ASSESSMENT OF THE WEIGHT OF FACTORS INFLUENCING FOOD LOSSES USING FUZZY MULTI-CRITERIA ANALYSIS

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A R T I C L E I N F O

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A B S T R A C T

The purpose of the paper is to show, through the selection of given criteria, which of them has the greatest impact on food losses in an agricultural-food company. For this purpose, an innovative expert method of multi-criteria decision-making, SiWeC (Simple Weight Calculation), and its fuzzy variant, was applied. The results show that the criteria "poor handling of products during transport" and "inadequate packaging and handling of products" have the greatest impact. Considering the already existing plan of the company to train this part of the work processes, the expert assessment confirms the results of the research. Also, the successful use of this method with the application of fuzzy logic was confirmed, and future research should be directed towards the development of new ways of researching the influence of individual factors on the entire process of supplying food to end consumers.

Introduction

Food loss occurs at various stages of the supply chain. A large number of participants in the supply chain of agricultural products represent potential food losers due to various factors affecting it. The actualization of this issue is becoming greater due to the emergence of complex technology of the food production process, which moves from the producer itself to the consumer. According to Chirostopfer (2005), supply chains for food and other products represent a network of interconnected business entities that work together with the goal of converting and distributing goods from raw materials to

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final products. Also, as concluded by Mokrane et al., (2023), globalization and changes in consumer preferences increase the distance between the places of food production and consumption, which in turn affects the length, complexity and number of participants in the food supply chain. In addition, by increasing the number of participants in the chain, as well as the path through which food moves from the place of production to the place of consumption, various resources are consumed, and many environmental problems arise (harmful impact on biodiversity, climate change, occurrence of greenhouse gases, water and land pollution). (Damnjanović et al., 2022) This is a universal problem, that is, it affects both developed and less developed countries in the world. Food production resources that are ultimately never used are being polluted. (Živković et al., 2021; Luković et al., 2023) Because of all this, there is great concern about food loss among many authors who conduct research on this topic, as well as among other members of the social community (Gruber et al., 2016; Niu et al., 2022; Krunić et al., 2023; Laba et al., 2022; Kumu et al., 2012).

Food products, that is, food has its own specificities in relation to other types of goods. It is a question of a set of various circumstances that influence its sustainability and the occurrence of loss, such as the specific characteristics of the product, its seasonal character, shelf life, perishability, the distance between the place of production and the place of consumption, etc. One of the prominent factors is sustainability. According to Petljak (2021), the global food chain contributes the most to the emission of greenhouse gases. They arise in all stages of the chain, from the production of food itself to the disposal of the same food at the end. Reset (2020) states that annually around 1.3 million tons of food are thrown away in the world, before that food is consumed. In this way, a loss of about 1 billion dollars is created annually, or 12% of the world's gross domestic product (GDP). According to an earlier FAO study (2013), it is estimated that around 8% of global greenhouse gas emissions are related to food loss and waste, which in turn leads to the loss of biodiversity itself.

Many authors have dealt with the issue in question in their earlier research. Thus, Petljak (2021) proposes innovative solutions when it comes to food losses and wastage in the fruit and vegetable supply chain. The same author concludes that food waste represents a missed opportunity to feed the global world population. In their research, Gustavsson et al., (2011) distinguishes, with regard to the type of product, the level of development of the food chain, and the level and degree of development of a country, patterns of food loss and wastage. Kummu et al., (2012) believes that in countries with a developed economy, more than 40% more food, that is, fruits and vegetables, is lost, requiring greater traceability in the aforementioned sector. The same authors believe that the rate of food loss and wastage is on average about 20-22% of the total produced grains, compared to 39-44% of fruits and vegetables and 33% of root vegetables, as well as 24% of seafood (Lipinski, 2013).

Jeremić et al., (2024) investigate international perspectives in food losses and waste along the entire supply chain. They conclude that food loss and waste is a global phenomenon characteristic of all countries, as well as of all food products in the supply chain. According to them, this phenomenon is caused by numerous factors that differ depending on the sector of the supply chain in which they occur. Furthermore, as the authors conclude, one of the key characteristics of this phenomenon is a wider range of implications that can be classified into the following three groups: social, economic and ecological. Some authors, based on the Eurostat database (2023), provide data for individual European Union member states when it comes to food wastage. Namely, they point out that Germany (18.70%), France (15.01%) and Italy (14.20%) are leading among EU countries when it comes to this phenomenon. Also, when it comes to the supply chain in the agricultural sector, other authors also dealt with the problem of food loss in their earlier research (Gile, 2013; Ghosh et al., 2015; Xue et al., 2017; Pantić et al., 2022; Papargyopoulou et al., 2014)

Considering the impact of a large number of factors on the loss and wastage of food, that is, agricultural products, the question of using a characteristic methodology to assess their impact arose. This certainly opened up space for the application of multi-criteria assessment and decision-making as an adequate methodological tool.

In order to make a decision that best meets the decision-making objectives, it is necessary to include as many criteria as possible in order to look at all the possibilities of certain alternatives. This kind of decision-making is multi-criteria decision-making (Ristić et al., 2024), because the decision is made by applying several criteria (Rahman and Muhammad, 2024). In this type of decision-making, it is necessary to first determine the importance of certain criteria, and then choose which of the alternatives best meets the set goals. If one of the criteria is more important, it has a greater influence on the final decision. When determining the importance of criteria, different methods are used (Stević et al., 2022).

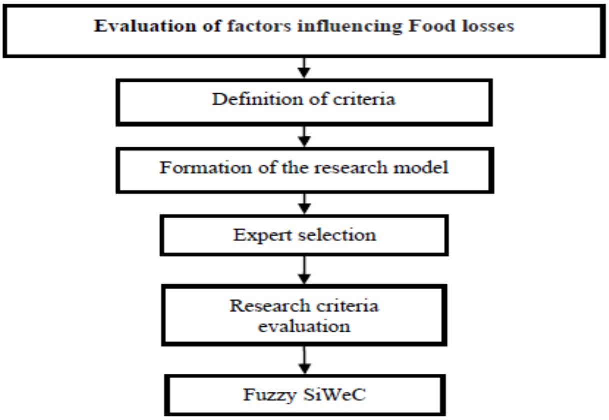
The previous researches are not rich in examples of the application of these methods in concrete cases of assessment of factors that affect the loss of food (agricultural products), therefore this confirms the justification and popularization of the application of such a method in a concrete case. Many earlier studies included multi-criteria analysis, but in the food industry they mainly focused on selecting the most favorable suppliers (Puška et al., 2024; Nedeljković, 2022; Gharakhani, 2012; Govindan, 2015; Jarosz, 2019; Stević, 2019), as and on their sustainability (Puška et al., 2022; Puška et al., 2021; Puška et al., 2023; Joshi et al., 2020; Ghosh et al., 2020; Baki, 2022; Durmić et al., 2020; Nancu, 2022; Nicolae et al., 2023), and in this way this research could gain importance due to its application in a completely new field.

According to the previous main goal of the work, the statement of the factors that influence food losses in its production with the successful application of innovative methods of multi-criteria decision-making. In accordance with the above, in the following work we will present the results obtained by applying the given methodology, and based on them draw certain conclusions and recommendations for future research.

Methodology

The application of the chosen work methodology required a research plan, which can be seen in the following figure 1. In the first step, based on the experience of earlier research, the impact criteria for the assessment itself were formulated. Their overview is given in table 1 below. Based on the given criteria, a survey form was created and filled out by the selected experts. The expert assessment was given by 6 experts in the subject area, and the research model was constructed on the basis of this. After the necessary calculations, we evaluated the given criteria and determined the weights of each of them using the applied method. The last step concerned drawing conclusions based on the previously performed weight assessment of the observed criteria.

Figures 1. Research methodology



Source: Authors

The selected criteria shown in the following table 1 represent common ways of losing products obtained by certain technological processes in one agricultural plant or farm. In general, they can be divided into losses caused by weather conditions and the human factor. The idea was to reduce them to the smallest possible extent after their importance was established.

Table 1. Evaluation criteria

Id	Criteria	Criteria type
C1	Bad weather	Cost
C2	Pests and diseases	Cost
C3	Inadequate handling of the production process	Cost
C4	Untimely harvest	Cost
C5	Lack of managerial skills in production	Cost
C6	Restriction of agricultural technique	Cost
C7	Failure to meet quality standards	Cost
C8	Inadequate storage conditions	Cost
C9	Poor handling of products during transport	Cost
C10	Inadequate packaging and handling of products	Cost

Source: Authors

In order to obtain more precise evaluations of individual criteria, we used *fuzzy* logic in the research. *Fuzzy* logic makes it possible for ratings not to be exact, but to be lower or higher, thus defining *fuzzy* numbers into which linguistic values are transformed. Each *fuzzy* number has its central value and additional values, where the first *fuzzy* number is always less than or equal to the central value, while the third *fuzzy* number is always greater than or equal to the central value. Situations where two *fuzzy* numbers are equal are at the smallest and largest value. The first *fuzzy* number cannot be smaller than the smallest value, and this value has the central value. The third *fuzzy* number cannot be greater than the largest value, because this value is precisely the central value. In this way, *fuzzy numbers* were defined and the membership function was formed. This function enables descriptive ratings (linguistic values) to be transformed into numerical ratings (*fuzzy* numbers). (Durkalić et al., 2019; Puška and Bosna, 2024) The application of the given methodology was done on the basis of the linguistic scale presented in the following table 2.

Table 2. Linguistic evaluations and fuzzy membership functions

Linguistic Values	**Fuzzy numbers**
Very low (VL)	(1, 1, 2)
Low (L)	(1, 2, 4)
Medium low (ML)	(2, 4, 6)
Medium (M)	(3, 5, 7)
Medium good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very good (VG)	(9, 10, 10)

Source: Puška et al., 2024

In this work, we use the multi-criteria decision-making method SiWeC and its fuzzy variant. The method is new and was developed by Puška et al., (2024) in a study that concerned the selection of sales channels for agricultural products. This method belongs to the method for subjectively determining the importance of criteria and determines the weights of criteria based on linguistic evaluations. With this method, employees do not have to compare criteria with each other or rank them according to importance, but simply determine the importance of these criteria using linguistic values. Based on these values, the criterion could have a very high importance or a very low importance, and based on that, these evaluations were formed. In addition, this method differentiates the experts involved in the research based on their evaluation. If one of them gave almost the same grades, the importance of his grades is less compared to those who gave different grades. This is because not all criteria can have the same importance, but there must be a difference between them. Because of all this, this method was chosen to determine the importance of the criteria. (Puška and Bosna, 2024).

The steps of the fuzzy SiWeC method are given below:

Step 1. Experts determine the importance of each criterion.

Step 2. Linguistic values are transformed into fuzzy numbers, represented as:

$$\tilde{x}_{ij} = \left(x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}\right)$$

where x_{ij}^{l} represents first, x_{ij}^{m} second, and x_{ij}^{u} third fuzzy number.

Step 3. The fuzzy numbers are normalized as:

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

where $max\ x_{ij}^{u}$ is the maximum value across all criteria.

Step 4. Calculation of standard deviation ($st.dev_j$).

Step 5. The normalized ratings are weighted using the standard deviation values:

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

Step 6. The sum of the weighted values for each criterion is calculated:

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

Step 7. The fuzzy values of the criteria weights are computed as:

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

Step 8. Defuzzification of the weights criteria

$$w_{j\ def} = \frac{w_{ij}^{l} + 4 \times w_{ij}^{m} + w_{ij}^{l}}{6}$$

Results and Discussions

The results were obtained by analyzing the subject agricultural company for the supply of apple products located in the territory of the city of Novi Sad. Apple and apple products represent an important nutrient in the diet of the population and a base for processing, after which various food products are obtained. This agribusiness enterprise was taken as an obvious example of food supply resulting from the production and processing of agricultural products. Playing an important role in the local food supply chain, the company belongs to the category of medium-sized enterprises and has about seventy employees, of whom 3 are agricultural engineers and 3 are food technology engineers. The rest of the workers are mostly secondary school graduates (agricultural technicians), while a certain number are also seasonal workers in the production and processing sector. Also, a few workers are employed in the administrative building, which includes the sector for general and legal issues as well as the premises of the general manager, that is, the director of the company. The company tries to follow the current standards in the quality of production and storage. In the coming period, their goal is to expand the storage facilities, as well as to modernize the methods of handling the transportation and storage of products, as well as to additionally train existing workers in other segments of the work process. For now, they are achieving good cooperation with local professional and educational institutions and advisory services, from where experts were chosen for the evaluation of the very criteria from the impact on losses.

Production is carried out on about 10ha and on properties located in a couple of locations near a populated place. Raw materials for processing are additionally provided from leased areas. In their range, they produce several varieties of apples, the most common of which is the "Ajdared" variety. It is a variety that was created by crossing several old American apple varieties and is the leading apple variety in our region. It has a juicy taste and is very popular with consumers. The company has all the necessary machinery for production as well as storage space. The market is mostly on the territory of our country, although certain quantities also end up on foreign markets. The processing sector consists of premises for the production of apple juice and concentrate with all adequate equipment and human staff. The space is located on an area of about 1000m^2.

After reviewing the company in question, the results of an expert assessment of the impact of the criteria on losses in the process of production, storage and handling of the product were presented. At the beginning, a linguistic evaluation of the criteria was given. (table 3)

Table 3. Experts' evaluations of the criteria importance

Expert	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
Expert 1 (E1)	VG	MR	MR	M	MG	MR	MG	MR	MR	VG
Expert 2 (E2)	MG	VG	MR	VG	MR	VG	M	MR	VG	VG
Expert 3 (E3)	MR	MR	VG	MG	MG	MG	MR	VG	VG	MR
Expert 4 (E4)	MG	MG	M	M	M	MG	MG	MR	MR	MR
Expert 5 (E5)	MG	VG	MR	MG	VG	VG	MR	MG	VG	MG
Expert 6 (E6)	VG	MG	MR	MR	MR	MR	VG	MR	MR	VG

Source: Authors

After converting the linguistic values of the experts' assessment based on the previously presented scale (table 2), a fuzzy decision matrix was formed (table 4), which was followed by the calculation of the weighting coefficients of the given criteria according to previously established mathematical statements (formulas) of the SiWeC method of multi-criteria decision-making. (table 4) Given that the obtained weights are not used in the selection of possible alternatives, it was necessary to perform a defuzzification of the weights of the last step in the calculation, where the final values of the observed criteria were obtained in this way.

Table 4. Fuzzy decision matrix

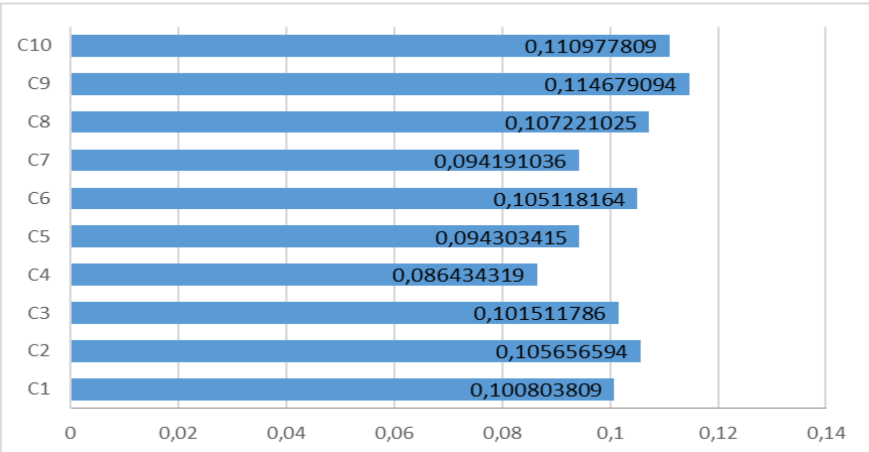
	C1	C2	C3	C4	C5…	C10
E1	(9,10,10)	(7,9,10)	(7,9,10)	(3,5,7)	(5,7,9)	(9,10,10)
E2	(5,7,9)	(9,10,10)	(7,9,10)	(9,10,10,)	(7,9,10)	(9,10,10)
E3	(7,9,10)	(7,9,10)	(9,10,10)	(5,7,9)	(5,7,9)	(7,9,10)
E4	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(7,9,10)
E5	(5,7,9)	(9,10,10)	(7,9,10)	(5,7,9)	(9,10,10)	(5,7,9)
E6	(9,10,10)	(5,7,9)	(7,9,10)	(7,9,10)	(7,9,10)	(9,10,10)

Source: Authors

The finally obtained calculation results, which are visually represented by Figure 1, show us that criterion 9 has the greatest weight (*Poor handling of products during transport*) and criterion 10 (*Inadequate packaging and handling of products)* have the greatest weight. In addition to them, influential criteria such as *"Inadequate storage conditions"*, *"Restriction of agricultural techniques"*, as well as the criterion *"Pests and diseases" are highlighted*. The criterion that has the least influence is *"Untimely harvest"*. We can find that there is generally a product handling problem in the company that should be reduced in the future.

The research results coincide with an earlier study by Gustavsson et al., (2011), where it was observed that food losses occur most often in the distribution (transport) phases. We also find confirmation in the research of Petljak (2021), which concludes that food losses in the production of fruit and fruit processing occur in all segments of the supply chain (from production to end consumers). Also, the same author emphasizes losses in product storage, which stand out as an important factor in losses in this research as well. Namely, as the author points out, during storage, significant losses occur due to inadequate storage infrastructure, and often also decisions made in the earlier stages of the supply chain, due to which the products have a shorter shelf life.

Figure 1. Rank of criteria weight



Source: Authors

Conclusions

From the above, it can be concluded that the occurrence of losses in supply chains, which concern food products, is more or less a problem at all levels of business. The agribusiness company in question in the case study, which is involved in food production, realizes certain losses. Factors influencing these losses were successfully evaluated by applying the innovative multi-criteria decision-making method SiWeC, using the fuzzy logic of expert decision-making. The greatest expert importance is given to the criteria concerning storage and poor handling of products during transport. Accordingly, the company should improve certain work operations in that domain in the coming period. Also, from the research side, the work represents a solid basis for the continuation of further research in connection with the development of new methods of importance for this type of problem.

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Conflict of interests

The authors declare no conflict of interest.

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