriculture in Serbia's GDP and the value of agricultural and food exports in the period from 2018 to 2025. It is noted that the share of agriculture in GDP remains relatively stable and fluctuates around 6%, with minor oscillations due to weather conditions and economic trends. On the other hand, the value of exports is continuously growing, which indicates the increasing competitiveness of this sector in the international market. A particular decline in the share of GDP was observed in 2022, which is a consequence of unfavorable climatic conditions, such as drought.

Projections for 2024 and 2025 indicate continued growth in exports and stabilization of the importance of agriculture in the overall economy. Of particular importance for the development of entrepreneurial agriculture in Serbia are IPARD funds, which enable investments in farm modernization, product processing, and marketing (Sedlak et al., 2016). Migration of the population from rural areas is one of the key problems that can be solved by strengthening entrepreneurial business models, and not only by traditional subsidy measures. Rural development programs specifically target young farmers, providing them with start-up capital and professional support for starting business activities (Pavićević & Ilić, 2026). In addition to financial incentives, the emphasis is on education, professional training, and the application of modern technologies to increase productivity. Strengthening agribusiness encourages innovation and product diversification, which can increase competitiveness in domestic and foreign markets. Financial regulation in Serbia also includes support for crop insurance (Stojanović et al., 2019), the creation of venture capital, and access to agrifintech platforms. The support system seeks to increase the resilience of producers to economic and climate challenges, including price volatility and variable benefits (Ilić & Anđelić, 2022). The development of innovative financial instruments enables easier access to credit, as well as better risk management in small and medium-sized farms. The key effect of these measures is to stabilize incomes, encourage long-term investment, and reduce dependence on state subsidies. The analysis indicates that, despite the existence of various forms of state support, financial regulation in Serbia still has a limited capacity to encourage the development of an entrepreneurial model of agriculture (Ilić, Stanković, & Ostojić, 2024). A key problem is the insufficient integration of innovative financial instruments into the existing institutional framework, as well as the low availability of alternative sources of financing. Compared to practices in the European Union and the United States of America, there is an evident lag in the development of market-oriented financing mechanisms, which limits the competitiveness of domestic agribusiness (Ljubičić et al., 2019).

Discussion

Financial regulation plays a key role in the development of agriculture, ensuring the stability and predictability of agricultural producers' income. While developed countries, such as the US and the EU, are increasingly focusing on innovative instruments such as income insurance, index insurance, and smart contracts, transition countries, including Serbia, continue to face fundamental challenges in accessing capital. In Serbia, it is necessary to develop specific financial products tailored to the needs of farmers, taking into account the specificities of agricultural production, climate risks, and market price volatility (Njegomir et al., 2017). The introduction of blockchain technology in Serbia could contribute to solving the problem of mistrust between producers and processors, as well as improving product traceability, which is an important prerequisite for exporting to demanding EU markets (Mollick, 2014). This technology provides greater transparency of transactions and security, but, as in other countries, low digital literacy and underdeveloped infrastructure, especially in rural areas, remain significant obstacles.

Support programs for young farmers in Serbia show positive results, providing access to start-up capital, vocational training, and financial incentives (Bajagić et al., 2022; Lutovac et al., 2024). However, it is necessary to increase the intensity and scope of this support to retain the young population in rural areas, which is crucial for stimulating entrepreneurial behavior and innovation. Environmental standards are becoming an increasingly important factor in agriculture. The transition to "green" and organic production requires significant investments that are often inaccessible to small farms in Serbia without adequate financial support. Therefore, "green loans", subsidies for organic production, and incentives for the application of environmental technologies are key elements of future financial regulation (Bajagić et al., 2022). At the same time, the integration of modern financial technologies and agrifintech solutions can facilitate access to credit, improve risk management, and increase productivity. The research results confirm that modern models of financial regulation are moving from a dominantly subsidy approach to integrated systems that combine market mechanisms, digital technologies, and risk management. In this context, Serbia is in a transitional phase in which it is necessary to redefine the role of the state – from a direct financier to a facilitator of the development of financial markets and innovative instruments (Njegomir et al., 2017). Such an approach would enable a more efficient allocation of resources and a long-term increase in the productivity of the sector. Education and training of farmers in the use of new tools and techniques are necessary in order to increase resilience to climate and economic changes. Financial regulation that combines traditional instruments and innovations enables income stabilization, encourages long-term investments, and reduces dependence on direct subsidies (Ljubičić, et al., 2019). In conclusion, Serbia has the potential to improve the system of financial regulation in agribusiness through the development of innovative instruments, support for young entrepreneurs, and the implementation of environmental standards, but it is necessary to provide a greater scope of support, improve infrastructure, and invest in education in rural areas to achieve sustainable and competitive agricultural production.

Conclusions

Research has shown that successful financial regulation in agribusiness requires the integration of traditional measures, such as subsidies, loans, and direct incentives, with innovative approaches such as fintech and agrifintech solutions, index insurance, and smart contracts. Analysis of the experiences of the United States of America, the European Union, and China indicates that the active role of the state in managing risks and ensuring the stability of the income of agricultural producers is crucial for the sustainable development of the sector. For the Republic of Serbia, the research results point to the need to continue reforms aimed at developing an entrepreneurial model of agriculture. It is necessary to simplify the procedures for obtaining loans and incentives, provide easier access to favorable sources of financing, and improve the education of farmers in the application of modern technologies and innovative tools. Also, more efficient use of pre-accession funds of the European Union, such as the IPARD program, can significantly contribute to the modernization of farms, development of processing, and improvement of product placement. The development of agrifintech solutions in Serbia has significant potential to contribute to overcoming the problem of limited access to finance, improve risk management, and increase productivity. However, the successful implementation of these solutions requires coordination and cooperation between the state, financial institutions, commercial banks, and the educational system in order to provide comprehensive support to farmers. The improvement of financial regulation in the agro-industrial complex of Serbia requires a systemic approach that includes the development of institutional capacities, digitalization of financial services, and strengthening of market-oriented financing mechanisms. The integration of agrifintech solutions, the improvement of the regulatory framework, and the continuous education of agricultural producers are key prerequisites for increasing the competitiveness and sustainability of the sector.

However, the research has certain limitations. It is based predominantly on secondary data and comparative analysis, which may limit the depth of insight into specific institutional and market conditions in the observed countries. Also, the limited availability of completely comparable and up-to-date data for certain indicators can affect the comprehensiveness of the analysis. Future research should be focused on the quantitative evaluation of the effects of individual financial instruments on the productivity and competitiveness of the agricultural sector. A special focus can be on empirical analyses of the application of agrifintech solutions and their impact on small and medium-sized agricultural holdings. Also, a more detailed investigation of the role of institutional reforms and digital transformation in improving financial inclusion in rural areas is recommended, in order to enable the adoption of empirically based policies in the field of agrarian economy.

Conflict of interests

The authors declare no conflict of interest.

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THE LEGAL STATUS OF AGRICULTURAL ADVISORY SERVICES IN THE EUROPEAN UNION AND THE REPUBLIC OF SERBIA: A COMPARATIVE ANALYSIS

Nina Maksimović Sekulić[1], Boriša Lečić[2], Ljubomir Madunić[3]
**Corresponding author E-mail: nina.maksimovicbg@gmail.com*

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ABSTRACT

Farm Advisory System (FAS) in the European Union are undergoing significant legal and institutional transformation in response to climate change, digitalization, and the evolving objectives of the Common Agricultural Policy (CAP). This paper analyses the changing legal position of advisory services within the Agricultural Knowledge and Innovation System (AKIS), with particular emphasis on Regulation (EU) 2021/2115. The study applies a comparative and qualitative approach to examine differences between advanced European Union models and the current regulatory framework of the Republic of Serbia. The findings indicate that Serbian legislation remains predominantly based on a traditional model of knowledge transfer and lacks sufficient digital and institutional integration. The paper argues that harmonization with European Union standards must extend beyond formal legal alignment and include the strengthening of advisory capacities, digital governance, and innovation-oriented support mechanisms. Such reforms are essential for the effective implementation of IPARD III and the sustainable development of rural communities.

1 Nina Maksimović Sekulić, Ph.D., Associate professor, Modern business school Belgrade, st. Terazije num. 27, 11 000 Belgrade, Serbia, Phone: +38162 206 642, Email: nina.maksimovicbg@gmail.com, ORCID ID: (https://orcid.org/0000-0002-4330-0666)

2 Boriša Lečić, Ph.D. associate professor, “Union” University - Belgrade, Faculty of Law and Business Studies, Dr. Lazar Vrkatić, Novi Sad, Bulevar oslobođenja no. 76, 21000 Novi Sad, Serbia, Phone: +381 63 500 449; E-mail: borisalecic@gmail.com, ORCID ID (https://orcid.org/0000-0002-6565-6399)

3 Ljubomir Madunić, M.Sc., ACHT d.o.o., Domovinskog rata 15, 21256 Čista Provo, Croatia, Phone: +385 21 582 604, E-mail: ljubomir.madunic1@gmail.com, ORCID ID: (https://orcid.org/0009-0003-5279-4682)

Introduction

In developed societies, particularly during the period of accelerated agricultural modernization following the Second World War, agricultural advisory services were predominantly oriented toward the transfer of technology. While this function remains relevant, contemporary approaches place increasing emphasis on empowering farmers to independently address on-farm challenges, make decisions essential for the viability of their holdings, identify emerging problems, and proactively seek information and solutions from both advisory services and a broader ecosystem of knowledge sources.

Accordingly, advisory services are evolving beyond their traditional role as mere "transmitters of information" toward a farmer-centered, user-oriented model. The focus of advisory practice is shifting from production processes per se to the farmer as a decision-maker, with particular attention to their capacity to assess concrete problems and evaluate alternative solutions within modern agricultural systems, frequently in line with environmental sustainability requirements (Djurić et al., 2019).

Contemporary agriculture increasingly operates as a complex, knowledge-intensive system structured around innovation and regulatory governance. Within this framework, advisory services assume a pivotal intermediary role, linking normative legal frameworks with the practical realities of agricultural production (Jovanić & Đelić, 2013). The concept of the Agricultural Knowledge and Innovation System (AKIS) encapsulates this integrative approach, connecting scientific research, agricultural practice, and public policy. Empirical studies demonstrate that AKIS enhances the efficiency of knowledge and innovation transfer, thereby positioning advisory services at the core of agricultural development processes (Kountios et al., 2024).

Moreover, the notion of micro-AKIS underscores the complexity of localized innovation networks and highlights the necessity of their institutional support. Within this context, advisory services play a central role in disseminating innovation and facilitating the implementation of sustainable practices at the farm level. Strengthening the institutional capacity of AKIS has a direct impact on the resilience and competitiveness of the agricultural sector (Kountios et al., 2024).

In this evolving governance landscape, advisory services are no longer confined to an educational function but emerge as key actors in the implementation of public policies and legal norms. Within the European Union, they form an integral component of the Common Agricultural Policy (CAP), contributing to the enforcement of legal standards and the promotion of sustainable development objectives (European Commission, 2023; OECD, 2024). By contrast, in the Republic of Serbia, the system remains in a phase of institutional development and progressive harmonization with EU standards (Dimitrijević & Stojić, 2019).

The 2003 reform of the CAP introduced the cross-compliance mechanism (Regulation (EC) No 1782/2003), which conditions direct payments to farmers upon compliance with baseline standards relating to environmental protection, food safety, animal and plant health, and animal welfare, as well as requirements for maintaining land in good agricultural and environmental condition (GAEC). This reform also imposed an obligation on Member States to establish a Farm Advisory System (FAS) aimed at supporting farmers in understanding and implementing EU regulatory requirements.

Since 2007, Member States have been required to provide advisory services to farmers, while rural development measures have actively incentivized the use of such services. Notably, advisory services are also required to cooperate with forecasting and reporting systems to ensure the application of Integrated Pest Management (IPM) principles, as mandated by Directive 2009/128/EC. Furthermore, Regulation (EU) No 1306/2013, particularly Article 11, emphasizes the need to align advisory systems with IPM principles (Djurić et al., 2019).

In parallel, the Farm Advisory System pursues the broader objective inherent to agricultural advisory services—namely, enhancing the competitiveness of agricultural activities at the farm level. Regulation (EC) No 1698/2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) provides for measures supporting professional training in agriculture and forestry (Measure 111), the use of advisory services (Measure 114), and advisory support for farm management and investment capacity building (Measure 115) (Djurić et al., 2019).

In the Republic of Serbia, agricultural advisory services constitute an important institutional mechanism for improving agricultural production and implementing agrarian policy. Their legal status is primarily governed by the Law on the Performance of Advisory and Professional Activities in Agriculture, which regulates the conditions for providing advisory services, organizational structures, and professional and licensing requirements for advisors. Additionally, the Law on Agriculture and Rural Development recognizes advisory services as a key instrument for sectoral development and support to agricultural holdings.

The legal and institutional framework in Serbia is characterized by a dominant role of the state in the organization and financing of advisory services. The system remains largely centralized, with advisory activities performed by public institutions and licensed professionals. Although empirical findings confirm their significant contribution to improving competitiveness and facilitating the adoption of modern technologies, advisory services continue to face structural constraints, including limited institutional capacity and insufficient digitalization (Dimitrijević & Stojić, 2019).

Recent developments indicate a broader transformation of advisory services—from traditional educational entities toward complex systems of knowledge governance and innovation management—reflecting their expanding role within contemporary agricultural and regulatory systems.

Materials and methods

The methodological framework of this study is grounded in qualitative legal research, relying on a combination of mutually complementary methods to ensure a comprehensive analysis of the subject matter.

At its core, the research employs normative legal analysis to interpret relevant sources of European Union law and the legal framework of the Republic of Serbia. This approach makes it possible to identify the key legal principles, regulatory mechanisms, and institutional features governing agricultural advisory services.

In addition, a comparative method is applied, enabling a structured comparison of legal solutions and institutional models in the European Union and Serbia. Attention is devoted to differences and similarities in institutional organization and the functional role of advisory services, with a view to identifying patterns of alignment and areas requiring further harmonization.

Further research incorporates content analysis of strategic and policy documents, including the Common Agricultural Policy (CAP), IPARD instruments, and relevant national strategies. This method allows for a more nuanced understanding of policy objectives and the evolving role of advisory services within contemporary agricultural governance.

Finally, the method of synthesis is used to integrate the findings of the normative and comparative analyses, providing the basis for drawing conclusions and formulating normative recommendations.

The analysis is based on both primary and secondary sources. Primary sources include European Union regulations within the framework of the Common Agricultural Policy, as well as the relevant laws and by-laws of the Republic of Serbia. Secondary sources comprise academic literature and reports issued by the European Commission, the OECD, and the FAO.

Literature Review

The literature review points to several key trends in the development of agricultural advisory systems. These include a transition from traditional advisory models toward innovation-driven systems, particularly within the framework of the Agricultural Knowledge and Innovation System (AKIS), the increasing digitalization of advisory services, and a growing role of the private sector within advisory structures.

European academic literature predominantly focuses on the role of advisory services in the implementation of the Common Agricultural Policy and the promotion of sustainable development. Authors such as Dwyer et al. (2018) and Borrás and Edquist (2019) emphasize that advisory services constitute a crucial link between EU normative requirements and their practical application at the farm level. In a similar vein, the European Commission (2021), through the AKIS concept, highlights the need for a more integrated approach that connects advisory services with research and educational institutions. The European Commission emphasizes that advisory services constitute a key instrument for achieving the objectives of the Common Agricultural Policy (European Commission, 2023). Similarly, the OECD highlights that advisory services play a crucial role in enhancing both the productivity and sustainability of the agricultural sector (OECD, 2024).

In the academic literature in Serbia, particular attention is devoted to the structural limitations of the advisory system. Authors such as Bogdanov (2015) and Djurić (2019) point to persistent weaknesses, especially in relation to financing and the lack of decentralization. At the same time, empirical analyses indicate that advisory services have a significant positive impact on agricultural development in Serbia, contributing to increased productivity and competitiveness. They play an important role in improving farmers' access to information and facilitating the adoption of modern technologies. However, the literature also identifies notable constraints, including limited resources and broader institutional deficiencies, leading to the conclusion that further systemic improvements are necessary in order to fully realize the potential of advisory services (Dimitrijević & Stojić, 2019).

The academic literature in Serbia also places strong emphasis on the process of harmonizing national legislation with the acquis Communautaire of the European Union, particularly highlighting the challenges associated with implementation and institutional strengthening of advisory services. Analyses of the EU legal framework underline that the development of advisory systems is closely linked to broader principles of sustainability, environmental protection, and food safety (Jovanić & Đelić, 2013).

Kountios (2024) further stress that agricultural advisory services represent a key institutional mechanism for the dissemination of innovation and the modernization of agricultural production systems in Serbia, primarily by facilitating the transfer of scientific and technical knowledge into practical application at the farm level. In this context, advisory services extend beyond a purely informational function and operate as development-oriented institutions that support structural transformation within the agricultural sector. The authors also highlight their contribution to enhancing the competitiveness of Serbian agriculture, enabling farmers to respond more effectively to evolving market conditions and rapid technological change. Attention is given to their role in human capital development, as advisory services strengthen farmers' knowledge, skills, and capacity for informed and strategic decision-making in increasingly complex rural environments. (Kountios et al., 2024).

Overall, the review indicates a relatively limited number of empirical studies within the Serbian academic context, which further underscores the importance of normative and theoretical analyses in this field.

Research results

The European Model of Agricultural Advisory Services

Under EU law, agricultural advisory services perform a public-goods function, even though they are often delivered through a combination of public and private providers. Their financing is secured from Common Agricultural Policy (CAP) funds, subject to conditions regarding quality, independence, and transparency. Economically, this design internalizes the positive externalities of advisory work (e.g., improved productivity, environmental compliance, and risk management) while preserving some market-based choice for farmers.

Within the CAP framework, advisory services are institutionally embedded through the Farm Advisory System (FAS). This system serves to: ensure compliance with regulatory standards, enhance the long-term sustainability of agricultural production, and tie direct payments to both legal obligations and performance-related conditionality.

The core legal basis lies in Regulation (EU) 2021/2115, which establishes the CAP strategic plans. Key complementary acts are Regulation (EU) 2021/2116 and Regulation (EU) 2021/2117, which specify the ways in which Member States must operationalize advisory services in practice.

A legal-economic analysis of Regulation (EU) 2021/2115 in the part governing agricultural advisory services (PSS) reveals a shift from advisory work as an exogenous support service to an endogenous, statutorily mandated component of the broader Agricultural Knowledge and Innovation System (AKIS). In economic terms, this strengthens the institutional complementarity between research, education, and on-farm decision-making, thereby improving the rate of technology adoption and the efficiency of public spending.

AKIS represents an integrated framework linking farmers, research institutions, advisory services, and public authorities. Advisory services are under a formal obligation to provide support in the areas of: sustainable management of natural resources, compliance with environmental and climate standards, and digitalization and innovation in agriculture.

These domains are also central to the economics of modern agriculture, as they shape long-run cost structures, risk exposure, and market access.

Article 15 of Regulation (EU) 2021/2115 functions as the “constitutional” core of the advisory system under the 2023–2027 CAP period. Unlike earlier regulations, which treated advisory systems as merely recommended, Article 15 imposes a binding obligation on Member States to establish a system that provides advice to farmers and other beneficiaries of CAP support. This transforms advisory services from a discretionary, potentially under-provided good into a policy-mandated service, correcting for market failures linked to asymmetric information, risk aversion, and bounded rationality.

Within the AKIS framework, advisory services are now defined as one of the three pillars (alongside research and farmers). This status implies that they are not simply information conveyors, but active participants in the co-creation and diffusion of innovation. From an economic perspective, this strengthens the link between knowledge creation and on-farm application, thereby improving the marginal productivity of agricultural inputs and facilitating structural adjustment.

A key innovation in Article 15(3) concerns objectivity and conflicts of interest. The Regulation requires that providers of advisory services act impartially, and it explicitly excludes EU-funded advice that promotes the seller's own inputs (e.g., seeds, pesticides, fertilizers). This rule functions as a regulatory safeguard against rent-seeking, aligning private incentives with the public interest in sustainable and cost-efficient farming practices.

The Regulation also specifies, in a binding manner, the substantive content of advisory services. This is no longer a matter of professional discretion, but reflects a statutory minimum that shapes the service bundle offered to farmers:

Conditionality: advisers must inform farmers about standards of good agricultural and environmental practice (GAEC) and the relevant statutory requirements on management (SMR), thereby reducing compliance risk and potential payment reductions.

Social conditionality: for the first time, advisory services are obliged to provide information on working-conditions standards and employers' obligations in agriculture, internalizing labour-cost and compliance considerations into farm-level planning.

Risk management: the Regulation requires advice on financial instruments and insurance, which complements the usual role of the banking sector and thereby improves farmers' capacity to manage income volatility and production risk.

The Regulation further introduces a formal requirement to use digital tools, such as the *Farm Sustainability Tool for Nutrients* (FaST). In institutional-economic terms, this pushes advisory services into a digital-data ecosystem that is interoperable with national parcel-identification systems (LPIS) and integrated administrative-control systems (IACS). With this trend, the Regulation indirectly activates stricter data-protection duties under the General Data Protection Regulation (GDPR), since advisers handle sensitive farm-level information whose mismanagement could affect both privacy and competitive positioning.

Within the legal architecture of Regulation (EU) 2021/2115, Annexes III and IV form the operational core of the new "green" and "social" conditionality. For agricultural advisory services (PSS), these Annexes are not merely technical checklists, but a legal-economic roadmap that defines the content of their work and the accountability of operators toward the state and the EU.

Annex III translates earlier "greening" elements into strict conditionality standards, directly linking non-compliance to reductions in subsidies. Advisory services therefore play a price-signal-transmission role: they help farmers interpret how environmental and soil-management rules adjust the effective net return to production. Key elements include: GAEC 1–3 (water and soil): protection of wet habitats, prohibition of straw burning, and preservation of river courses. Here, the adviser acts as a technical planner, assisting farmers in mapping buffer zones and thus internalizing spatial-land-use trade-offs into farm-level decisions.

GAEC 7 (crop rotation): stricter rules on crop rotation to preserve soil productivity. Legal-agronomic analysis finds advisers need both agronomic and legal knowledge to ensure cropping plans meet statutory requirements, supporting a shift from short-term profits to long-term capital preservation. GAEC 8 (biodiversity): the obligation to maintain a minimum share of non-productive areas (e.g., hedgerows, trees). From an economic-institutional perspective, the adviser functions as an ecological-norm interpreter, helping farmers to treat such areas not as “lost” land, but as conditionally necessary for retaining subsidy income.

Annex IV (social conditionality) links the payment of agricultural subsidies to compliance with fundamental workers’ rights. Under Article 15, advisory services must incorporate elements of labor law into their portfolio, including Directive 2019/1152 on transparent and predictable working conditions and Directive 89/391/EEC on occupational health and safety. In economic-legal terms, this expands the advisory role into the domain of labor-cost and compliance risk management.

In this framework, the adviser assumes something akin to the role of a *compliance economist*: the adviser no longer only checks whether the wheat crop is properly fertilized, but also—indirectly—ensures that seasonal workers are duly registered and provided with adequate protective equipment. Given that breaches of labor-law requirements since 2025 have triggered penalties across the entire subsidy amount, advisory assistance in interpreting Annex IV has become one of the most economically valuable components of the service for large holdings employing hired labor.

The Legal Status of Agricultural Advisory Services in the Republic of Serbia

The legal position of agricultural advisory services in the Republic of Serbia is primarily shaped by a dual normative framework that combines sector-specific regulation with broader agrarian and rural-development legislation. At the core of this framework lies the Law on the Provision of Advisory and Professional Activities in the Field of Agriculture (Official Gazette of the Republic of Serbia, No. 30/10.), which defines the conditions and modalities for providing advisory services, the organization of the system, and the professional and licensing requirements for agricultural advisers. The Agriculture and Rural Development Act (Official Gazette of RS”, Nos. 41/2009, 10/2013 - other law, 101/2016, 67/2021 - other law, 114/2021 and 19/2025) identifies advisory services as essential tools for agricultural sector growth and support, integrating them into broader agrarian policy.

Within this structure, the advisory system in Serbia is characterized by a strong role of the state in both organization and financing. The system remains largely centralized, with advisory activities carried out by public institutions and licensed private advisers operating under state-approved programs (Dimitrijević & Stojić, 2019). The legal framework grants these entities a quasi-public function: their primary objective is not direct profit generation, but the improvement of agricultural productivity, competitiveness, and the adoption of modern technologies and sustainable practices (Ministry of Agriculture, Forestry and Water Management- MAFWM, 2025).

The Law on the Provision of Advisory and Professional Activities in the Field of Agriculture further establishes a formal licensing regime for agricultural advisers, including requirements related to education, professional experience, and continuous training. This licensing system functions as a gate-keeping mechanism, aiming to ensure that advisory services meet minimum quality standards and contribute to the professionalization of the agricultural sector. In addition, the law mandates the planning of advisory activities through a medium-term and annual program, which aligns the provision of advice with national agrarian priorities and EU-compatible policy objectives (Regulation on the Establishment of the Medium-Term Programme for the Development of Agricultural Advisory Services for the Period 2026–2030,"Official Gazette of the Republic of Serbia", No. 119 of 29 December 2025).

The Agriculture and Rural Development Act reinforce this institutional role by explicitly linking advisory services with other key components of the agricultural-policy framework, such as the Register of Agricultural Holdings, rural-development programs, and support schemes for innovation and modernization. In this sense, advisory services are no longer treated as marginal support bodies, but as central actors in the implementation of agrarian policy and the translation of legal and regulatory requirements into on-farm practice. This is particularly evident in the context of cross-compliance-related obligations and the gradual integration of Serbia's agricultural-support system with European Union-inspired conditionality mechanisms (Dimitrijević & Stojić, 2019).

Empirical analyses indicate that advisory services in Serbia have a significant positive effect on agricultural productivity and competitiveness, primarily by improving farmers' access to information and facilitating the adoption of modern technologies and management practices (Djurić, 2019;, Stojić & Đurić, 2020). At the same time, this body of research identifies structural weaknesses, including limited financial resources, insufficient decentralization, and delayed digitalization, which constrain the ability of advisory services to fully match the evolving demands of the sector (Dimitrijević & Stojić, 2019). The recent adoption of the *Regulation on the Establishment of the Medium-Term Programme for the Development of Agricultural Advisory Services for the Period 2026–2030* aims at addressing these shortcomings by modernizing service delivery methods, expanding the use of digital tools, and improving the integration of advisory activities with broader data and monitoring systems (Ministry of Agriculture, Forestry and Water Management- MAFWM, 2025).

Regulation serves as a strategic legislative bridge toward the EU's Common Agricultural Policy (CAP). It orchestrates a fundamental paradigm shift, transforming agricultural advisers from mere "field administrators" into "knowledge managers." This reform provides substantive evidence that Serbia has commenced a deep-seated harmonization process—at least at the level of secondary legislation—thereby addressing the pivotal recommendations outlined in the European Commission's Progress Reports.

Far from being a routine technical extension of previous initiatives, this Decree explicitly introduces the concept of the Agricultural Knowledge and Innovation System (AKIS) into the Serbian legal corpus for the first time. By doing so, it provides the legal legitimacy required to transition from a traditional, linear "advisor-to-farmer" model to a sophisticated network-based collaborative framework.

The Regulations mandates the adoption of an integrated digital ecosystem, characterized by two primary legal innovations:

- Verification of Performance: Advisory activities are now legally recognized only if recorded in real-time via a dedicated platform synchronized with the eAgrar system.
- Institutional Interoperability: The integration of advisory logs with the Directorate for Agrarian Payments facilitates seamless data exchange. This significantly alleviates the administrative burden on producers regarding the evidentiary requirements for Good Agricultural Practices (GAP).

A cornerstone of this Regulation is the establishment of rigorous criteria for the accreditation of non-state advisory service providers:

Regulatory Alignment: In direct response to Article 15 of Regulation (EU) 2021/2115, the Decree introduces stringent "anti-bias" provisions and conflict-of-interest protocols (e.g., prohibiting affiliations between advisers and input distributors).

IPARD III Accessibility: This framework establishes the necessary legal pathway for activating Measure 9 of the IPARD III program, enabling the utilization of EU funds for co-financing private-sector advisory services—a mechanism previously obstructed by legislative gaps.

Diverging from legacy programs that prioritized yield maximization, the current strategic framework reorients focus toward:

Eco-Schemes: Advisers are repositioned as primary facilitators for the implementation of complex, performance-based eco-payment models.

Animal Welfare: The introduction of a mandatory training module on animal welfare addresses a critical normative deficit identified in previous legislative analyses, aligning domestic practice with high European ethical and sanitary standards.

Negotiating Chapter 11: Alignment of Serbia's Agricultural Policy with the EU CAP Framework

Negotiating Chapter 11 encompasses one of the most complex and financially demanding policies of the European Union – the Common Agricultural Policy (CAP). The CAP serves as the EU's central instrument for regulating agricultural production, stabilizing markets, ensuring farmers' income, and fostering the sustainable development of rural areas. Its legal basis is enshrined in Articles 38–44 of the Treaty on the Functioning of the European Union (TFEU), which delineate the objectives of agricultural policy, including increased productivity, market stability, food security, and a fair standard of living for the agricultural community.

In the contemporary legal landscape, the CAP is intrinsically linked to the objectives of sustainable development, environmental protection, and climate action, particularly following the 2013 and 2021 reforms. The new CAP for the 2023–2027 period is structured around the principles of "Green Architecture," which integrates eco-schemes, conditionality, and the enhancement of rural development through the Second Pillar of the CAP.

In this context, Farm Advisory Services (FAS) have become a mandatory institutional mechanism for EU Member States, as mandated by Regulation (EU) 2021/2115. Their purpose is to provide professional, technical, and legal support to farmers in implementing EU standards, specifically regarding:

- Environmental protection and biodiversity,
- Climate mitigation and adaptation measures,
- Food safety,
- Animal welfare,
- Digitalization and innovation in agriculture.

The European Commission's Progress Reports for Serbia (Chapter 11) consistently highlight the following normative and structural shortcomings:

1. Legal Fragmentation: The advisory system remains isolated from research institutes. The Law of 2010 fails to account for "innovation brokering," which is a prerequisite under the modern AKIS (Agricultural Knowledge and Innovation System) model.
2. Erosion of Public Function: It is noted that the Agricultural Advisory and Professional Services (PSSS) in Serbia devote excessive resources to the administration of subsidies, rather than the transfer of knowledge concerning environmental standards (GAEC – Good Agricultural and Environmental Conditions).
3. Accreditation Deficit for IPARD III: Without legislative amendments to allow private consultants to become "authorized service providers," Serbia will remain unable to utilize funds from Measure 9 of the IPARD program.

Discussion

A comparative analysis reveals that while Serbia possesses a foundational normative framework, it lacks the functional integration and systemic flexibility inherent in the EU model.

Under EU regulations, animal welfare is strictly treated as a prerequisite for subsidy eligibility (Conditionality). In contrast, Serbian legislation primarily links advisory work to “enhanced productivity and competitiveness.” Within the EU context, advisors are legally mandated to train farmers in standards that transcend mere economic gain, incorporating ethical and ecological dimensions. In Serbia, these aspects currently fall within the jurisdiction of veterinary inspections rather than the advisory remit.

Article 15 of Regulation (EU) 2021/2115 stipulates that advisory systems must be integrated into national AKIS Strategic Plans through the mandatory use of digital logs.

The Serbian Gap: Current Serbian law still relies on an “Advisory Log” (Advisory Service Work Log) which is frequently maintained in paper form or isolated Excel formats, lacking interoperability with eAgrar.

The IPARD Requirement: Without a statutory obligation for digital, real-time reporting of farm visits—including GPS coordinates and digital signatures—it is impossible to satisfy EU transparency requirements for the disbursement of IPARD funds.

Regulation 2021/2115 introduces the legal concept of the “Innovation Broker.” This normative innovation redefines the advisor as a critical bridge between academia (universities) and practical application.

Definition Deficit: Article 3 of the Serbian Law defines advisory work as “the provision of expert advice, instructions, and practical demonstrations.” This definition preserves a linear, top-down model of knowledge transfer, whereas the EU mandates a network-based model characterized by multi-actor interaction within the AKIS framework.

EU regulations require Member States to ensure that advisors undergo continuous professional development and maintain a status of impartiality.

The Certification Void: A significant legislative vacuum exists in Serbia regarding the licensing of private-sector advisors. The prevailing law focuses almost exclusively on experts within public services (PSSS). The absence of a clear legal framework for the certification of independent consultants prevents the emergence of a competitive “knowledge market,” directly hindering the implementation of the Green Deal in Serbia.

The Serbian Law on Advisory Services has become obsolete relative to the CAP 2023–2027 paradigm. While it was designed to support conventional agricultural production, the EU Regulation demands a framework that fosters sustainable resource management, digitalization, and social responsibility. To ensure success in the EU integration process, an urgent revision of Articles 3 and 4 of the Serbian Law is required to incorporate the concepts of animal welfare, digital integration, and institutional impartiality.

Conclusions

Agricultural advisory services represent a key instrument of sustainable agrarian policy. The EU model, built on the Agricultural Knowledge and Innovation System (AKIS) approach, demonstrates a high degree of legal coherence and institutional efficiency (European Commission, 2023; Kountios, 2024). The legal status of advisory services thus constitutes a central element of the contemporary agricultural system. While the European Union has developed a relatively advanced and integrated model, Serbia remains in a phase of institutional transformation and harmonization with EU standards (Dimitrijević & Stojić, 2019).

In Serbia, the legal framework governing advisory services rests primarily on laws that regulate their organization, licensing, and supervision. These acts define the conditions under which advisory activities may be carried out, the professional requirements for advisers, and the role of public authorities in overseeing the system. However, analyses indicate a significant gap between the normative framework and practical implementation. Research suggests that advisory services in Serbia play an important role in agricultural development, but they also face persistent institutional constraints (Dimitrijević & Stojić, 2019). The main challenges include the high degree of system centralization, insufficient digitalization, and limited institutional capacity. These shortcomings point to the need for further development of the legal and institutional framework.

In the European Union, the digitalization of agriculture and rural areas is regarded as one of the main pathways toward a more modern, competitive, and sustainable sector. The European Commission stresses that digitalization promotes the adoption of digital technologies and data-driven approaches, aiming both to enhance productivity and to improve the quality of life in rural communities (European Commission, 2023; OECD, 2024). Within the new Common Agricultural Policy (CAP) for the period 2023–2027, the AKIS framework plays a central role in the modernization of agriculture and rural areas by linking knowledge, innovation, and digitalization. Member States are expected to show, in their strategic plans, how they will connect advisory services, research institutions, and support networks, thereby ensuring that technological and policy innovations reach farmers in a systematic and effective way (Kountios, 2024; European Commission, 2023).

In this context, the EU is moving beyond simply promoting new technologies to build an integrated ecosystem that embeds them into everyday farm management. Satellite-based crop monitoring, digital parcel maps, sensors, systems for tracking soil moisture and temperature, precision treatment of crops, and artificial-intelligence-based decision-support tools are increasingly treated as standard components of farm management (European Commission, 2023). The EU's comparative advantage lies not only in the technical availability of these tools, but in the institutional architecture that supports them—through public policies, research programs, advisory services, training, and financial instruments (Kountios, 2024).

For Serbia, the alignment of the legal status of its advisory services with EU requirements will require further development of the legal and institutional framework. The adoption of a new Law on Agricultural Advisory Services is necessary, as the current legislation does not explicitly recognize concepts such as "innovation brokering" or the use of digital registers of advisory visits, which are mandatory in the EU for transparency and monitoring purposes (European Commission, 2023). Serbia's legal framework should allow private advisory agencies to participate equally in IPARD III, especially Measure 9 (Advisory Services), to enhance system pluralism and efficiency.

In the EU, the integration of databases is a key requirement. In Serbia, however, data on advisory activities are often isolated from the eAgrar system, which prevents the effective monitoring of how advice affects farm productivity and the implementation of conditionality rules. A key policy recommendation for Serbian lawmakers is to transform agricultural advisory services from being mere "executive bodies of the Ministry" into innovation-facilitating actors within a broader AKIS-type architecture. This shift should be accompanied by the introduction of formal legal mechanisms for the accreditation of private advisers, clearly defined quality standards, and digital interoperability between advisory-activity records and national agricultural-information systems.

Conflict of interests

The authors declare no conflict of interest.

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Acknowledgements

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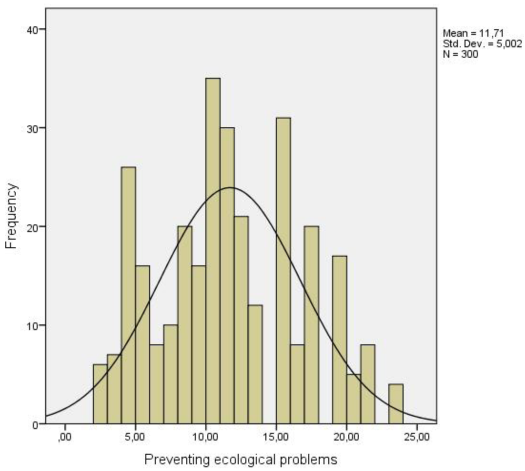
Table 1. The distribution cost of packaged goods from Subotica to retail-store objects

Indicators	Period			Total
	Month 1	Month 2	Month 3	
Distance crossed (km)	12.926	11.295	13.208	37.429
Fuel consumption (litre)	3.231	2.823	3.302	9.356
Value of fuel consumption (RSD)	242.378	211.790	247.653	701.821
Total time spend on touring (hour)	314	266	417	997
Value of total time spend on touring (RSD)	47.048	39.890	62.570	149.508
Number of tours	98	77	102	277
Toll value (RSD)	0	0	0	0
Number of pallets transported (piece)	1.179	976	1358	3.513
Total weight transported (kg)	602.600	429.225	711.116	1.742.941
Vehicle maintenance costs (RSD)	203.858	164.970	224.806	593.634
Lease costs (RSD)	480.938	454.214	565.784	1.500.936
Total sum (RSD)	974.222	870.864	1.100.813	2.945.899

Source: Petrović, 2012

All illustrations whether diagrams, photographs or charts are referred to as Figures. The name and number of figures should be centered on the line above a figure.

Figure 1. Agriculture, value added (% of GDP)



Source: Authors' calculations

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