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Factors influencing post-harvest losses in rice production amongst smallholder farmers in Liberia

Eric Emmanuel Pluato[1] and Joao Mutondo[2]

[1]Department of Socio-Economics and Applied Statistics, Central Agriculture Research Institute (CARI), Suakoko, Bong County, Liberia.
[2]Faculty of Agronomy and Forestry Engineering, Eduardo Mondlane University, Maputo, Mozambique

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Demand for rice remains high in Liberia, with low farm-level productivity due to postharvest losses. Rice output has continuously declined, with PHL (post-harvest losses) accounting for about 10 to 40%. The ability of smallholder rice farmers to improve output levels depends on efficient postharvest operations at the farm level and hence on technical post-harvest efficiency. The study described PHL along the rice value chain and the effect of factors influencing post-harvest rice loss. A one-way ANOVA was used to describe PHL along the rice value chain, whereas logistic regression analysis was used to determine factors influencing post-harvest rice loss in Liberia. The study revealed that rice farmers incurred higher PHL at the harvesting and packaging stages of the rice value chain, while age, household size, post-harvest training, climatic season, storage method, and harvesting techniques are potential determinants of postharvest losses in Liberia. Therefore, rice handling practices should be considered among the key policy priorities. There is need to reduce PHL while promoting efficient resource utilization to improve the livelihood and gross margin of smallholder rice farmers in Liberia.

Key words: Liberia, Post-harvest losses, rice, smallholder farmers.

INTRODUCTION

One key sector that plays a significant role in the overall economic performance of Liberia, in terms of its contribution to gross domestic product (GDP), is agriculture. According to the Country Commercial Guide, the agricultural sector is the primary livelihood for more than 60% of Liberia's population, accounting for 31% of Liberia's 2021 real GDP. The sector also plays a significant role in enhancing food security, poverty alleviation, and employment (Taiwo and Bart-Plange, 2016). It provides income for many households engaging in rice, cassava, vegetable, rubber, oil palm, cocoa, and sugarcane production. Rice and cassava are the primary staple food crops, with rice and vegetables occupying about 87% of the cultivated land in Liberia (Bruce, 2022).

Rice belongs to the family Gramineae, a cereal grain believed to be the most widely cultivated crop in the world, as well as being the most important food crop among almost half of the world's population (Cosslett and Cosslett, 2017). The demand for rice in most African and Asian countries is overwhelming, and by the year 2050, the current world's population of 9.7 billion is expected to increase by one-third, while the global rice demand will

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

increase by 70% more than is consumed today (Devaux et al., 2020). This scenario will also be true for Liberia because, over the past 15 years, rice consumption has increased by 4.6% yearly, and has a per capita consumption of 133 kg (World Bank, 2023). In Liberia, rice is a primarily preferred staple food (Hilson and van Bockstael, 2012), consumed by more than 80% of people. It accounts for nearly one-half of the calorie intake of adults and about 15% of the overall spending of an average household (LISGIS, 2017; Miklyaev et al., 2017). Liberia's annual per capita consumption is one of the highest in Africa and was estimated to be more than 133 kg per year (Chauhan et al., 2017), compared to the West African average consumption of 84.5 kg per capita, and it is considered the fifth-highest consumer of rice in West Africa.

The crop is mainly produced by smallholder farmers scattered across the country (Etefa et al., 2022). Rice cultivation in Liberia is extensive and characterized by poor technical and post-harvest handling practices (Taiwo and Bart-Plange, 2016); therefore, the total volume of locally produced rice is far less than the country’s rice demand (Billy et al., 2016). Billy et al. (2016) showed that Liberian farmers are unable to produce enough rice to meet their household demand, with 66% of farm households not being able to produce what they need for consumption. The annual rice production in 2021 was estimated at 170,000 metric tons, which is below the demand of 400,000 metric tons, with over a 50% gap filled by imported rice (Food and Agriculture Organization [FAO], 2022). The low production is compounded by high post-harvest losses (PHL), limiting the availability of locally produced rice in the country. According to a study conducted by CRS (2011), rice farmers in Liberia were losing between 10–40% of production due to insects, rodents, spoilage, bruising, disease attack, spillage, contamination, and poor storage practices. However, appropriate post-harvest operations, despite leading to unprecedentedly high rice losses among smallholder rice farmers, have not been taken seriously (MoA, 2012). Postharvest losses impede not only the economic well-being of smallholder farmers but also the efforts of the government to ensure food security.

The implication is that if no special attention is given to reversing the situation, the country stands a chance of increasing its importation bills, facing severe food insecurity, and experiencing negative outcomes that hinder poverty reduction efforts by the government of Liberia. Additionally, a knowledge gap limits farmers’ ability to act towards reducing losses, as well as policymakers’ ability to formulate appropriate policies to mitigate these losses. Henceforth, it is essential to have clarity on questions like: what are the determinants of post-harvest rice losses? What are the critical loss points along the post-harvest handling chain? How do different factors lead to post-harvest rice loss? What measures can be put in place to reduce rice loss in Liberia? To remedy the situation, the study aimed at filling the knowledge gap, thereby assessing PHL in rice production and measures to mitigate losses incurred by smallholder rice farmers in Liberia.

Determinants of PHL

The causes of PHL in developing countries, which some estimates suggest could range from 10 to as high as 40% in Liberia of what is produced, can occur during any of the various stages of the post-production system (Taiwo and Bart-Plange, 2016). Losses after produce has left the retail market are generally difficult to control by agricultural means. Idah et al. (2007) believed that improper post-harvest sanitation, poor storage and packaging practices, and mechanical damage during harvesting, handling, and transportation resulting from vibration by undulation and irregularities on the road can enhance losses. It has been contended by most researchers on this topic that many PHL are a direct result of production management.

For instance, the number of days that the crop spent in the field before being sold had a significant and positive effect on losses. This indicates that the more days before the harvest is sold, the higher the mean percentage of PHL; and this was chiefly attributed to poor storage facilities and unreliable markets. The product deterioration rate increases as the time it stays in the market increases (Kader, 2013; Ayandiji and Adeniyi Omidiji, 2011). Mebratie et al. (2015) also found similar results and concluded that female farmers incur higher postharvest losses than male-headed households in Ethiopia.

Furthermore, Kikulwe et al. (2018) also found access to markets (distance to market and distance to tarmac roads) to have significant negative effects on PHL. This implies that farmers who are far from tarmac roads in the Rakai district (that is, mean distance to tarmac is 14.4 km) have a lower level of PHL of 0.093% than Isingiro farmers who are further away from tarmac roads (that is, mean distance to tarmac road of 39.7 km).

According to Expert Consultation (Atanda et al., 2011), losses occur due to poor pre-production and post-harvest management, as well as a lack of appropriate processing and marketing facilities. These losses have several adverse impacts on farmer income, consumer prices, and the nutritional quality of the produce. Because of poor planting material and cultural practices, including harvesting methods and handling practices, the quality of harvested produce is below standard. The absence of a farm storage facility and a proper pack house/packing station results in the perishable produce being marketed immediately after harvesting without primary processing and adequate packaging.

According to Atanda et al. (2011), microbiological, mechanical, and physiological factors cause most of the losses in perishable crops. Physiological factors that lead to PHL are caused by natural respiratory losses, which occur in all living organisms. This accounts for a significant level of weight loss, and the process generates heat. Changes that occur during ripening and senescence, including wilting and termination of dormancy (for example, sprouting), may increase the susceptibility of the commodity to mechanical damage or infection by pathogens. A reduction in the nutritional level and consumer acceptance may also arise with these changes, whereas the production of ethylene results in the premature ripening of certain crops (Atanda et al., 2011).

Atanda et al. (2011) further found that non-assistant capital expenditures, technology, and quality control, including inadequate harvesting, packaging, and handling skills, lack of adequate transport and handling of perishables, and storage facilities, are other determinants of PHL. Poor drying equipment, poor drying seasons, and traditional processing and marketing systems can be responsible for high losses. Therefore, knowledgeable management is essential for maintaining tools in good condition during marketing and storage, and bumper crops can overload the post-harvest handling system or exceed consumption needs and cause excessive wastage (Atanda et al., 2011; Bourne, 1977; Bourne, 2004).

METHODOLOGY

Sampling and data

Secondary data from the Liberia Post-harvest and Food Security Assessment (LPFSA), 2021, conducted by the World Food Program, were used to analyze the determinants of postharvest losses among smallholder rice farmers in Liberia. It contains data on socio-economic and demographic characteristics and agriculture, including subjects related to PHL and climatic and post-harvest factors. Structured and semi-structured questionnaires were administered to gather data on PHL from rice producers in Liberia. A Random Geographic Cluster Sampling (RGCS) method was used in the survey. In the RGCS design, points (latitude and longitude) were randomly selected, and then a circular cluster of a given radius was created around each central point. All eligible respondents found within each cluster were selected, and face-to-face interviews were conducted by trained field enumerators. The sampling area stretches across the 15 counties of Liberia, which are subdivided into districts and further subdivided into clans. A total of 823 rice farmers were sampled in the research region and interviewed. For this study, 10 independent and dependent variables were used for logistic regression analysis (Gender, Age, Marital Status, Household Size, Education Level, Harvesting Method, PHL Training, PHL Season, Storage Method, and post-harvest loss).

A statistical package, STATA software version 15.5, was used to analyze the description of PHL and estimate the determinants of PHL in Liberia, while MS Excel was used to develop various graphs and charts. The data obtained were subjected to descriptive statistics, ANOVA, and logistic regression analysis.

Sample analysis

Table 2 lists the basic demographics and socio-economic characteristics of the respondents. Of the 823 respondents, more than half (63.49%) were males, while females accounted for 36.57%. This implies that rice farming is dominated by male farmers and could be attributed to the cultural setting of the area, in which land is mainly allocated to males while females are deprived of direct land ownership. It can also be explained by the fact that rice is both a food staple and an income crop, and males are well known for being engaged in the production of cash crops. More than half (83.75%) of the respondents were between the ages of 18 and 45 years, implying that a good number of the farmers in the area are in their economically active age. This fact can positively affect the development of the rice value chain, as young farmers are more willing to adopt and implement improved technologies. In addition, the study revealed that 86.51% of the farmers were married and had household sizes of between 1 and 12 members, accounting for 88.45 and with an average household size of 6 persons. For the educational status of the respondents, 83.89% of the farmers had completed primary and secondary education, while only 13.97% had tertiary education. The result agrees with the findings of Dorley et al. (2022) and Omidiji and Ayandiji (2011), who found that the sector is dominated by farmers with low levels of or no education. The dominance of illiterate farmers limits them in instituting appropriate post-harvest practices that minimize losses (Table 1).

About 91.73% of farmers used manual harvesting methods, while 8.63% used mechanical methods, which include the use of machines. This is consistent with Kumar and Kalita (2017), who reported that crop harvesting is performed manually using hand-cutting tools such as sickles, knives, scythes, and cutters in most developing countries. The dominance of the manual method of harvesting leads to an increase in the level of PHL because manual harvesting takes a long time. The study has further disclosed that more than half, 58.81% of farmers, experienced PHL during the rainy season, while 41.19% of farmers incurred losses during the dry season. It is expected that humidity and the development of diseases and pests, which can cause PHL, are prevalent during the rainy season.

Major post-harvest constraints reported by respondents in Liberia, as presented in Table 3, include pests and diseases, including birds, climatic conditions, and rodents. This is consistent with the findings of Hussen et al. (2013), who found that inadequate control of pests and diseases, including birds, are the major factors contributing to losses of cereal, maize, and commercial horticultural crops, respectively.

Description of rice PHL

The supply, demand, and price dynamics of rice are shaping food insecurity and poverty in Liberia. Rice makes up over 20% of total food consumption, accounts for nearly half of the calorie intake of adults, and accounts for about 15% of the overall spending of an average household in the country. Demographic trends and a strong preference for the commodity are the main drivers of demand. Yet Liberia produces only a third of its rice needs due to several constraints, including limited access to technology, inefficient post-harvest practices, and a fragmented value chain, among other factors that have kept productivity low. The low production is compounded by high PHL along the value chain, limiting the availability of locally produced rice in the country. To describe PHL along the rice value chain, descriptive statistics were used. Specifically, the percentage of quantity loss and means were computed for various post-harvest stages, whereas frequency distribution tables and charts, including graphs, were used to summarize PHL across key socioeconomic characteristics of rice farmers along the rice value chain. For socioeconomic characteristics, percentages of PHL were computed for categorical variables such as gender (male, female), marital status (married, separated, single, and widow/widower), and education level (completed college, completed primary, completed secondary, and no schooling). The goal of computing these percentages was to provide basic information about the influence of those categories on PHL. Specifically, the study analyzed the significance of rice PHL along the various stages of the rice value chain. The analysis of variance (ANOVA) test was used to determine if there are differences

Table 1. The basic demography and socio-economic characteristics of respondents.

Characteristic	n=823	Description	%	Mean SD	Min.	Max.
Gender	522	Male	63.43	0.488	**0**	**1**
	301	Female	36.57			
Age (years)	41	18-24	4.98	0.468	**0**	**3**
	663	25-54	80.56			
	109	55-64	13.24			
	10	64-Above	1.22			
Marital status	712	Married/living as partner	86.51	0.79	**1**	**4**
	44	Separated/Divorced	2.43			
	20	Single	5.71			
	47	Widow/widower	5.35			
Household size		No. of persons in a household	6	4.05	1	12
Education level	18	No school	2.19	0.95	0	3
	418	Complete primary	50.79			
	272	Complete secondary	33.05			
	115	Complete College/University	13.97			
Harvesting method	752	Manual	91.73	0.282	0	1
	71	Mechanical	8.63			
PHL training	778	No	94.53	0.258	0	1
	45	Yes	5.47			
PHL season	484	Rainy	58.81	0.487	0	1
	339	Dry	41.19			
Storage method	339	Kitchen	41.19	1.451	1	6
	377	Bag	41.19			
	36	Silo	45.81			
	71	Warehouse	4.37			
Post-harvest loss	145	No	17.62	0.804	0	1
	678	Yes	82.38			

in losses between the various stages of the post-harvest value chain. The hypothesis being tested is:

H_o: PHL is equal in the various stages of the rice value chain.
H_1: There is a significant difference in PHL along the various stages of the rice value chain.

This method was adopted by Mapiemfu-Lamare et al. (2023), Upadhyay et al. (2021), and Sugri et al. (2021) to evaluate the loss points of PHL. To validate the ANOVA results, tests for homogeneity of variances and normality were conducted. The Bartlett test of equal variances was used to test for homogeneity of variance between the percentages of quantity losses along the post-harvest value chain. The Bartlett test statistic is designed to test for equality of variances across groups against the alternative that variances are unequal in losses for all the post-harvest stages (harvesting, threshing, drying, processing, transportation, packaging, and marketing). The hypothesis tested is that there is no significant difference in the variances of PHL along the rice value chain. The test statistics for the Bartlett test are obtained with the following equations:

$$T = \frac{(N-k)\ ln S^2 p - \sum_{i=1}^{k} (Ni-1) ln S^2 i}{1+(1/(3(k-1)))((\sum_{i=1}^{k} 1/(Ni-1))-1/(N-K))}$$

where si^2 is the variance of each stage, N is the total sample size, Ni is the sample size for each stage, k is the number of stages, and Sp^2 is the pooled variance. The pooled variance is a weighted average of the group variances and is defined as:

$$Sp^2 = \sum_{i=1}^{k} (Ni-1) s^2 i / (N-K)$$

Table 2. Variables description and expected signs on the determinants of PHL.

Variable	Descriptions	Expected Signs
PHL[a]	Dummy variable equal to 0 if no PHL is Incurred and 1 if PHL is greater than 0	
Gender	Dummy variable coded as 1 if female and 0 otherwise.	+
Household size	Continuous variable, Number of persons living in the household.	-
Marital status		
Widow(er)	Is a categorical variable with three dummies (1 = Widow(er) 0= otherwise, 1= Divorced 0= otherwise, and 1 = Single 0= otherwise) and married as reference variable.	+
Divorced		+
Single		+
Age	Age is a categorical variable with three dummies, (1=25-54 years and 0=otherwise, 1=55-64 years and otherwise, and 1=65 years and above and 0=otherwise) with 18-24 years as a reference variable.	+
Education level		
Complete primary	Education level is a categorical variable with three dummies (1 = complete primary 0= otherwise, 1= complete secondary 0= otherwise, and 1 = complete college/university 0= otherwise) and no education as reference variable	-
Complete secondary		-
Complete college/university		-
No. of harvest days	Number of days takes to harvest.	+
Post-harvest training	Post-harvest training for Respondents is coded as 0 if acquired training and 1 otherwise.	+
Climatic seasons	Major season PHL is incurred equal 0 if Dry season and 1 if rainy season.	+
Storage method		
Bags	Storage Method is also a categorical variable with three dummies (1 = bags 0= otherwise, 1= silo 0= otherwise, and 1 = warehouse 0= otherwise), with traditional storage as a reference variable.	-
Silo		-
Warehouse		-
Harvesting techniques	Harvesting techniques used during harvest and it is coded as 1 if Manual and 0 otherwise.	+

a: Dependent variable for the regression analysis.

The variances are judged to be unequal if the probability value is less than α=0.05. If the ANOVA test is statistically significant, we proceed to test the differences in losses between pairs of the post-harvest stages using the Tuckey HSD (Honestly Significant Difference) test. This test uses pairwise post-hoc testing to determine whether there are differences between the mean of all possible pairs of the post-harvest stages with α=0.05 significant level (Dunn,1961). The relevant statistic is:

$$\text{HSD} = q\,\frac{\sqrt{MSE}}{n}$$

where n is the size of each of the group samples, MSE is the mean squares of errors and q is the critical values for this q distribution, and are presented in the Studentized Range q table based on the values of α, k, and degree of freedom. Additionally, the study analyzed the gender dimension of PHL using a t-test, while per county distribution and causes of PHL at various stages of the rice postharvest value chain in Liberia were also analyzed. The percentage of quantity loss at different stages was computed between males and females and within the fifteen counties of Liberia.

Table 3. Logit and logistic estimate of the determinants of PHL.

Variable	Coef.	P-value	Std. Err	Marginal effects	Odds ratio
Gender	-0.0067	0.980	0.2673	-0.0007	0.9933
Age (18-24 omitted)					
25-54	1.0883	0.026**	0.4898	0.1040	2.9694
55-64	1.7375	0.004***	0.6055	0.1531	5.6832
64-Above	2.2780	0.044**	1.1288	0.1872	9.7572
Household size	-0.0581	0.015**	0.0239	-0.048	0.9435
Marital status (married omitted)					
Widow(er)	0.3542	0.492	0.5154	0.0281	1.4251
Divorced	-0.3655	0.575	0.6524	-0.0319	0.6938
Single	-0.4148	0.408	0.5015	-0.0365	0.6605
Education level (no school omitted)					
Complete primary	-0.6849	0.404	0.8206	-0.0538	0.5041
Complete secondary	-0.3910	0.641	0.8380	-0.0294	0.6763
Complete college/university	-0.6173	0.479	0.8726	-0.0480	0.5394
No. of harvest days for harvest	0.0125	0.016**	0.0052	0.0010	1.0126
Post-harvest training	2.7591	0.000***	0.2600	0.2296	15.784
Climatic season	1.7440	0.000***	0.3627	0.1451	5.7199
Storage method (no storage omitted)					
Bags	-0.9076	0.002***	0.2979	-0.0782	0.4035
Silo	-0.3559	0.549	0.5938	-0.0279	0.7006
Warehouse	0.2607	0.633	0.5463	0.0184	1.2978
Harvesting techniques	0.0210	0.026**	0.0095	0.0018	1.0213
Cons	-5.8997	0.000***	1.1978		0.0027
Pseudo R^2			0.4099		
Log-likelihood			-229.55644		
Prob. > $Chi^2(18)$			0.0000		
Number of observations			823		

***; ** and *: Statistically significant at 1, 5, and 10% respectively.

Determinants of PHL

To analyze the determinants of postharvest losses, the study used a binomial logistic regression. Logit models have been widely used to estimate the determinants of postharvest losses in developing countries (Ndwiga, 2015; Agada and Uga, 2017; Ayandiji and Adeniyi Omidiji, 2011). Rice farmers were classified either as "Yes" if they had incurred PHL or "No" otherwise. Whether or not the farmers incurred PHL is a binary/dummy variable and is coded as 0 and 1. [0 = farmers that said no, they did not incur PHL (NO PHL), 1 = farmers that said yes, they incurred PHL (PHL is greater than zero)] and it is used as the dependent variable in the logistic regression model. The Logit model is specified as follows:

$$ln\left[\frac{P}{(1-P)}\right] = \beta_0 + \sum_{i=1}^{n}(\beta_i X_{ij}) + \varepsilon j$$

where $ln\left[\frac{P}{(1-P)}\right]$ Is the log-odds (ratio of the probabilities of incurring PHL), X_j is the vector of independent variables, ε=error term, and β_0 and β_1 are constant and estimated parameters of PHL respectively. The Marginal effects were computed to determine the actual impact of the independent variables on the dependent variable. That is, it allows us to interpret the direct effects that changes in regressor have on our outcome variable. It was calculated by taking the derivative of the outcome variable to the predictor of interest.

$$\frac{\partial PHL}{\partial X_j} = (\beta_i X_{ij})$$

The choice of explanatory variables used in this study is based on previous studies conducted by Ndwiga (2015), Agada and Uga

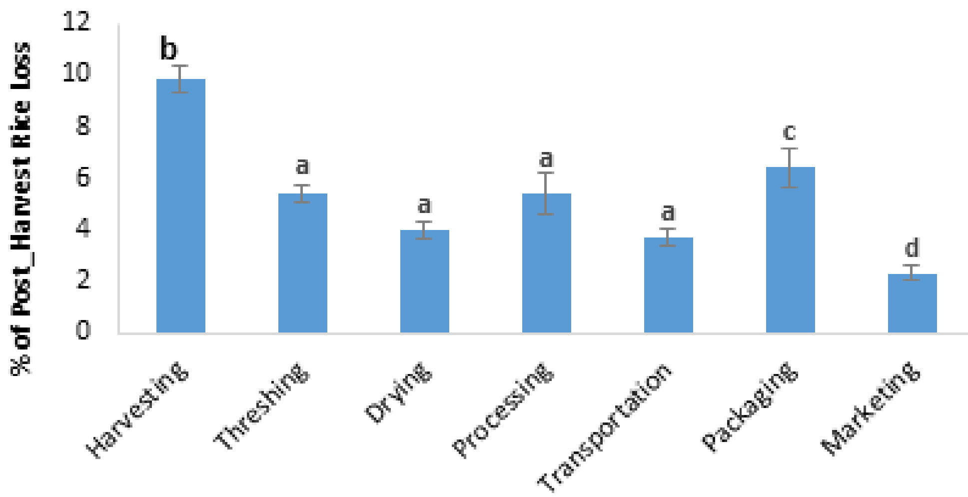

Figure 1. Loss point of rice PHL in Liberia.

(2017), and Omidiji and Ayandiji (2011). These variables include socioeconomic and post-harvest variables such as the number of harvest days, post-harvest training, climatic seasons, storage method, time spent on the farm, and harvesting techniques. Table 2 presents the included variables as well as their respective definitions and expected signs.

RESULTS AND DISCUSSION

Description of PHL along the rice value chain

Rice post-harvest loss occurs at all stages of its value chain (harvesting, threshing, drying, processing, transportation, packaging, and marketing). Loss of rice produced is a major problem, and therefore it is important to describe the specific areas within the postharvest value chain where higher losses occur. The results of the ANOVA test show statistical significance with Prob > F (0.000). This implies that the percentage of quantity loss at each stage of the postharvest value chain statistically differs from one stage to another.

The ANOVA results were validated using the Bartlett test for equal variances. The result implies that there is homogeneity in the variances of PHL for all stages of the rice value chain. This means that the variances for the percentage of quantity loss along the rice value chain are the same.

The Tukey's Honestly Significant Difference Test was used to analyze the differences in PHL at various stages of the rice value chain. The results shown in Figure 1 indicated a significant difference between the losses among different stages of the post-harvest value chain. Specifically, the results reveal that losses are high during harvesting and low during marketing. On average, a smallholder rice farmer incurs losses of up to 9.34% at harvesting. These losses occur due to rats, birds, insects, lodging, and shattering. Harvesting too early results in a larger percentage of unfilled or immature grains, which lowers yield and causes higher grain breakage during milling, while harvesting too late leads to excessive losses and increased breakage in rice. The lack of appropriate and/or poorly designed harvesting tools, equipment, and harvesting containers, as well as the use of primitive methods of harvesting, are other factors influencing rice loss at harvesting. This finding is in agreement with Bräutigam et al. (2014), who suggested that rice harvest losses were increased by farmers' poor harvesting operation skills, pest and disease infestation, and a lack of relevant policies. Mishra and Satapathy (2021) found that inadequate infrastructure, poor awareness of grain-saving and loss-reduction practices, lag in harvesting operation technology, and small-scale scattered production were common factors affecting post-harvest rice losses in China and other developing countries. This could be true for Liberia because activities along the rice value chain are characterized by the use of primitive methods, including poor infrastructure and limited technical know-how.

Abass et al. (2014) also found that the highest losses of maize (25%) occur at the field/harvest stage. These results are further consistent with Murthy et al. (2009), who found that most farmers experience losses during harvesting. A study carried out in Punjab also revealed that delays in harvesting caused losses to increase by approximately 67%, owing to high shattering losses (Kumar Balai et al., 2018; Singh et al., 2013).

Similarly, Kannan et al. (2013) also found that delayed harvesting owing to insufficient harvesting equipment would increase paddy harvesting losses by 10.3%. The harvesting method is conventional; the producers lack sufficient knowledge about when and how to harvest, and the harvesting implements—sticks, sickles, spades, hoes, and axes—cannot preserve the appropriate quality of the

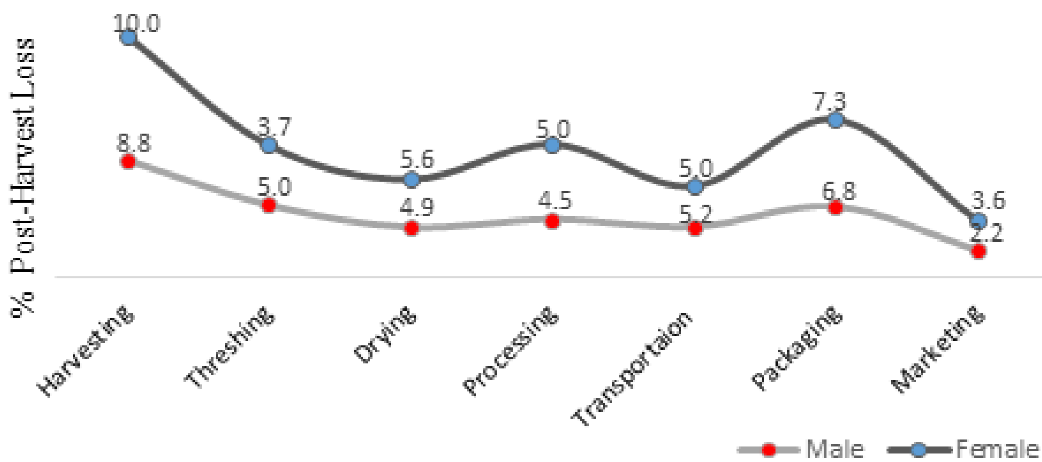

Figure 2. Gender dimension of PHL in Liberia

produce (Emana et al., 2015). Owing to the greater likelihood of rough handling and improper post-harvest handling practices, these harvesting techniques result in high PHL (Muluken Bantayehu et al., 2019; Ibrahim et al., 2018; Parmar et al., 2017).

On the other hand, at the marketing stage of the rice value chain, smallholder farmers experienced the lowest PHL of 2.82%. This is because most farmers reside far away from marketplaces and are not able to engage in various markets due to bad road conditions and difficulty accessing transportation. The study further shows that there is no significant difference in PHL at threshing, drying, processing, and transportation. This might be due to the use of similar techniques employed by smallholder rice farmers during these PH operations. However, packaging accounts for the second highest PHL at 7.04% compared to other PH stages. This is because farmers use local methods of packaging rice in tarpaulin, cribs, silos, and bags. These methods lead to the contamination of packaged rice by rodents, birds, insects, molds, etc.

To curtail these losses, mitigating strategies that reduce losses at the harvesting and packaging stages of the rice value chain should be integrated into agricultural programs to provide affordable solutions to smallholder rice farmers in Liberia. The study also found that smallholder rice farmers experience an overall loss of 37.2% due to poor postharvest handling and practices. This finding agrees with a study conducted by CRS (2011), which found that rice farmers in Liberia were losing between 10–40% of production due to PHL.

Gender dimension of PHL

Despite these losses, there has generally been limited investment in understanding and addressing gender-equity issues during various postharvest operations (Nordhagen, 2021). Figure 2 shows the gender dimension of PHL along the postharvest value chain. The results of the t-test show that there is a significant difference in losses between males and females at the processing and packaging stages of the rice value chain. Findings from this study show that female farmers are more susceptible to incurring PH losses than male farmers. Results show that the percentage of quantity loss of 10.0% and 7.3% at the harvesting and packaging stages, respectively, of the post-harvest value chain is higher for female compared to male farmers, with losses of 8.8 and 6.8%, respectively. These results are consistent with Cole et al. (2018) and Kaminski et al. (2020), who found that losses were higher for female than male smallholder farmers. This is because female farmers have limited access to resources, knowledge, and skills related to the post-harvest management system, including gender roles and responsibilities. Women tend to face greater difficulties than men in accessing productive resources (land, labor, and capital) and markets. They have limited access to credit and information they need to carry out their tasks effectively. The results are further consistent with a study conducted by FAO (2019), Nordhagen (2021), and Palacios-López and López (2015), who found that postharvest losses among female farmers are influenced by access to technology, market information, knowledge, training, transport, and infrastructure. All of these factors are also influenced by gender, with women (particularly in rural areas) generally having lower access than men. Unlike other stages of the post-harvest value chain, the percentage of quantity loss is similar, and there is no significant difference between males and females. The Tukey's Honestly Significant Difference Test with α = 0.05 significance level indicates that there is a significant difference in the percentage of quantity loss within the geographical regions of Liberia. Figure 3 presents the geographical distribution of PHL by counties in Liberia. The results show that Lofa County reported the highest percentage of quantity loss (18.13%) compared to Sinoe,

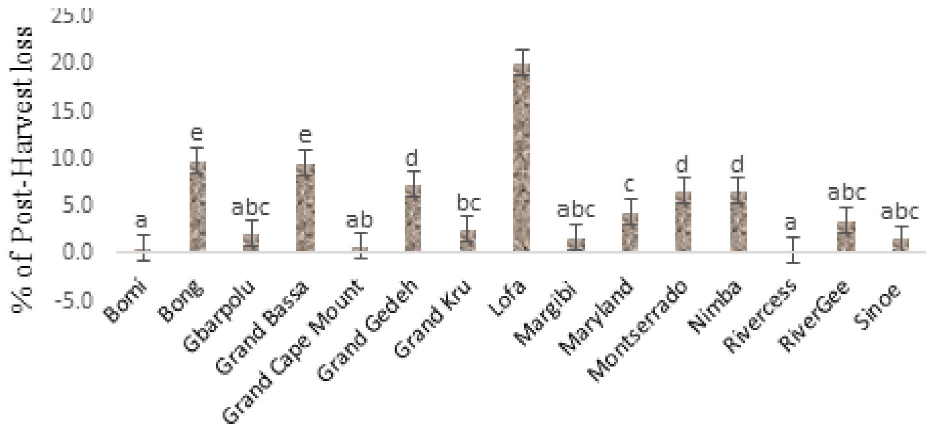

Figure 3. Geographical distribution of post-harvest loss in Liberia.

Bomi, Rivercess, and Grand Cape Mount with the lowest PHL. This is because Lofa County is the highest rice-producing county in Liberia and is considered the bread basket of the country (Dorley et al., 2022). Lofa's Spatial Development Plan shows an ambition of covering 30% of the county with agriculture and has a high potential to increase its agricultural production to combat food insecurity in Liberia. However, Bong and Grand Bassa account for the second-highest PHL of 12.11 and 10.71%, respectively, compared to other counties in Liberia.

Confirming the previous results, these results further reveal that Lofa, Bong, and Grand Bassa counties incur the highest losses of 33.6, 31.0 and 23.2%, respectively, compared to Bomi, Grand Cape Mount, and River Gee counties with the lowest PHL at the harvesting stage. Again, at packaging, Lofa, Bong, Grand Gedeh, and Grand Bassa counties incur losses of up to 25.7, 16.1, 13.3 and 13.0%, respectively, as compared to Bomi, Rivercess, Sinoe, and River Gee counties with the lowest PHL. PHL is high because smallholder rice farmers in these counties use traditional methods of packaging with poor-quality packaging materials and improper handling of products. The use of incorrectly wrapped packages and damaged packaging material, such as torn or punctured wraps or damaged pouches, can lead to the contamination of packaged rice by rodents, birds, insects, molds, etc. These results are consistent with Saba and Ibrahim (2018) and Olayemi et al. (2012), who reported that most farmers still use traditional baskets and sacks as their packaging materials and that rice stored in these structures is susceptible to damage by natural disasters and attack by microorganisms, insects, and rodents, causing considerable damage and loss.

Factors influencing postharvest rice losses

Table 3 presents the results obtained from the logistic regression analysis on the factors influencing PHL among smallholder rice farmers. The log-likelihood ratio (LR) tests show that there is a significant relationship between the probabilities of incurring postharvest losses and the explanatory variables included ($p < 0.000$). Thus, using the LR test, we conclude that the logit model fits the data quite well. Most estimated coefficients exhibit similar levels of statistical significance. The F-statistic was significant at 1%, implying that the explanatory variables as a whole had a joint impact on the level of post-harvest rice loss.

Age and household size were the demographic variables that significantly affected postharvest losses in rice production. The results show that the age of smallholder rice farmers has a positive relationship with PHL. That is, a farmer between the ages of 25–54 years is 1.088 times more likely to incur PHL than a farmer in the next lower age group. This means the odds of incurring PHL for farmers between the ages of 25–54 years increase by 8.8%, whereas the probability of incurring PHL is increased by 10.40% compared to a farmer between the ages of 18–24 years. Furthermore, the results also show that the probability of incurring PHL for a farmer between the ages of 55–64 years is increased by 15.31% compared to a farmer between the ages of 18–24 years. Finally, farmers aged above 65 years are 2.278 times more likely to incur PHL. The study found that the probability of incurring PHL for farmers above 65 years of age is increased by 18.72% compared to farmers between the ages of 18 and 24 years. This is because activities at various stages of the post-harvest value chain are labor intensive, and older farmers may not have the necessary strength needed to perform certain postharvest operations. They may face physical limitations that can affect their ability to handle and perform certain post-harvest activities. This can result in increased losses if they are unable to perform tasks such as lifting heavy tools and loads or maintaining storage facilities properly. Moreover, they may be less inclined to adopt new technologies and innovations that can help reduce PHL. The findings disagree with Begum et al. (2012), who found that PHL were negatively associated with age for rice farmers in the Northern Regions of Bangladesh.

Also, household size was found to have a significant and negative relationship with postharvest losses incurred. Farmers with larger household sizes are 0.0581 less likely to incur PHL than farmers with smaller household sizes. This implies that when household size is increased by one person, the probability of incurring PHL decreases by 4.8%. An addition of one person to the family reduces rice PHL because rice production is labor intensive, and therefore an increase in the number of active laborers in the family is expected to reduce PHL. The size of a household determines the number of potential workers available to work on the farm. Larger households tend to have more family members who can contribute to farm labor. These findings are consistent with those of Amentae et al. (2016), who found that the amount of PHL decreased by 3.75% with an increase in family size by one person in Ethiopia. Furthermore, the results agree with those reported by Aidoo et al. (2014), who found that farmers with larger household sizes tended to have lower levels of postharvest losses by 0.0638% because they had a relatively high amount of family labor that helped with tomato harvesting, making the process faster and more efficient, ceteris paribus.

The results indicate that climatic season (rainy) has a positive effect on the level of PHL of rice. Results show that farmers are 1.744 times more likely to incur PHL during the rainy season compared to the dry season. The results indicated that the probability of smallholder rice farmers incurring PHL during the rainy season is increased by 14.51% compared to the dry season. This is because variations in temperature, precipitation, and extreme weather events harm rice yield, making it more susceptible to pests and disease infestation. Smallholder farmers in Liberia are still subjected to primitive methods when performing postharvest operations, and the influx of rain increases the infestation of pests and diseases, subsequently increasing PHL. This finding is similar to Abass et al. (2014) and Su and Kuo (2023), who found that most farmers considered changes in weather and climate as a major factor that exacerbates PHL, and most farmers experienced high postharvest losses during the rainy season.

The studies further disagree with Raghuvanshi et al. (2018), who stated that weather was found to be negatively significant with PHL, thus reducing losses by 0.3250 at the farm level in Chhattisgarh. Taner et al. (2004) also indicated that rainy weather impairs pest problems and premature senescence, resulting in a decreased maturation rate and thus yield losses. Moreover, prolonged exposure of mature rice to high temperatures and humid environments would increase perishability, resulting in reduced yield and quality of rice (World Bank, 2011). Continuous rainy weather would not only lead to a sharp drop in the biological production of rice but also result in mildew of unhusked rice spread on the ground due to untimely sun-drying (Fei et al., 2013). Furthermore, it increases the lodging area of rice and harvest difficulty, resulting in shattering and pre-harvest sprouting during reaping and threshing, thus increasing PHL (Wang et al., 2022).

On the other hand, storage method shows a negative relationship with PHL for farmers who stored in bags and was significant at 1%. The study found that farmers who stored harvested rice in bags are 0.0782 less likely to incur PHL compared to farmers who used the traditional method. This implies that the probability of incurring PHL for farmers who store in bags is reduced by 7.82% compared to those who store using traditional methods. This is because proper storage conditions can lead to a decrease in spoilage caused by moisture, temperature, and pest infestation. Other methods of storage such as silos and warehouses were statistically insignificant. This result might be due to the limited usage of these methods for rice storage in Liberia. This finding concurs with those of Maziku (2019), Rugumamu (2003), and Suleiman and Rosentrater (2015), who found that PHL were higher for farmers who were using traditional storage facilities. They argued that the traditional storing method facilitates insect and pest infestation, mold, and fungal growth, and does not incorporate modern postharvest techniques that can reduce losses.

The number of harvest days was also found to have a significant and positive effect on PHL experienced by smallholder rice farmers. The study found that a one-day additional increase in the number of harvest days increases the odds of incurring losses by 1.26%, while the probability of incurring PHL is increased by 0.10%. This is because, if harvest is spread out over a longer period, there is a higher likelihood of spoilage and damage to rice produced that may increase PHL. The longer the rice is left in the field, the more it is exposed to environmental factors such as pests, disease, weather conditions, and seed shattering. This calls for the development and use of suitable harvest machinery, which can reduce harvest time to reduce PHL.

Post-harvest training was found to have a positive relationship with postharvest losses and was significant at 1%. The results show that farmers without postharvest training are 2.7591 times more likely to incur PHL compared to farmers with post-harvest training. That is, the probability of incurring postharvest losses for farmers without postharvest training is increased by 22.96%. The lack of training leads to limited knowledge of postharvest management practices, thereby increasing the probability of incurring losses. These results are similar to those reported by Abass et al. (2014) and Ismail and Changalima (2019), who suggested that associated postharvest losses, could be reduced through the provision of training for farmers on postharvest management.

CONCLUSION AND POLICY IMPLICATIONS

Postharvest loss reduction throughout the rice value chains is an important pathway to addressing food security in Liberia. This study revealed that PHL are high at harvest compared to other stages of the rice value chain. This is due to the use of inappropriate harvesting techniques, pest and disease infestation, premature or delayed harvesting, shattering, rough handling, and the lack of improved harvesting tools, equipment, and containers. Therefore, policies aimed at investment in improved harvesting technologies, provision of improved harvesting tools and equipment, information dissemination on timely harvest, and rice handling practices should be considered among the key priorities. Additionally, Lofa, Bong, and Grand Bassa counties incurred higher losses at the harvesting and packaging stages of the rice value chain. Losses are high in these counties because they are major rice-producing counties and smallholder farmers use traditional methods of harvesting and packaging. Policy towards value addition, and especially value chain development policies articulating good packaging practices for rice, can be considered to reduce PHL.

The study also found that age, household size, post-harvest training, climatic season, storage method, and harvesting techniques are potential determinants of postharvest losses in rice production in Liberia. It is imperative to address the problem of postharvest losses through the promotion of postharvest management technologies, thereby providing smallholder farmers with technical knowledge on handling practices that could empower them to adopt new technology. The provision of up-to-date storage facilities and post-harvest handling tools could be prioritized. This could be done through specific post-harvest programs and projects or even technical and financial support to farmers through credit and subsidy provisions from government and development agencies.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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