ANALYZING THE IMPACT OF REDUCING FOOD LOSSES OF RICE ON FOOD SECURITY IN BENIN

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A R T I C L E I N F O

Original Article

Received: *xx25 July 2022*

Accepted: *15 September 2022*

doi:10.59267/ekoPolj230199A

UDC
338.439.4.053.23:633.18(668.2)

Keywords:

food losses; rice; food insecurity; food consumption score; Benin

JEL: *Q16, Q18, R31*

A B S T R A C T

A substantial amount of rice grains is lost along the value chain, contributing to food insecurity among farming households in Benin. While food losses are inevitable along the value chain, it is imperative to determine the minimum acceptable loss for rice. This study aims to quantify the food losses of rice and determine its effect on food security using the Food Consumption Score (FCS) and Linear model. The results show a positive effect of a low loss rate on the FCS. In addition, a low loss rate increases the probability of FCS by 82.4 for the overall rice farmers and 83.7 for the efficient rice producers. Thus, reducing the loss rate throughout the food chain to a maximum of 10% would increase the amount of local rice on the market and allow producers to achieve food security. The study recommends sensitizing stakeholders along the rice value chain on strategies or technologies to reduce losses.

Introduction

The rising of food prices since 2006-2008 and the threat of food shortages in the future have renewed interest in agricultural development in Sub-Saharan Africa (SSA). For the majority of the population in SSA, cereal grains are an essential component of smallholder livelihoods and form the basis for food security. Cereals account for

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about 55% of the African basket of goods. For every 1% increase in food prices, food expenditure falls by 0.75% in developing countries. Cereal production is one of the best ways to ensure food security. According to the FAO (2018), about 374 million people suffer from severe food insecurity exacerbated by high food losses, and an effort to reduce these losses could be helpful. Rice is the second most important crop worldwide, and the demand will continue increasing given the population growth (Teye et al., 2019). Low production coupled with food losses is among the important causes of malnutrition and food insecurity. Ndindeng et al. (2021) estimated the rice's food losses in SSA at $10.24 billion, about 47.63% of the total production. According to IRRI's world statistic 2020, a huge part of the rice production in SSA in 2018 could not reach consumers' tables due to the losses along the value chain. The authors reported that about 17% of the production was lost due to inadequate equipment or practices. The challenge of food losses affects all countries, especially developing countries where farmers are still using conventional agricultural production (Balana et al., 2022). Food losses have contributed considerably to poverty, food insecurity and low quality of life in developing countries (Brander et al., 2021; Tesfaye & Tirivayi, 2018). Hashim et al. (2022) reveal that up to 70% of the food produced can be lost if an appropriate solution is not found to reduce the losses while increasing production. Reducing food losses became a common challenge and is the object of attention worldwide. In addition to quantitative losses, there is also the problem of loss of grain quality during postharvest, which can lead to loss of market opportunities and a decline in nutritional value (Bhattacharya & Fayezi, 2021).

The major causes of losses are harvesting methods, handling methods, drying techniques, storage methods, bird attacks, rats, insect damage, and parasites. By reducing quality and available quantity, food losses lead to higher prices for available food. In recent decades, a significant amount of attention and resources have been devoted to increasing food production. Increasing agricultural productivity is critical to ensuring global food security, but it is not enough. Food production currently faces the challenge of limited land and water supply and increased weather variability due to climate change. To achieve sustainable food security, food availability must also be increased by reducing food losses at the farm, retail, and consumer levels (Affognon et al., 2015). Quantitative losses of rice lead to a reduction in the volume of usable end product from harvested paddy leading to prices escalation (Morris et al., 2019). Qualitative losses are caused mainly by physical damage, which reduces the value of the usable product and renders the grains unappealing to consumers. A reduction in food losses may reduce the cost of production and retail distribution and the price to consumers. Mintenet al. (2020) stated that reducing food losses would improve food security, ensure the availability of high-quality food at lower prices, and reduce the impact on the environment.

In general, losses that occur during postharvest are due to different constraints that producers face during each step of postharvest and different methods used for each activity. These constraints and methods vary from one activity to another and have an important impact on food losses. It is then crucial to evaluate the value chain to identify the constraints at each step and quantify the loss. This is seen as the first step to collect accurate information to propose an adequate, sustainable solution to reduce constraints and losses and guide farmers not to pass the food security border.

Benin's total rice production accounts for only 3.15% of the production of Western Africa. In the same line as the other Western African countries, Benin rice's consumption has considerably increased during the past decade, leading to an increase in local production (Maertens & Vande Velde, 2017). Moreover, Benin has defined the Development Strategic Orientations and the Growth Strategy for Poverty Reduction, which pointed to the agricultural sector as the most crucial sector for poverty reduction. Among the strategies adopted are diversification and promotion of cereal crops. Thus, a policy plan was developed to diversify agriculture with rice as the priority sub-sector. However, recent data show that Benin is one of the African countries with the highest prevalence of malnutrition, with an estimated one in five people being undernourished.

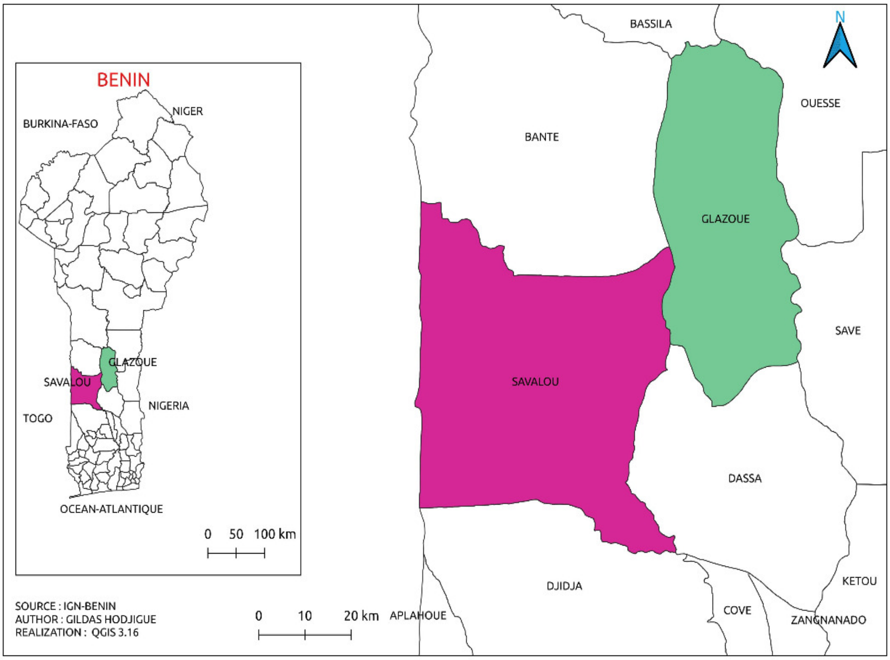
In Benin, very little literature and research were conducted to estimate and quantify the losses along with the harvest and postharvest processes. Such a study would provide the literature and policymaker accurate information on the quantified loss at each step and the constraints. Such information would also guide rice farmers to know where significant losses occur along the value chain, identify constraints related to the losses, and devise strategies to reduce losses and ensure food security. A novelty, this study aims to identify the minimum loss rate ''Authorized'' to keep farmers' food secure. This paper would be the first that provides the minimum loss rate for food security and estimate the impact of this minimum rate on the Food Consumption Score, including farmers' socio-economic characteristics. To this end, we analyze the constraints that occur during the harvest and postharvest process, quantify the food loss and estimate the impact of a low loss rate on food security.

Materials and methods

Data collection

The data used for this study were obtained from a baseline survey in Benin covering the area shown in Figure 1. Data collection was done in two communities in Benin (Glazoue and Savalou) using Mlax, an application developed by the AfricaRice Center to reduce errors and time spent on data collection. The sampling methodology for this survey was designed to include a spread of villages/communities. For the sampling of villages, the stratification criteria were the environment of rice cultivation (agro-ecosystem), accessibility to the village (based on the quality of the road to allow enumerators to reach farmers without major difficulties), and predominant crop. Based on these criteria, all villages where rice is grown in the target agro-ecosystem were first identified and listed. A total of 314 producers in 20 villages were interviewed on different postharvest activities.

Figure 1. Survey area in Benin



Identification of constraints and ranking

During the survey, each producer identified and ranked the constraints for harvest and postharvest activity. Each producer assigned a rank to each constraint. Kendall's rank correlation was used for data analysis. This non-parametric test measures the strength of dependence and gives the rank order. The following formula was used to calculate the value of Kendall's rank correlation (Abdi, 1955):

$$\tau = \frac{n_c - n_d}{1/2n(n-1)} \quad (1)$$

Where n is the number of observations, n_c is the number of concordances and n_d the number of discordant.

Determination of food loss rates

Food loss is the loss of physical grains that occur during the harvest and postharvest activities. It is a measurable qualitative and quantitative food loss along the supply chain, starting at the time of harvest until consumption or other end uses (Balana et al., 2022). The loss rate can be estimated from the input and output for each operation. For this study, the data used were collected by enumerators who asked specific questions to the farmers on different parameters needed for the estimation at each step along the value chain. Since there were no initial paddy rice quantities for the harvest step, a mathematical estimation was not possible. Rice farmers provided us with an intuitive estimation of the loss that normally occurs during the harvest process based on their experiences. Even though methods such as crop-cutting could be used to estimate the amount of rice on a square meter before harvest, we could not do that because the survey was organized at the end of the season after farmers had already harvested the rice.

In addition, we intended to estimate the grain loss through drying. This is because there is a loss of weight during drying due to moisture removal, which rice farmers could not estimate. We also considered that farmers could not control the weight loss due to drying. Moreover, we believe that the quantity of grain loss due to animal attacks or wind destruction could be avoided with proper protection. We estimated the loss rate as follows:

The loss rate for threshing = [(Initial quantity of paddy rice after harvesting– Final quantity of paddy rice obtained)/ Initial quantity of paddy rice after harvesting] *100

The loss rate of drying= [(Initial quantity of paddy rice after threshing – Final quantity of paddy rice obtained)/ Initial quantity of paddy rice after threshing] *100

The loss rate of winnowing = [(Initial quantity of paddy rice after drying– Final quantity of paddy rice obtained)/ Initial quantity of paddy rice after drying] *100

The loss rate of storage = [(Initial quantity of paddy rice after winnowing– Final quantity of paddy rice obtained)/ Initial quantity of paddy rice after winnowing] *100

Determination of FCS

The food security analysis was performed using the FCS, which is a proxy indicator of household food security based on the weighted frequency of intake of eight food groups. Therefore, the FCS is a pertinent indicator of the accessibility dimension of food security and the quality of food consumption affecting the nutritional status (World Food Program, 2008). The score is based on the frequency of food consumption which is a specific context and measured over a recall period of seven days. Foods were regrouped for analysis into eight groups (*Table 1.*) which are weighted by a value corresponding to their estimated nutritional role. Measurement of quantity was not included in the calculation of FCS. However, foods consumed in very small amounts were recorded as condiments (except for oil and sugar), in order not to overestimate the consumption of certain foods such as meat or fish, which can often be used to complement sauces, but whose nutritional intake is limited. The FCS is calculated using the following formula:

$$FCS = \sum_{i=1}^{8}(a\_i\ x\_i) \quad (2)$$

Where i = food group, a = weight, x = frequency.

Table 1. Food groups, weights, and levels of FCS

Food items	**Food groups**	**Weight**
Maize, rice, sorghum, millet, pasta, bread, and other cereals Cassava, potatoes, and sweet potatoes	Cereals and tubers	2
Beans, peas, groundnuts, and cashew nuts	Pulses	3
Vegetables and leaves	Vegetables	1
Fruits	Fruit	1
Beef, goat, poultry, pork, eggs, and fish	Meat and fish	4
Milk yogurt and other diaries	Milk	4
Sugar and sugar products	Sugar	0.5
Oils, fats, and butter	Oil	0.5
Levels of FCS and categorized profiles		
Levels of FCS	Profile	
0-21	Poor level of consumption	
21.5-35	Borderline of consumption	
>35	Acceptable level of consumption	

Source: (World Food Program, 2008)

The FCS captures both qualitative (different food groups/dietary variety) and quantitative (food frequency) elements of food security. A positive correlation has been demonstrated between measures of caloric intake and the food poverty line. The main criticism of this indicator is that it does not take into account individual dietary needs or seasonal variations. Therefore, we estimated three FCS for each household: one for the abundance period, one for the average availability period, and one for the lean or scarcity period. The thresholds were used to divide households into these three groups. The cut-off points were used to categorize households into three FCS profiles (*Table 1.*).

Estimation of the effect of constraints on food loss

Several factors have a positive or negative effect on the loss rate. It is important to note that the loss rate, assimilated with the index of technical efficiency, allows us to hypothesize that the registered losses are due to producers' responsibility (technical errors) and to random factors that are not controllable by producers. Thus, the controllable factors are most often associated with the technical performance of producers, which are affected by physical constraints. These constraints affect the loss rate at different levels of postharvest processes. Tobit regression was used to identify the constraints that have the greatest influence on the loss rate throughout the postharvest process. In this study, the total loss rate was estimated as the sum of the loss rate calculated at each level of the postharvest process. A bootstrap option was used to obtain robust standard errors in the estimation. To investigate the factors affecting postharvest losses at the farm level in food rice, functional analysis was carried out as described by Nag et al. (2000).

Linear model with endogenous treatment effects

The endogenous regression model is also known as the *endogenous binary variable.* This uses a linear model for the outcomes and forces a normal distribution to model gaps to the conditional independence assumptions of the estimators. In treatment effect jargon, the endogenous binary variable model is a linear potential outcome model that allows for a specific correlation between the unobservable structure affecting the treatment and the unobservable factors affecting the potential outcomes. Heckman (1978, 1976) studied this model and investigated some empirical applications of it, and described it as an endogenous switching model limited. Barnow et al. (1981) provided another useful branch of this model. That model focuses on the derivation of the conditions for which, using the Ordinary Least Squares estimator of the treatment effect, δ is nonzero and has a particular sign. Wooldridge (2010) examined the binary endogenous variable model as an endogenous treatment effects model, following up on recent work. Formally, the endogenous treatment regression model consists of an equation with an outcome y_j and endogenous treatment t_j. The objective is to determine the effect of the endogenous treatment (representing the loss rate) on food security over the total food consumption value. Since the endogenous variable must be binary, we made the loss rate variable binary, following the logic of technical efficiency explained by Farrell (1957). Just like the level of technical efficiency, the loss rate is an index used to evaluate the technical efficiency of producers and agents. Thus, the technical inefficiency observed in an actor consists of two parts. Firstly, inefficiency due to the fault of the producer; secondly, inefficiency due to random phenomenal effects that cannot be controlled by the producer. Then, we categorized the loss rate variable into two intervals.

0-10 (coded 1): The producers with an overall loss rate between 0 and 10%. These producers were categorized as "efficient" because we assume that the actors' 10% losses are due to random effects or uncontrollable factors. The causes of food losses are multiple and are not all related to the technical performance of the producer/actor but may be attributed to events such as floods, drought, or theft.

Over 10 (coded 0): are producers with an overall loss of over 10%. These producers were thus classified as "less effective/inefficient" because they have a high loss rate that can severely affect their incomes and food security. Such significant losses can not be entirely attributed only to uncontrollable factors but also to the technical performance of the producers.

To achieve our objective, we used a simultaneous equation model that allowed us to combine the two equations in our study (the " FCS equation with the endogenous variable" and the " food loss rate" equations). The advantage of this model is that, in addition to the linear regression estimates, it allows us to obtain the "Average Treatment Effect" (ATE) and Average Treatment Effects on Treated (ATET). This model also allows us to identify the determinants of low loss rates (0-10%). The equation system is made up of equations (3) and (4):

$$\begin{cases} fcs_j = \sum_j \theta_j \mu_j + \delta_j hphl_j + \varepsilon_j & (3) \\ hphl_j = \sum_j \delta_j x_j + \epsilon_j & (4) \end{cases}$$

Where *fcs* represents food consumption indices which are a truncated variable between 0 and 1;

x_j, and μ_j represent independent variables. *hphl* is the endogenous variable that connects the two equations. This method allowed us to simultaneously have both the value and the signs of the coefficients and the ATE and ATET resulting from loss levels.

Results and discussions

Characteristics of farmers

The results (*Table 2*.) show that the average age of farmers was 46 years. This shows that the respondents were adults and could decide on the choice of technologies and methods used during production and postharvest. The average household size was 7.22, and the average rice income per year was $384. The respondents had an average experience of 7.27 years in rice production. This means that most producers were proficient in rice production. More than half of the farmers had received training, which is an important factor in understanding the food losses and the adoption of technologies. Membership of the agricultural association is one of the means to improve access to new information (Raghunathan et al., 2019). It allows farmers to easily access information on new technologies, behaviors, methods, equipment, and techniques recommended to reduce food losses.

Table 2. Socio-economic characteristics of farmers

Variables	Mean	Minimum	Maximum	Std. Deviation
Age (Years)	46	19	80	12.06
Household size	7.22	1	18	2.86
Rice income ($/Year)	384	30	2520	440
Experience in rice production (Years)	7.27	1	42	9.34
Area of rice (ha)	1.01	0.1	8	1.36
Gender Male (%)	85.42	-	-	35.41
Group Membership (%)	61.11	-	-	48.91
Formal Education (%)	54.86	-	-	49

Identification of harvest and postharvest constraints and ranking

Many studies focus on the causes of losses and ignore the real constraints faced by producers. Tadesse et al. (2018) pointed out that the losses incurred at each step vary according to the organization and technology used in the food supply chain. It includes all activities from production to the final product for the end customer (Goletti &

Samman, 2007). The losses from one activity to another and the constraints faced by producers during each activity vary. The results show that the first major constraint during harvesting, drying, threshing, storage, transportation, and ginning is the "difficulty in obtaining equipment" (*Table 3.*). According to Hodges et al. (2011), greater losses in developing countries occur during harvesting. drying, storage, processing, and transportation where the supply chain is less mechanized. These constraints could be addressed by using mechanization or improved technology to reduce losses. Besides, there are higher labor costs associated with drying and threshing and losses due to rodents and insects. All these constraints are mainly due to external factors. These constraints require technologies to improve traditional methods and reduce losses at each step. These findings align with Kiaya (2014), who stated that postharvest technologies could contribute to food security in several ways. They can reduce postharvest losses and thereby increase the amount of food available for consumption by farmers and poor rural and urban consumers.

Table 3. Summary of constraints and ranking by activities

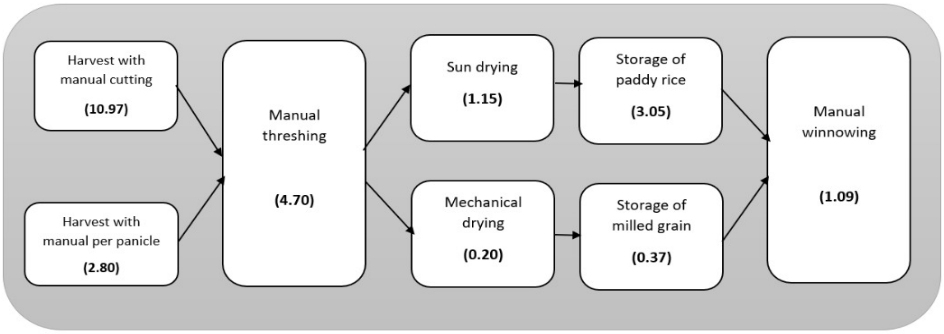
Activities	Constraints	Rank	Average	Test result
Harvest	Difficult acquisition of equipment	1	1.83	W de Kendall 0.47*** Khi-deux 16.95
	Relevance of method	2	1.92	
	Physical loss of grain during harvest	3	3.08	
Threshing	High cost of labor	1st	2.90	W de Kendall 0.033*** Khi-deux 15.04
	Difficult acquisition of equipment	2nd	3.27	
	High loss rate	3rd	3.79	
Drying	Difficult acquisition of equipment	1st	2.68	W de Kendall 0.033*** Khi-deux 15.04
	High cost of labor	2nd	2.87	
	Difficult management of equipment	3rd	3.08	
Storage	Loss caused by rodents	1st	2.77	W de Kendall 0.09*** Khi-deux 49.93
	High cost of storage products	2nd	3.35	
	Loss caused by insects	3rd	3.44	
Transport	High cost of transport	1st	2.19	W de Kendall 0.06*** Khi-deux 18.16
	Distance from market higher	2nd	2.52	
	Difficult access to market	3rd	2.55	
Winnowing	Difficult acquisition of equipment	1st	3.25	W de Kendall 0.02*** Khi-deux 35.46
	Labor cost higher	2nd	3.43	
	Difficult management of equipment	3rd	3.71	

*P <0.01, **P <0.05 and ***P <0.001

Estimation of food loss rates

Food losses of rice occur from harvest to consumption. *Figure 2.* shows the average loss rate for the main methods used in each activity from harvest to storage. Based on the methods used, it can be seen that the mechanical method is used to a very low extent and, as expected, recorded the lowest loss rate (0.2%). In Benin, 76% of the agricultural operations are manual, 23% with animal traction and only 1% are mechanized (Mounirou, 2018). Manual cutting contributes a high loss rate of 11%, while manual panicle cutting contributes a loss rate of only 3% for the harvesting activity. In 2007, the International Rice Research Institute estimated the loss during harvesting to be between 5 and 16%, and a further 5 to 21% is lost during drying, storage, milling, and processing (Sadiq Saba & Ishaq Ibrahim, 2018). It is known that the harvesting process includes other activities such as crop handling, threshing, and grading. Redfern et al. (2012) reported similar estimates of rice losses in Southeast Asia. A survey conducted in 13 member countries of the Africa Rice Center showed that some major problems common to many countries are improper harvesting and field management practices that cause severe food losses. The Africa Rice study shows that the estimated losses during harvest and postharvest are about 15 to 50% of the market value and are as high as \$30 to \$75 per ton (Sadiq Saba & Ishaq Ibrahim, 2018). The findings of this study are also supported by the findings of Appiah et al. (2011), who found that harvesting losses ranged from 3.03 to 12.05% using the panicle and sickle method; threshing losses ranged from 0.53 to 4.04% using the traditional method commonly known as “Bambam” method in Ghana while drying losses ranged from 1.57 to 1.76%. Despite increasing agricultural production, qualitative and quantitative postharvest losses along the rice value chain remain very high due to poor postharvest practices (Mopera, 2016). Often, qualitative losses are due to physical damage on the grains resulting from high levels of breakage, chalky grains, and the presence of impurities, which are usually sold unbranded (Mopera, 2016; Ndindeng et al., 2015). Efforts to reduce postharvest losses to 10% would significantly increase the availability of rice on the market, thereby increasing the availability of locally produced rice within the short term (Ndindeng et al., 2015). A systematic analysis of the overall value chain with the participation of the actors is the logical first step in designing an appropriate strategy or technology to reduce food losses.

Figure 2. Diagram of food losses along the value chain



Determination of the FCS

In the case of this study, the FCS is used to estimate the level of food security among farmers. *Table 4.* shows the frequency of food consumption rating by gender on three intervals of FCS rating. These results indicate that 28.5% of households where the household heads are “male” fall within FCS between “0-21” compared to the 14.3% of female-headed households. We find that the frequency of female-headed households falling within FCS between "21.5-35" is significantly higher than for males. At the acceptable FCS, we find that 58.5% of male-headed households have a level of FCS greater than 35, compared to 47.6% in a female-headed household. These results can be justified since the responsibilities in the rural household are not always the same for men and women. However, this could be different if men and women are put in the same condition, which is usually not the case in African society, especially in a rural household. However, international organizations know and recognize that gender equality is also a key for achieving food security (Garcia & Wanner, 2017). Overall, 56.9% of the farmers have an FCS of more than 35, which means that more than half of the households have an acceptable level of food intake. But this again leaves 44.6% that need to improve their food security level by increasing production capacity and reducing food losses in order to make more food available.

Table 4. FCS estimation

Levels of FCS	Decision	Frequency (%)		
		Male	**Female**	**Together**
0-21	Poor level of consumption	28.46	14.29	26.39
21.5-35	Borderline of consumption	11.38	38.10	15.28
>35	Acceptable level of consumption	58.54	47.62	56.94

Determination of the effect of the constraints on food losses

This part of the study focused on the effect of constraints on losses. Thus, the two main constraints were taken at each step of the postharvest process level, and a Tobit regression was used (*Table 5.*). In addition, socioeconomic characteristics were used to triangulate with the food loss rates. The results show that overall the model is significant at a 1% level. Quantity, gender, and group membership are the socio-economic variables used in the model. Quantity and gender are significant at 5% and 1%, respectively. These results show that the quantity produced positively and significantly affects the loss rate. Moreover, a negative sign in gender means that male farmers tend to have higher losses than female farmers. Women would inherently have management skills that enable them to improve their effectiveness. These results agree with those of Tadesse et al. (2018), who also found that gender and size of production were among the determinants of food losses in potato production. This is in contrast to the findings of Aidoo et al. (2014), who found that female farmers are more prone to high losses than their male counterparts. In the same line, Cole et al. (2018) found that women experience more losses in fishing activities because they often have less time and have limited access to processing, storage, and handling technologies.

On the other hand, Babatunde et al. (2019) reported that household size and farm size are the determinants of food losses in rice production. We see that all significant constraints have a negative impact on losses. Thus, lack of equipment, higher cost of labor, higher cost of stored products, and higher cost of transportation negatively impact food losses, which can be addressed by providing farmers with new technologies or equipment to effectively reduce food losses.

Table 5. Summary result of Tobit regression

	Variables	**Coefficient**
	Constant	114.87*** (40.27)
Harvesting	Lack of equipment	-35.40 (33.89)
	Labor cost higher	-21.01(21.98)
Threshing	Labor cost higher	14.01(12.47)
	Lack of equipment	-26.35*(14.52)
Drying	Labor cost higher	-20.40*(12.21)
	Lack of equipment	-5.60 (22.65)
Storage	Cost of products higher	-32.66**(13.96)
	Rodent	1.195 (9.20)
Transport	Cost of transport higher	-11.75 (8.66)
	Long-distance	-1.70 (9.84)
Winnowing	Labor cost higher	-36.57***(14.02)
	Lack of equipment	-45.67***(16.14)
Socioeconomics factors	Quantity produces	0.01***(0.00)
	Gender (1=male)	-157.51***(27.57)
	Members of group (1=Yes)	-12.92 (8.10)

*P <0.01, **P <0.05 and ***P <0.001

Impact of low loss rate on FCS: ATE and ATET

Increasing agricultural productivity is critical to ensuring global food security, but it may not be enough. Food production currently faces the challenge of limited land and water supply and increased weather variability due to climate change. Food availability must also be increased by reducing losses during the harvest and postharvest processes at the farm, retail, and consumer levels to sustain food security goals.

As stated in the methodology, these parts of the study allow us to measure the effect of a low loss rate (0-10%) on the level of food consumption. Indeed, since the main objective is to reduce losses as much as possible, the second part of this model shows the factors that determine a low loss rate. The results (*Table 6.*) show that the model is globally significant at a 1% level. The likelihood ratio also shows that we can reject the null hypothesis that there is no relationship between treatment errors (low loss rate) and misperceptions (FCS). In the first part of the model, we can see that the variable “low loss rate” is positive and significant at 1%. These results prove that a low loss rate positively affects the FCS. Thus, reducing the loss rate to a maximum of 10% in the whole food chain would allow producers to achieve food security. The more the loss rate decreases throughout the food chain, the more food is available to consumers qualitatively and quantitatively, which may ultimately lead to food security.

A likely solution is to prevent losses by relying on the availability of the actors working in food management, the appropriate technologies, and the necessary information that would assist farmers in reducing food losses. According to the 2013 Advancing Food Security report of the Chicago Council on Global Affairs, there is a recommendation for action to “halve food losses by 2023” (Bertini and Glickman, 2013). The authors argued that ‘’without adequate infrastructure for crop storage and transportation, enormous amounts of food are lost on the way from the farm to the consumer’s table and therefore, efficient food management systems are required (IFPRI, 2019). Indeed, recent studies provide evidence that food losses are substantial, with one commonly cited estimate stating that one-third of the world’s agricultural production is wasted. However, the idea that reducing food losses can impact food security is not necessarily new. Moreover, other variables besides the loss rate influence the level of food consumption. For example, the model shows that the variables “number of days per month or household having one meal per day”; “one meal per week” and “number of days without food,” although significant, have a negative effect on farmers’ FCS. These results can be explained by the fact that the frequency of food consumption is a very important factor that positively affects household food security. The higher the frequency of consumption, the more the farmers tend towards food security.

The second part of our model shows factors that determine the low loss rate. Among these variables, we have: “the use of manual equipment” (hand-held devices), significant at 1%, negatively affecting the low loss rate. This result once again shows the importance of adopting mechanized equipment to reduce losses at all stages. Capacity and machinery building is crucial to address these losses. Implementation of appropriate protective measures should be encouraged to reduce losses during milling and threshing. Area, group membership, technical efficiency, and education are also positive and significant. The larger the area, the lower the loss rate. This result can be explained by the fact that producers with large holdings use the most equipment to reduce losses and working time. Groups or producer associations are more often places for information exchange and training in technology. Thus, producer members of a group are more likely to have the opportunity to receive information and benefit or other advantages from training. Technical efficiency is an index that shows the performance of producers in using these inputs rationally. So a producer with technical efficiency will have a low rate loss, which explains the positive effect on low rate losses. Education is a factor that facilitates the understanding and management of production.

Table 6. Result of simultaneous equation/ FCS and low-rate loss

Variables	**Coefficient**
Food consumption score	
Number of days per month / one meal per day	-0.01***(0.002)
Three meals per day	25.95*(13.81)
One meal per week	-40.73**(18.11)
Numbers of days without food	-2.61***(0.61)
Number of days per month / two meals per day	32.45*(17.18)
Food loss [0 – 10]#c. Sex	
0	-1.66(13.43)
1	35.13**(17.92)
Food loss [0 – 10]	51.18***(19.18)
Constant	-26.53(27.00)
Food loss [0 – 10]	

Variables	Coefficient
Age	0.01(0.01)
Manual equipment	-2.23***(0.71)
Area	1.69**(0.66)
Members of group	0.83***(0.27)
Technical efficiency	1.16**(0.60)
Instructs	0.74**(0.29)
Constant	-0.93(0.68)
/athrho	-1.40***(0.50)
/lnsigma	3.72***(0.16)
rho	-0.88(0.10)
sigma	41.54(6.76)
lambda	-36.85(10.12)
*P <0.01, **P <0.05 and ***P <0.001	

The results also show the average treatment effect (ATE) of all producers and the average treatment effect of "efficient" producers (ATET) (*Table 7.*). The results suggest that a low loss rate increases the probability of improvement in the FCS to 82.4. The probability of improvement in the FCS of efficient producers (with loss rates between 0 and 10) is 83.7. These results confirm that rice producers' low loss rate (between 0 and 10%) positively affects their food security.

Table 7. ATE and ATET estimation

	Efficiency level	Probability	Standard error
ATE	(1* vs 0**)	82.36	23.36
ATET	(1 vs 0)	83.68	23.87

*: Efficient; **: Less efficient

Conclusion and policy implications

Food insecurity, lack of nutritional diversity, and food losses are major problems in much of the developing world. Clearly, food production must be significantly increased to meet the future needs of a growing population. This study has expanded our knowledge of the relationship between food losses and food security. Using descriptive analysis and the application of an econometric model (linear regression and simultaneous equations), this study showed that a low loss rate of rice has a positive effect on food security. Thus, reducing the loss rate to a maximum of 10% in the whole food chain would allow producers to achieve food security. The use of manual methods can increase the loss rate of rice. Therefore, there is a need to emphasize measures to reduce losses during harvest and postharvest. These measures need to consider the various activities taking place from harvest to the point of sale that might increase the loss rate of rice. It is important firstly, educate the actors in the rice value chain on the issue of food losses through training and awareness-raising as suggested by Morris et al. (2019); secondly, to inform the chain actors of the importance and necessity of using improved technologies and equipment that could reduce food losses; and finally, to disseminate new and practical methods that will enable producers to remain efficient in their operations and reduce losses. This requires a holistic approach involving value chain actors, development partners, and policymakers to come together to develop and introduce new, affordable and accessible technologies and approaches that could significantly reduce food losses. The authors acknowledge that the study has some limits, which can be summarized in two points:

- The initial sample size is bigger, but we could not get accurate information since farmers provided an intuitive estimation of the loss. The estimation is sometimes complicated, even impossible for some farmers. We would suggest a bigger sample and broaden the overall community producing rice study.
- Minten et al. (2020) mentioned that there is a difference between the intuitive estimates of loss provided by farmers and directly measured losses. However, the authors believe that it won't be a significant difference in the finding. A more structured study could be initiated to measure the loss at each step directly.

Data availability and material: The data used for the analysis are available and will be provided on request.

Ethical Statement

Funding: No funding was received for conducting this study.

Conflict of interest

The authors declare that they have no conflict of interest.

Informed consent

This study is based on quantitative data collected from rice farmers who consent to participle in the study.

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