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DETERMINANTS OF POST-HARVEST LOSSES IN RICE PRODUCTION AMONGST SMALLHOLDER FARMERS IN LIBERIA

BY

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Declaration

I, Eric Emmanuel Pluato, do hereby declare to the Faculty of Agronomy and Forestry Engineering, Eduardo Mondlane University that, this dissertation is my original work done within the period of registration and that it has neither been submitted nor being concurrently submitted for a degree in any other institution.

Eric Emmanuel Pluato

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Date

Dedication

This thesis is dedicated to God Almighty for his provision and protection, my father Mr. Roland Pluato, my mother Mrs. Siannah Pluato, my fiancée, Teta Sumo, My Daughter Erica Siannah Pluato and my unborn children. May this work motivate and inspire my children to aim higher.

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Acronyms

ANOVA	Analysis of Variance
CFSNS	Comprehensive Food Security and Nutrition Survey
CRS	Catholic Relief Services
FAO	Food and Agricultural Organization
GM	Gross Margin
GRiSP	Global Rice Science Partnership
LPFSA	Liberia Post-harvest and Food Security Assessment
LRD	Liberian Dollars
MOA	Ministry of Agriculture
MOI	Ministry of Information
LNRDS	Liberia National Rice Development Strategy
PH	Post-Harvest
PHL	Post-Harvest Losses
RL	Republic of Liberia
RGCS	Retinal Ganglion Cells

Abstract

Demand for rice remains high in Liberia with low farm-level productivity arising due to Postharvest losses. Insects and rodents as well as spoiling, bruising, disease attack, spillage, contamination, and poor storage practices are major factors influencing rice yield. Rice output has continuously declined with post-harvest losses accounting for about 10 to 40%. The ability of smallholder rice farmers to improve output levels and attain sustainable yield depends on efficient postharvest operations at the farm level, and hence technical post-harvest efficiency. The study described post-harvest losses along the rice value chain, determined the effect of factors influencing post-harvest rice loss, and estimated the effect of post-harvest losses on smallholder rice farmers' Gross Margin in Liberia. A one-way ANOVA was used to describe PHL along the rice value chain, whereas a logistic regression analysis was used to determine factors influencing post-harvest rice loss among smallholder rice farmers in Liberia. The study revealed that rice farmers incurred higher post-harvest losses, particularly at the harvesting and packaging stages of the rice value chain whereas, Age, Household Size, Post-Harvest Training, Climatic Season, Storage Method, and Harvesting Techniques are potential determinants of postharvest losses in Liberia. Furthermore, Lofa, Bong, Nimba, and Grand Bassa counties incurred higher, thus reducing their gross margins. The average gross margin of post-harvest loss was LRD 3,512.475 much lower than the average gross margin without loss LRD 8,826.114. This implied a 39.79% reduction in the gross margin of smallholder rice farmers due to post-harvest loss valued over 2.8 million Liberian Dollars. The study also found birds, climatic conditions, and rodents to be major causes of postharvest rice loss. Therefore, improvement of old-age practices and the development of new technology through organized research efforts is necessary to prevent huge postharvest losses of rice to meet the demand for food. There is an intense need to reduce PHL while promoting efficient resource utilization to improve the livelihood and gross margin of smallholder rice farmers in Liberia.

Keywords: Liberia, Post-Harvest Losses, Rice, Smallholder Farmers

1. Introduction

One key sector that plays a significant role in the overall economic performance of Liberia in terms of its contribution to GDP is Agriculture. According to the Country Commercial Guide, the agricultural sector is the primary livelihood for more than 60 percent of Liberia's population and accounted for 31 percent of Liberia's 2021 real gross domestic product (GDP). The sector also plays a significant role in enhancing food security, poverty alleviation, and employment (Taiwo and Bart-Plange, 2016a). 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 percent of the cultivated land in Liberia (Bruce E., *et al.* 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, 2018). The demand for rice in most African and Asian countries is overwhelmed and by the year 2050, the current world's population of 9.7 billion is expected to increase by one-third, increasing the global rice demand by 70 percent 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 percent yearly, and has a per capita consumption of 133 kg (World Bank, 2023).

In Liberia, rice is a primary preferred staple food (Hilson and Van Bockstael, 2012) and it is consumed by more than 80 percent of people. It accounts for nearly one-half of the calorie intake of adults and about 15 percent of the overall spending of an average household (LISGIS, 2017b; Wailes, 2015). Liberia's annual per capita consumption is one of the highest in Africa and was estimated to be more than 133 kg per year in 2010 (MOA, 2012), compared to the West African average consumption of 84.5 kg per capita and considered the fifth-highest consumer of rice in West Africa.

The crop is mainly produced by smallholder farmers scattered across the country (Saysay et al. 2018). Rice cultivation in Liberia is extensive and characterized by poor technical and post-harvest handling practices (Taiwo and Bart-Plange, 2016b), and therefore the total volume of locally produced rice is far less than the country's rice demand (MOA, 2009). Tiepoh (2012) showed that

Liberian farmers are unable to produce enough rice to meet their household demand and 66% of the farm households are not able to produce what they need for consumption. The annual rice production in 2021 was estimated at 170,000 metric tons with over 50 percent gap filled by imported rice (FAOSTAT, 2022). The low production is added to the high post-harvest losses 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 percent of production due to insects and rodents as well as spoiling, bruising, disease attack, spillage, contamination, and poor storage practices. However, appropriate post-harvest operations leading to unprecedented high rice losses amongst smallholder rice farmers have not been taken seriously (MOA, 2012).

1.1Problem Statement

Food provision for all is an important basis for eradicating extreme poverty and hunger. While there has been significant progress made to maximize rice production in Liberia, more than half of the population does not have access to adequate rice supplies due to several factors that influence the rice value chain. One of these factors that reduces production and limits the availability of rice is post-harvest losses (PHL), despite the increase in the area used for rice production. For instance, since the end of the Liberia civil war, the area under rice production has steadily increased (Vorrath, 2018). Many people have taken up rice farming, and the sector now employs more than 51% of the Liberian population (Knoema, 2019).

Concerted efforts of the government, the World Bank, and non-governmental organizations have seen the rice sector receiving support in the form of agriculture equipment and inputs such as fertilizers and improved varieties (MOA, 2014a). However, rice output has continuously declined (MOA, 2014a). For example, rice production declined from 257,995 metric tons in 2018 to 170,000 metric tons in 2021 (Mwah, 2012; FAOSTAT, 2022) with post-harvest losses accounting for about 10 to 40% (CRS, 2011). These losses not only reduce rice production but also increased Liberia's reliance on rice imports.

According to FAO (2022), Liberia relies significantly on imports to meet its domestic cereal requirements. Imports of rice in 2021 were estimated at 350,000 metric tons valued over USD 100 Million, making up around 65 percent of total annual rice consumption requirements. Amid low production and high demand, the increase in imported rice prices continues to fuel food insecurity, poverty, and vulnerabilities in Liberia, (Gweh *et al.*,2023). Domestic rice production would need to triple to satisfy local demand, but increasing production would require significant investments in the rice value chain as well as policy actions. Efforts to develop the rice value chain should also concentrate on infrastructure and services for reducing PHL. Appropriate post-harvest operations leading to unprecedented high rice losses amongst smallholder rice farmers have not been taken seriously (MoA, 2012).

Many studies have been conducted on PHL such as "Reducing Postharvest Loss in Liberia" (Russell J. *et al.*, 2022), "Profit Loss Per Hectare Among Smallholder Rice Farmers in Central Liberia" (Saysay L. *et al.*, 2016), and the Determinants of Smallholder Rice Farmers' Willingness-To-Pay for Private Extension Services on Postharvest Management System in Liberia (Togba S. *et al.,* 2023). However, these did not analyze the factors influencing PHL, the description of postharvest loss points along the postharvest value chain, and the effect of PHL on smallholder rice farmer's gross margins. Moreover, more than 50% of smallholder rice farmers still experience high PHL in Liberia. The postharvest losses impend not only the economic well-being of the smallholder farmers but also the efforts of the government to ensure food security.

The implication is that if no special attention is given to reverse the situation, the country stands a chance of increasing its importation bills, facing severe food insecurity and negative outcomes that hinder poverty reduction efforts. Additionally, a knowledge gap limits farmers' ability to act towards reducing losses as well as policymakers from formulating 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.

1.2Objective

1.2.1 General Objective

The main objective of this study is to analyze the factors causing PHL among smallholder rice farmers in Liberia.

1.2.2 Specific Objectives

i. Describe the Post-Harvest Losses along the rice post-harvest value chain.
ii. Determine the effect of factors influencing Post-Harvest Rice loss.
iii. Estimate the effect of post-harvest losses on smallholder rice farmers' Gross Margin.

2. Literature Review

2.1. Overview of Rice Production in Liberia

An Assessment of the Agriculture Sector prepared by Liberia's Ministry of Agriculture (2007) suggests that Liberia's agriculture can be characterized as comprising three different production systems. First, are large plantations with farm sizes of more than 10 hectares that focus on export crops (rubber, palm oil, coffee, and cocoa). Most of the production originates from plantations that are privately owned, but there are also several state-owned plantations operated by the Liberian Palm Products Corporation and the Liberian Cocoa and Coffee Corporation.

The second component of Liberia's agriculture sector consists of privately owned commercial farms of medium size between 4-10 hectares which also focus on industrial crops for export and to a lesser extent on livestock for the local market. Finally, the bulk of the population engaged in agriculture belongs to small household farms (2-4 ha) which rely on traditional production techniques that generate low yields due to the lack of inputs, and inappropriate postharvest operations, and thereby focus on subsistence production (CAAS-Lib, 2007; MOA, 2007).

Rice is the staple food of the country, with over half of the households reported to have produced some rice in 2005 (CFSNS, 2006). There are two systems of rice cultivation: upland rice and swamp rice. The former dominates: data from the CFSNS (2006) indicate that 63% of households fully relied on upland rice techniques, while 17% opted for swampland; 21% used a mixture of both, although upland was also more common in this group. Techniques differ across Liberia and reflect local agro ecological conditions. Upland rice dominates in Bong, River Cess, Grand Kru, and Nimba, while the majority of households in Lofa grow swampland rice only. Lofa County has the highest concentration of developed swamplands in the country as a result of past investment by donor-funded agricultural development projects.

Swamp rice is traditionally grown in inland valleys that have been cleared, usually using hand labor. The rice varieties are usually different from those grown on the uplands and the seed is usually transplanted. The swamps are extensively used for the production of rice in the rainy season and vegetables during the dry season. Other crops, such as cassava, are planted on mounds during the dry season (CAAS-Lib, 2007). They are uprooted and stem cuttings are transferred and planted out on the uplands at the beginning of the rice growing season, when the mounds face the danger of submergence. Mounds constructed by inversion of soil and burying of stubble/grass help to decompose plant materials and thus improve soil fertility. The rice is usually panicle harvested and stored in the same way as upland rice. Farm sizes are usually smaller and yields higher than on the uplands. A variant of the traditional swamp rice production system is what is known as 'recession agriculture', which is practiced largely during the dry season. The farmers take advantage of the residual moisture of the soil in the swamps to grow vegetables (MOA, 2007).

A small number of more modern swamp rice production systems exist on specially developed swampland, where irrigation and drainage systems have been laid out to feed permanently cropped fields. Water control activities include digging and clearing canals/drains, bonding, flooding, drainage, plowing and puddling, and leveling and repair. The varieties of rice grown are usually different from the upland varieties and of shorter duration. A few swamps attempt two rice crops a year and these are mainly the perennial swamps (CAAS-Lib, 2007). Drainage is generally poor. Typical lowland rice production activities involve nursery, brushing and clearing, plowing, puddling and transplanting, weeding, fertilizer application (if needed), and harvesting. Fertilizer application rates are low: fertilizer is rarely available and, when it is, costs are high.
The rice is usually harvested with a sickle, threshed in the field, and stowed and carried in bags from the field. Locally produced rice is used mainly for consumption. The inability of the country to produce enough rice to feed the population has led to massive imports and has been one of the (many) factors that have led to high levels of food prices and insecurity (Tsimpo *et al.*, 2008).

2.2. Concept of Post-Harvest Loss

Post-harvest loss means any change in the availability, edibility, wholesomeness, or quality of the food that prevents it from being consumed by people. Losses may be direct or indirect. A direct loss is the disappearance of crops by spillage, or consumption by insects, rodents, and birds. An indirect loss is the lowering of quality to the point where people refuse to eat it. In the words of Grolleaud (2004), direct losses occur when the disappearance of a foodstuff is caused by leakage (for example, spillage from bags) or consumption by pests (insects, rodents, birds), whereas indirect losses occur when a reduction in quality leads to the consumer's refusal to purchase. Post-harvest losses are measurable reductions in crops and may affect either quantity or quality (Tyler and Gilman, 1979; Kumari *et al.*, 2010).

Kader (2002) also defines Postharvest loss as the degradation in both quantity and quality from harvest to consumption. Quality losses include those that affect the nutrient/caloric composition, the acceptability, and the edibility of a given product. These losses are generally more common in developed countries whereas quantity losses refer to those that result in the loss of the amount of a product. Loss of quantity is more common in developing countries (Kitinoja and Gorny, 2010).

Parfitt *et al.* (2010) also refer to post-harvest loss as the decrease in edible mass throughout the part of the supply chain that specifically leads to a reduction in edible food for human consumption. Losses take place at the production, post-harvest, and processing stages of the value chain. Put differently, post-harvest losses mean that production resources such as land, water, energy, fertilizers, labor, and effort are wasted, and ultimately, profitability for growers is reduced. Similarly, Usman (2000) defined post-harvest loss as the reduction in the amount of food (in quality and quantity) available for consumption.

Grolleaud (2004) shared the same view that loss is the total modification or decrease in quantity or quality which makes it unfit for human consumption. According to Tolulope and Adeladun (2021), post-harvest losses may be grouped broadly into food losses due to social and economic reasons. He pointed out that the first distinction in agro-food losses is between quantity and quality. Quantitative loss is a loss in terms of physical substance, meaning a reduction in weight and volume, and can be assessed and measured. Whereas, Qualitative loss is concerned particularly with the food and reproductive value of products and requires a different kind of evaluation. Apart from these, other types of losses are weight loss, quality loss, food loss, seed viability loss, and commercial loss. In the same vein, Kader (2003) mentioned the following as the categories of losses that are generally recognized weight loss, quality loss, nutritional loss, loss of seed viability, and commercial loss.

Weight loss is the reduction in weight of a commodity usually as a result of reduced moisture content. Moisture changes can also lead to an increase in weight and in most cases, the production of water by insect infestation may partly offset the loss caused by insect feeding. It is customary to describe the weight losses on a dry-weight basis (Kader, 2003). Ovharhe *et al.* (2021) called this physical loss.

Quality loss is noticed when the quality of a product is assessed in different ways according to those factors considered important by the consumers or traders. Generally, quality is based on appearance: shape, size, value, condition, etc., the amount of foreign material (which may include insects and insect fragments); and damage including insect damage. The higher the standard set by the consumer, the greater will be the potential for loss (Kader, 2003).

Nutritional loss is described as the product of quantitative and qualitative losses, but more specifically, it is the loss in terms of nutritional value to the population concerned. Some insect larvae, for example, that feed preferentially on the germ of the grain will remove a large proportion of the protein and vitamin content of the grain (Kader, 2003). Put simply, it is a loss in the nutritional contents of food crops.

Loss of seed viability relates to loss in seed germination which is important for its effect on future food supplies. Insects that selectively attack the germ will cause a greater loss in germination than those feeding on the endosperm (Kader, 2003). Commercial loss or economic loss is the translation of the various types of loss discussed above into economic and monetary terms. This may occur as a direct consequence of any of the foregoing factors, or indirectly as the cost of any preventive or remedial actions required. For example, a control measure that has to be used to ensure that a commodity remains saleable can be counted as an economic loss and this is perhaps most easily accountable. Indirect consequences of loss may be encountered where measures have to be taken to prevent the loss of goodwill or to cover legal costs arising from the marketing of commodities that are unacceptable because of the presence of insects or insect-related damage (Kader, 2003).

Farmers and food sellers have been concerned about losses since agriculture began. Yet the problem of how much food is lost after harvest to processing, spoilage, insects and rodents, or to other factors takes on greater importance as world food demand grows. Cutting postharvest losses could, presumably, add a sizable quantity to the global food supply, thus reducing the need to intensify production in the future.

2.3. Post-Harvest Systems

A post-harvest system, according to Grolleaud (2004), encompasses a sequence of activities and operations that can be divided into two groups. The first group contains technical activities which include harvesting, field drying, threshing, cleaning, additional drying, storage, and processing; while the second group, economic activities include transporting, marketing, quality control, nutrition, extension, information and communication, administration, and management. Within the food system, there is a stage of preparation for production (preproduction); a period of production; a time for harvest; occasions for transportation; stages where assembly, packaging, or selection occur; several periods of short or long-term storage; and stage for distribution to the consumers (White *et al.*, 2013). Grolleaud (2004) went further to list the following as the main elements of the post-harvest system: harvesting, transport, drying, threshing, storage, processing, and marketing. According to him, the time of harvesting is determined by the degree of maturity.

With cereals, a distinction should be made between the maturity of stalks (straw), ears or seedpods, and seeds, for all these affect successive operations, particularly storage and preservation. Drying is mainly for cereals and pulses. Extended field drying ensures good preservation but also heightens the risk of loss due to attacks (birds, rodents, and insects) and molds encouraged by weather conditions, not to mention theft. On the other hand, harvesting before maturity entails the risk of loss through molds and the decay of some of the seeds (Grolleaud, 2004).

The author pointed out that much care is needed in transporting a mature harvest, in order to prevent detached grain from falling on the road before reaching the storage or threshing place. Collection and initial transport of the harvest thus depend on the place and conditions where it is to be stored, especially with a view to threshing. Post-harvest drying requires time and the length of time needed for full drying of grains depends considerably on weather and atmospheric conditions. In structures for lengthy drying such as cribs, or even unroofed threshing floors or terraces, the harvest is exposed to wandering livestock and the depredations of birds, rodents, or small ruminants. Apart from the actual wastage, the droppings left by these marauders often result in higher losses than what they eat.

On the other hand, if grain is not dry enough, it is vulnerable to mold and can rot during storage. Moreover, if the grain is too dry it becomes brittle and can crack after threshing, during hulling or milling. This applies to rice if milling takes place a long time (two to three months) after the grain has matured when it can cause heavy losses. During winnowing, broken grain can be removed with the husks and is also more susceptible to certain insects (e.g. flour beetles and weevils). Lastly, if grain is too dry, this means a loss of weight and hence a loss of money at the time of sale. While stressing the need for threshing, Grolleaud (2004) stated that if a harvest is threshed before it is dry enough, this operation will most probably be incomplete. Furthermore, if the grain is threshed when it is too damp and then immediately heaped up or stored (in a granary or bags), it will be much more susceptible to attack from micro-organisms, thus limiting its preservation.

However, excessive hulling or threshing can also result in grain losses, particularly in the case of rice (hulling) which can suffer cracks and lesions. The grain is then not only worthless but also becomes vulnerable to insects such as the rice moth (Amit Vincent, 2021). They argued that storage facilities, hygiene, and monitoring must all be adequate for effective, long-term storage. In closed structures (granaries, warehouses, hermetic bins), control of cleanliness, temperature, and humidity is particularly important. Damage caused by pests (insects, rodents, and molds) can lead to the deterioration of facilities (e.g. mites in wooden posts) and result in losses in quality and as well as quantity. Marketing on the other hand is an essential and decisive element in the post-harvest system, although it can occur at various points in the agro-food chain, particularly at some stage in processing. Moreover, it cannot be separated from transport, an essential link in the system.

2.4. Loss Point at Post-Harvest Chain

Losses occur anywhere from the point the food has been harvested to the point of consumption. Post-harvest losses in fresh agricultural crops have their origin in damage during harvesting, physiological processes, infection by decay organisms and, occasionally, pest infestation. Losses caused by these processes may occur during all stages of the post-harvest system from crop maturity, through harvesting, transportation and marketing. The degree of loss associated with these factors is determined by the plant material involved, the prevailing environmental conditions and management of the value chain (Kader, 2003). The pattern of losses varies widely from country to country.

These losses arise from the fact that harvested agricultural produce is a living thing that breathes and undergoes changes during post-harvest handling. Losses of quantity (weight or volume) and quality (altered physical condition or characteristics) can occur at any stage in the postharvest chain. Figure 1 shows estimated losses along the postharvest value chain.

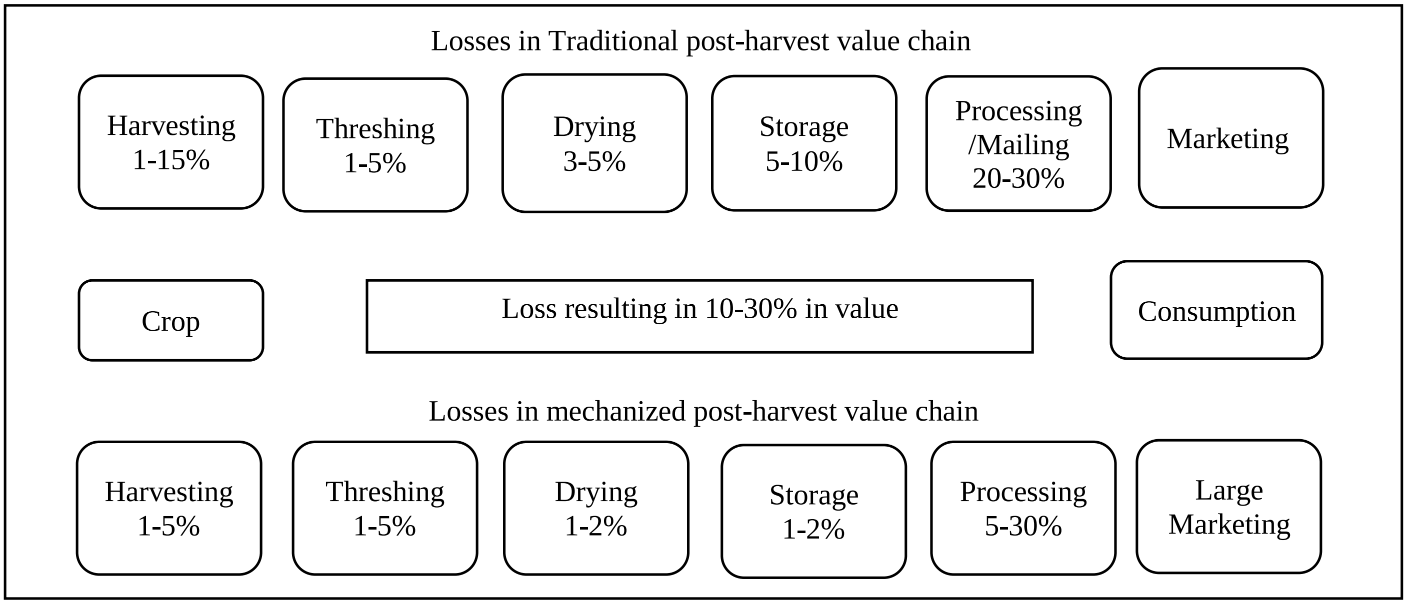

Figure 1: Estimated losses from the postharvest chain for rice in south Asia (Hodges et al. 2011)

There is a marked contrast between the site of major losses in developed countries and developing countries. In a typical developed country loss may be fairly low because agricultural machineries are used to perform major activities along the post-harvest value chain. Considerable low quantities of foods may be discarded because they are of the wrong size, shape or color. Losses are generally small during processing, storage and handling because of the efficiency of the equipment, good quality storage facilities, and close control of critical variables by a highly knowledgeable cadre of managers.

In contrast, post-harvest losses in low-income countries mainly occur in the early and middle stages of the food supply chain, with less amount wasted at the consumer level (Parfitt *et al*., 2010). They are usually high because most of the crop is handpicked using traditional methods. Losses in processing, storage, and handling tend to increase because of poor facilities and frequently inadequate knowledge of properly caring for food (Hodges *et al*., 2011; FAO, 2011). Reliable statistics on losses are few. The extent of losses is highly variable depending on several conditions.

Stable foods such as cereal grains can be stored in good condition for several years, whereas perishable foods such as fruit and vegetables spoil quickly unless given special treatment such as canning and freezing. (Kader, 2003). It is empirical to examine the post-harvest value chain because it is crucial for economic growth, food security, and nutrition.

2.4.1. Harvesting

Harvesting is considered the first step in the grain supply chain and is a critical operation in deciding the overall crop quality. It is the process of collecting the mature crop from the field. The time of harvesting is determined by the degree of crop maturity and weather conditions. By ensuring timely harvesting, immature grain is also prevented because the time needed to harvest depends on how long the crop has been mature (Khan, 2010). In developing countries, crop harvesting is performed manually using hand-cutting tools such as sickle, knife, scythe, cutters, etc. whereas in developed countries, almost all of the crop is harvested using combine harvesters.

Harvesting timing and method (mechanical vs. manual) are two critical factors dictating the losses during the harvesting operations. A large amount of losses occurs before or during the harvesting operations if it is not performed at adequate crop maturity and moisture content. Too early harvesting of crops at high moisture content increases the drying cost, making it susceptible to mold growth, and insect infestation, and resulting in a high amount of broken grains and low milling yields (Khan, 2010). However, leaving the matured crop un-harvested results in high shattering losses, exposure to birds and rodent attacks, and losses due to natural calamities such as rain, hailstorms, and tsunamis (Baloch, 2010). According to a study conducted in Punjab, India, due to high shattering losses, harvesting losses were found to increase by about 67% due to delay in harvesting (Singh *et al.*, 2013). Another postharvest loss study in India estimated a 10.3% increase in paddy harvesting losses due to delayed harvesting because of a lack of adequate harvesting equipment (Kannan *et al.*, 2013).

According to Ban-jaw (2017), severe PHL and quality deterioration of crops occur during harvesting, followed by marketing, transportation, and storage time. The harvesting system is conventional; the producers do not have enough knowledge regarding how and when to collect, and the tools used to harvest, sticks, sickle, spade, hoe, and ax, are not able to maintain the proper quality of the produce (Emana *et al.*, 2015). These methods of harvesting cause high PHL due to the increased possibility of rough handling and inappropriate post-harvest handling and practices (Bantayehu *et al.*, 2018; Rahiel *et al.*, 2018; Parmar *et al.*, 2017). A study conducted by Emana *et al.* (2015) found that about 76% of the producers and 60% of the traders encountered high PHL of tomatoes due to physical damage during harvesting and transportation in eastern Ethiopia. Humble and Reneby (2014) reported that the most significant PHL of avocado is the result of the cracking down during harvesting.

Other reports on bad harvesting techniques that affect cereal, fruit, and vegetable losses are published by Emana *et al.* (2015), Bereda (2016), and Rahiel *et al.* (2018). A study carried out by Olayemi, Adegbola, Bamishaiye, and Daura (2011) revealed that most of the tomatoes, bell, and hot pepper farmers experience losses of 10-30% during harvesting and transportation stages. These practices by the farmers often result in a reduction in profit and the availability of these products all through the seasons.

Additionally, a study conducted by Nshimyumuremyi *et al.* (2023) in the Nyagatare District of Rwanda also revealed that postharvest losses occurred at various stages, and were found to be maximum during harvesting at a rate of 43.4%.

2.4.2. Threshing

The purpose of the threshing process is to detach the grain from the panicles. The process is achieved through rubbing, stripping, or impact action, or using a combination of these actions. The operation can be performed manually (trampling, beating), using animal power, or mechanical threshers. Manual threshing is the most common practice in developing countries. Grain spillage, incomplete separation of the grain from the chaff, and grain breakage due to excessive striking, are some of the major reasons for losses during the threshing process (Khan, 2010; Shah, 2013). Delay in threshing results in significant quantity and quality loss, as the crop is exposed to the atmosphere, and is susceptible to rodents, birds, and insect attacks (Alavi *et al.*, 2012). As in the case of harvesting, lack of mechanization is the major reason for this delay that causes significant losses.

High moisture accumulations in the crop lying in the field may even lead to mold growth in the field. The cleaning process is performed after the threshing to separate whole grains from broken grains and other foreign materials, such as straw, stones, sand, chaff, and weed seeds. Winnowing is the most common method used for cleaning in developing countries. Screening/sifting is another common method of cleaning, which can be performed either manually or mechanically. Inadequately cleaned grains can increase insect infestation and mold growth during storage, add unwanted taste and color, and damage the processing equipment. A large amount of grains is lost as spillage during this operation, and grain losses during winnowing can be as high as 4% of the total production (Sarkar *et al.*, 2013).

Candia *et al.* (2012) found that insufficient removal of rough rice and rough rice scattering are the main causes of threshing losses. According to FAO (2007), threshing losses ranged from 2% to 6% in the Philippines and from 5% to 13% in Malaysia.

2.4.3. Drying

Drying is the process of reducing the moisture in grains to avoid the infestation of pests and diseases. Grains are usually harvested at high moisture content to minimize the shattering losses in the field. However, the safe moisture content for long-term storage of most of the crops is considered below 13% (Baloch *et al.*, 2010). Even for short-term storage (less than 6 months), the moisture should be less than 15% for most of the crops. Inadequate drying can result in mold growth and significantly high losses during storage and milling. Therefore, drying is a critical step after harvesting to maintain the crop quality, minimize storage losses, and reduce transportation costs. Drying can be performed naturally (sun or shade drying) or using mechanical dryers. Natural drying or sun drying is the traditional and economical practice for drying the harvested crop and is the most popular method in developing countries. Sometimes, the whole crop without threshing is left in the field only for drying (Calverley, 1996). For example, after harvesting, stacks are made of 10–15 bundles of tied crops and left in the field for drying. Sun drying is weather-dependent, requires high labor, slow, and causes large post-harvest losses. Grains lying in the open for sun drying are eaten by birds and insects and also get contaminated due to the mixing of stones, dust, and other foreign materials.

Unseasonal rains or cloudier weather may restrict the proper drying, and the crop is stored at high moisture, which leads to high losses due to mold growth. About 3.5% and 4.5% losses were reported during maize drying on raised platforms in Zambia and Zimbabwe respectively (Abass *et al.*, 2014; Calverley, 1996). Some farmers use mats or plastic sheets for spreading the grains, which reduces the contamination with dust and makes the collection of grains easy. Mechanical drying addresses some of the limitations of natural drying and offers advantages, such as a reduction in handling losses, better control over the hot air temperature, and space utilization. However, they suffer from the limitations of high initial and maintenance costs, adequate size availability, and lack of knowledge to operate these dryers, especially with smallholder farmers. Due to these limitations, these dryers are rarely used by farmers in developing countries (Alavi *et al.*, 2012).

2.4.4. Packaging

Packaging is the process by which harvested produce will reach in a safe condition to the consumer from the production center. Packaging also plays an important role in the maintenance of the quality of the produce. Various packaging materials are used to wrap the fresh produce to save them from mechanical, and biological damage during handling operations (Bantayehu *et al.*, 2018). The packaging requirements depend on various factors such as susceptibility to water loss, microbial infections, heat accumulation, and primary consideration of the type of package needed (Idah *et al.*, 2007). Packaging helps to protect the produce from physical, chemical, and microbial attacks and helps to elongate the shelf life of the produce. A well-designed packaging method helps to reduce damage to products (Fellows, 2011). However, in most developing countries, packaging materials are traditional and rudimentary to maintain the required quality of the products and prolong the shelf life. As a result, farmers face severe PHLs in their products before they arrive at the consumer level (Debela *et al.*, 2011; Mebratie *et al.*, 2015; Bantayehu *et al.*, 2018; Rahiel *et al.*, 2018).

2.4.5. Storage

Storage is the state of keeping agricultural produce safe and preventing it from entry or multiplication of microorganisms. Crops having specific quality can only be stored properly. Controlled storage conditions have made a year-long supply of fresh produce. Throughout the world, there is the availability of a wide range of storage structures to store produce (Victor *et al.*, 2014). The main purpose of the storage is to slow down the rate of aging, make them available in the off-season, protect them from frost, prevent shortages, and keep them in good condition to fetch higher prices (Khan *et al.*, 2017). Lack of knowledge of temperature requirements leads to loss of produce during storage. Storage plays a vital role in the postharvest value chain, and several studies reported that significant losses happen during this operation (Aulakh *et al.*, 2013)

In most places, crops are grown seasonally and after harvesting, grains are stored for short or long periods as food reserves, and as seeds for the next season. Studies report that in developing countries, about 50%–60% of the grains are stored in traditional structures (e.g., Kitchen, Huts, Kanaja, pots, Gummi, and Kacheri) at the household and farm level for self-consumption and seed (Singh, 2013). The indigenous storage structures are made of locally available materials (grass, wood, mud, etc.) without any scientific design, and cannot guarantee to protect crops against pests for a long time. Costa (2014) estimated losses as high as 59.48% in maize grains after storing them for 90 days in traditional storage structures (Granary/Polypropylene bags).

2.4.6. Processing

The processing operations vary for different grains. In the case of rice, the purposes of processing are to remove the husk and bran layers of paddy to provide cleaned and whole white rice kernels for human consumption. The operation can be performed manually or using milling machines. Traditionally, in rural areas, processing is performed manually by repeated pounding. Yields are highly dependent on the processing method, skills of the operator, and crop conditions. Processing of paddy containing foreign materials results in a high amount of cracked and broken kernels and can also damage machines. Inadequately maintained processing (milling) machines result in a high amount of broken kernels and low milling yields.

Alavi *et al.* (2012) reported that processing losses are highest among the losses during postharvest operations of rice in five Southeast countries: China, Thailand, Indonesia, the Philippines, and Vietnam. The yield of rice in all these five countries was reported well below the theoretical yield of 71%–73%. The yields from the village level were as low as 57% due to small scale, poor calibration, and lack of maintenance. High moisture and an inadequately cleaned paddy aggravate the situation and reduce yields.

2.4.7. Transportation

Transportation is an important operation of the grain value chain, as commodities need to be moved from one step to another, such as field to processing facilities, field to storage facilities, and processing facilities to market. The lack of adequate transportation infrastructure results in damage to food products through bruising and losses due to spillage. Transportation losses are relatively very low in developed countries due to better road infrastructure engineered facilities on the field and processing facilities to load and unload the vehicles rapidly with very little or no damage (Alavi *et al.*, 2012). At the field level, most of the crop is transported in bullock carts or open trollies. Grains for self-usage are usually transported in bags from field storage to processing facilities in bullock carts, bicycles, small motor vehicles, or open trucks. Poor road infrastructure along with these improper and poorly maintained modes of transportation results in large spillage and high contamination. Multiple movements of crops are another major reason for high transportation losses (Baloch *et. al.*, 2010).

During each movement, some grains are lost as spillage. Unlike efficient bulk handling systems in developed countries, loading and unloading of grains from wagons, trucks, and rails at processing facilities is performed mostly manually in developing nations, and results in high spillage (Alavi *et al.*, 2012). Low-quality Jute bags are used commonly during transportation and even storage, which results in high spillage rates due to leakage from the sacks. Large quantities (usually 100 kg of grains) in each bag, and hooks used to lift these bags cause a tear and result in high spillage (Baloch *et. al.*, 2010). Alavi *et al.* (2012) reported 2%–10% losses during handling and transportation of rice in Southeast Asia. According to a report from the World Bank, (1999) estimated 7%–10% of grain loss in postharvest operations during transportation, and 4%–5% loss at the market and distribution stage in India. Hussen *et al.* (2013), also found that such methods of transportation as described above contributed to 5–20% of the total PHLs.

2.4.8. Marketing

GRiSP (2013) found that losses of rice during the postharvest operations affect the quality and quantity of the crop along the supply chain, thus, affecting the market value of rice by 10-30%. It often forces farmers to sell their rice immediately after harvest at a low price and so lose out on maximizing their return. Due to inadequate postharvest operations in Africa at the post-harvest handling level, farmers are vulnerable to selling their rice immediately after harvest at the lowest price and expose themselves to food insecurity (Harvey *et. al.*, 2013). Gesellschaft *et. al.* (2014) also found that postharvest losses of rice in Nigeria contribute significantly to the loss of revenues for farmers.

Alavi *et al.* (2012) compiled data on postharvest losses in rice value chains from different studies conducted by the FAO and reported 10%–37% losses in rice in Southeast Asia. In China, the losses were estimated in the range of 8%–26%. In Sub-Saharan Africa alone, 20-30% of rice produced is lost at various points of post-harvest operations (Hodges 2011). It is estimated that 10% of rice is lost during post-harvest operations. In Nigeria, 15-20% of rice is lost during post-production process (Mrema and Rolle 2002). The losses during these stages are caused by spillage, losses to pests, low milling yields, inappropriate postharvest management practices, delays in the postharvest chain, outdated postharvest equipment and infrastructure, and low operator skills (GRiSP 2013).

2.5. Determinants of Post-Harvest Losses

The causes of post-harvest losses in developing countries, which some estimates suggest could range from 10 to as high as 40 percent in Liberia of what is produced can occur during any of the various stages of the post-production system (Taiwo and Bart-Plange, 2016b). 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 post-harvest losses are a direct result of production management.

For instance, a study carried out by (Ayandiji, 2011) on the determinants of post-harvest losses among tomato producers shows that distance from farm to market, age, area of land put to tomato cultivation and the number of baskets harvested are the major determinants of post-harvest losses in tomato production. 94.8% of the variation in the quantity of loss from harvesting to the marketing stage is explained by these variables.

Additionally, Nithya *et. al.* (2023) used functional analysis (Regression model) to estimate the determinants of post-harvest losses of Major Vegetables in South India. They found that area under cultivation, unfavorable weather, packing materials, and incidence of pests and diseases were the factors found positively significant with PHL, while the farming experience was negatively significant. They found that post-harvest was reduced by 0.050% for farmers with better experience than those without because, these farmers were found following the basic post-harvest management practices like pre-cooling, grading and sorting, etc.

Another study conducted by Mary Kulwijila (2021) on the Socio-Economic Determinants of Post-Harvest Losses in the Grape Value Chain in Dodoma Municipality and Chamwino District, Tanzania, found that the quantity produced, the time spent on the farm, and the distance from the farm to the market positively and significantly affected post-harvest losses. It indicates that a unit increase in the quantities produced increases the level of PHL by 1.427%. Since traders have no storage facilities at their premises, it becomes difficult for them to maintain product quality, resulting in severe post-harvest losses.
She further found that distance from the farm to the market significantly and positively influenced PHL. The longer the distance it would take for the produce to get to the market, the higher the mean percentage losses.

Ayandiji and Adeniyi (2011) found that high losses of tomatoes were associated with long distances to the market in Nigeria. They emphasized that postharvest loss could be attributable not only to distance and hassles in transportation but also to the time it takes in transportation.

Similarly, 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 are sold, the higher the mean percentage of posh-harvest losses; and this was chiefly attributed to poor storage facilities and unreliable market. Similar results are also reported by Mbuk *et al.* (2011) and Mebratie *et al.* (2015) who stated that the number of days in finishing selling had a positive impact on the proportion of the spoilage of tomatoes and bananas. In addition, the product deterioration rate increases as the time it stays in the market increases (Kader, 2005).

Furthermore, a study conducted by Mutebi *et al.* (2018) on banana production found that sex, household size, education, and distance from farm to market influence the level of PHL at the farm level. The author found that females experience higher levels of PHL than the male. This is because of the intensive nature of banana production and marketing. Males are usually in charge of looking for markets, they tend to travel long distances away from their respective villages searching for markets for their produce, inputs, and other household needs when compared to female farmers (Wooldridge 2002; Jost *et al.*, 2016; Mayanja and Mudege, 2016). In so doing, men can even sell their products to distant markets and this can reduce the level of post-harvest losses when compared to their female counterparts. Mebratie *et al.* (2015) also found similar results and concluded that female farmers incur higher postharvest losses than male-headed households in Ethiopia.

Furthermore, Enoch *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 (i.e., mean distance to tarmac is 14.4 km) have a lower level of post-harvest losses of 0.093% than Isingiro farmers who are further away from tarmac roads (i.e., mean distance to tarmac road of 39.7 km).

According to Expert Consultation (2010), 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 the 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 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 post-harvest losses 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 (e.g., sprouting) may increase the susceptibility of the commodity to mechanical damage or infection by pathogens. A reduction in 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. Drying equipment poor drying season, 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 the consumption need and cause excessive wastage. (Olm *et al.*, 2004; Bourne, 2004; Atanda *et al.*, 2011)

Nshimyumuremyi *et al.* (2023) also analyzed the determinants of post-harvest losses and their impact on farmers' income in Nyagatare district using a multiple linear regression analysis. They found Education level, Land size, Farming Experience (training), seed quality, storage, mode of transportation, and weather conditions to be major determinants of post-harvest losses.

Weather condition: At the 5% significance level was positively and significantly related to postharvest losses. Farmers who have experienced bad weather are more likely to suffer losses. A similar finding was found by Ognakossan *et al.* (2018) who reported that bad weather leads to the infestation of pests and diseases including rodents accounting for 0.5% of losses.

Age: Farmers between the ages of 36 and 45 experience smaller post-harvest loss, as predicted. At the 5% level of significance, the coefficient of 1.514 indicates that postharvest losses are reduced by 1.514 for farmers between the ages of 36 and 45 years.

Gender was significant at 1% with a coefficient of -4.416 implying that PHL is reduced by 4.416 for male farmers compared to female farmers. This gender distribution conforms to existing notions and statistics about the pattern of men's participation in post-harvest. Women may be more vulnerable to high post-harvest losses due to limited access to resources and information and a lower ability to implement loss-reduction technologies (Nordhagen, 2021).

Moreover, Nshimyumuremyi *et al.* (2023) also found farmer's Education level to have a negative correlation with postharvest loss in that being more educated reduces postharvest loss by 1.896% compared to uneducated Farmers. This finding is closer to those of Yeshiwas & Tadele (2021) who found that as the education status of the farmer increases the post-harvest losses decrease.

There are many factors influencing rice harvest losses, and intensive studies have been carried out from several different perspectives. Table 1 provides a preliminary summary of the main conclusions of these studies. Based on previous research findings, factors influencing post-harvest losses are summarized in three categories, demographics, production characteristics, and harvesting operation characteristics, as shown in Table 1.

Table 1 Typical studies on post-harvest losses and their influencing factors

Literature	***Country (region)***	***Variety***	***Influencing factors***
Akar et al. (2004)	Africa	Rice	Harvest weather, rice varieties with different mature periods, and variety maturity.
Appiah et al. (2011)	Ghana	Rice	Respondents' gender, planting years, family age structure, and mechanization level of rice harvesting.
Parfitt et al. (2010)	EU	Cereals	Rice market price, farmers' skills, power grid installation, and irrigation conditions.
Hodges et al. (2011)	Southeast Asia	Cereals	Respondent's education, and grain-saving and loss-reducing awareness.
Basavaraja et al. (2007)	India	Rice	Respondents' age and education, rice planting area, and number of family laborers.
Aulakh and Regmi (2013)	Africa	Cereals	Mechanization level of cereal harvesting, climatic conditions, and harvest weather.
Abass et al. (2014)	Tanzania	Cereals	Timely harvest, harvest weather, farmers' skills, mechanization level of rice harvesting, and grain-saving awareness.
Nshimyumuremyi Vincent *et. al.*, 2023	Rwanda	Soybeans	education level, land size for soybeans, soybean farming experience, soybean seed quality, PHL value, weather conditions, age, and gender.
Maziku, P. et al 2019	Tanzania	Maize	education level, family size, quantity of maize production, market experiences, type of storage facilities, bad weather conditions, and distance to the market.
Amentae *et al.*, 2016	Ethiopia	Teff	sex, family size, level of output, bad weather conditions, distance to the nearest market, and storage facilities
FALOLA A. et al., 2022	Nigeria	Onions	farm size, output, distance to market, and length of storage. Educational level, household size, extension services, and access to credit.
Changalima, I. A. 2019	Tanzania	Maize	postharvest training, mode of transportation, storage facility, storage periods, and quantity of maize produce transported.

2.6. Impact of Postharvest Losses on Smallholder Farmer's Gross Margin

Rice losses, especially along the post-harvest supply chain, have been identified as one of the major causes of food shortage problems in most developing countries and Liberia in particular. Farmers often record a great amount of produce loss which translates to a waste of resources, a reduction in their income, and ultimately their welfare. Research conducted by Omidiji D. and Ayandiji (2011) found that post-harvest loss significantly reduces the income of smallholder farmers. They found the average gross margin with post-harvest loss (9,251.41 ₦) was less than the average gross margin without loss (72,752.55₦). This goes to show that post-harvest losses reduce income and negatively impede the welfare of farmers. Abimbola (2014) also concluded that a reduction in post-harvest food loss could guarantee an increase in food availability thereby reducing the need for food importation and consequently impacting positively on the income of farmers. That is, a reduction in post-harvest losses will lead to increased market participation, per-capita income, and consequently improved welfare of the farmers.

Taiwo and Bart-Plange (2016b) stated that when post-harvest losses occur there are effects on food security, poverty, and, sustainable use of resources. Both quantitative and qualitative losses of rice could harm the producer's income since there is a serious socio-economic reduction in the output. On the other hand, the losses incurred by the producer could result in a gain if measures are instituted to mitigate these losses, thus, increasing income and improving the livelihood of the farmers.

A study conducted by Emmy Owoicho Okadonye (2022) also analyzed the impact of post-harvest loss on the income of smallholder rice farmers in Benue state. They found that the gross margin with losses (₦8,275,000/$18,658.40) was less than the Gross margin without losses (₦61,825,000/$139,498.40). This shows that post-harvest losses reduce the income of the smallholder rice farmers in Makurdi Local Government Area of Benue State by 13.38%. This goes to show that post-harvest losses have an adverse effect (relationship) on the income of farmers.

Moreover, Nshimyumuremyi *et al.* (2023) also analyzed the impact of post-harvest on the income of soybean farmers in the Nyagatare district. They found that the average gross income of a Soybean farmer is 1,763,947 Rwf/ha, with a minimum income of 135,000rwf and a maximum income of 12,750,000rwf. The results above clearly indicate how much postharvest losses of soybeans reduce farmers' incomes cultivating Soybeans in the study area.

3. Methodology

3.1. Study Area

The study was conducted in Liberia, West Africa, with a population of 5.36M people (digital Liberia, 2023). It is home to many types of grass, trees, and shrub species and possesses about 40% of the remaining Upper Guinean rainforest. The area has a Hot and humid climate with temperatures ranging from 65 ^{0}F to 85 ^{0}F. The main soil type for producing rice includes silt and alluvial or swamp soils (MOA, 2012). Liberia is situated on the Atlantic coast of West Africa and has a land area of 11 1,369 km2 and a total coaster line of 579 km (MOI, 2007). It borders the North Atlantic Ocean, Sierra Leone to the northwest, Guinea to the north, and Côte d'Ivoire to the east. The absolute location of Liberia is latitudes 6.4281° N and 9.4295° of the prime meridian. The temperatures range between 20° C (68° F) and 36° C (97° F) with little variation throughout the year. The average rainfall ranges from more than 4500 mm along the coast to about 2000 mm in the interior. There are two seasons in Liberia. The rainy season begins in April and ends in October, while the dry season is from November to March. Most of the country comprises forest except a narrow strip along the coast where mangrove vegetation alternates with coastal savanna. The study area is shown in Figure 3.

Figure 3. Map of Liberia with bordering countries (in rose color)
Source: Map data, 2023

3.2. Conceptual Framework of PHL

The conceptual framework of post-harvest losses as shown in Fig. 2 represents how various factors (inputs, socio-economic and demographic factors, infrastructural and climatic factors) inter-relate to influence rice productivity and gross margins of smallholder farmers in Liberia. The yield from rice farming is influenced by several factors and post-harvest practices along the PH value chain (harvesting, threshing, drying, processing, transportation, packaging, and marketing).

Postharvest processing along the rice value chain are subjective to farming practices employed by smallholder rice farmer. Losses occur due to several factors such as Physical and Infrastructural factors, Demographic factors, socioeconomic factors (Gender, Age, Marital Status, Education level, Household Size), and farm practices leading to a decline in productivity. These losses account for a significant reduction in the gross margins of smallholder rice farmers.

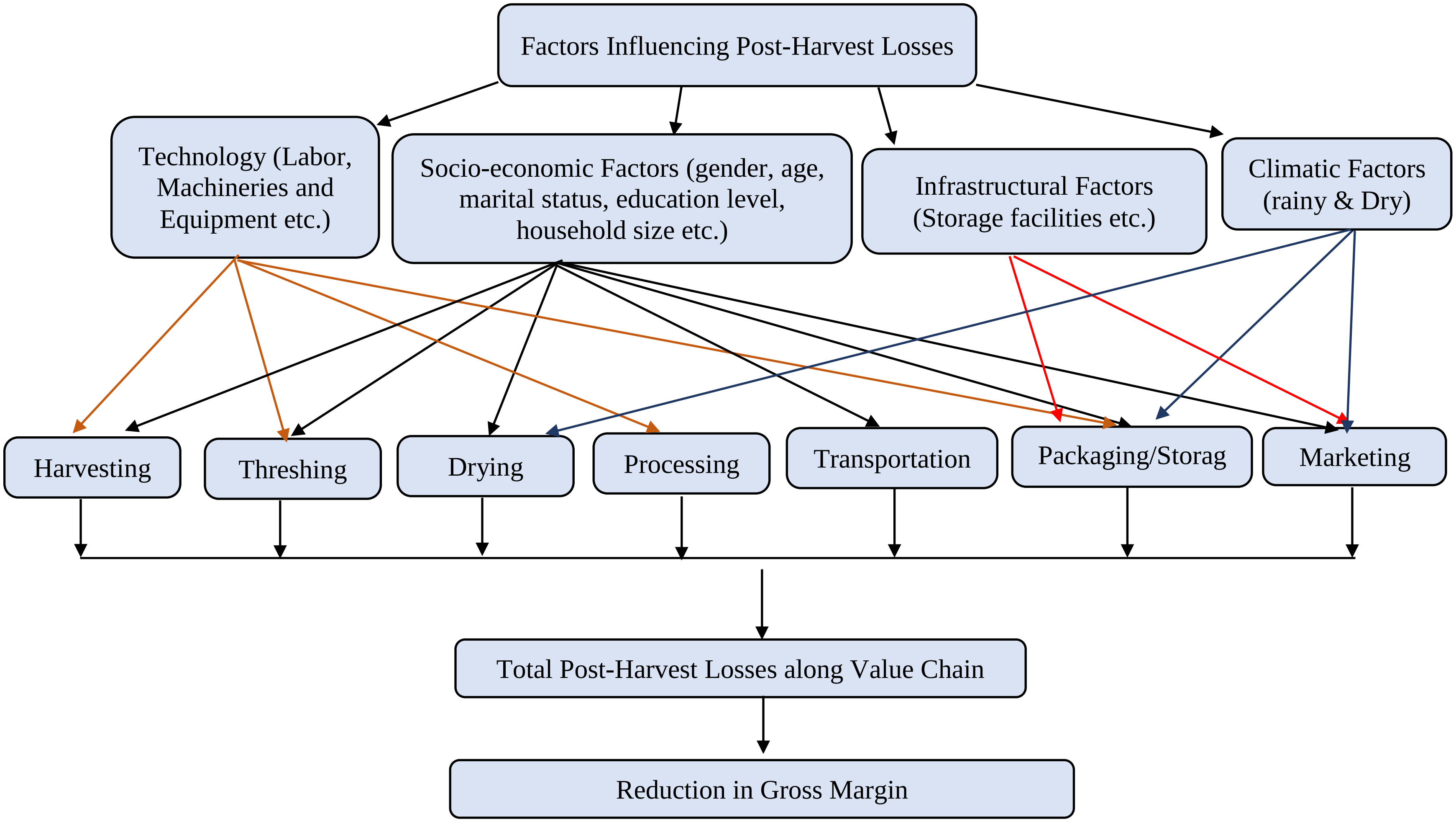

Figure 2: Conceptual Framework of Postharvest Losses in rice Production

3.3. Theoretical Framework

The Walt Whitman Rostow approach to the modernization theory of economic development was used in the study. Any society can achieve economic development by following the steps outlined in the Rostow modernization theory. According to his theoretical framework, five prerequisite stages must be completed before economic development can occur: the traditional stage, the take-off stage, the drive to maturity, and the age of mass consumption. According to Rostow, for any society to experience economic growth, these stages must be adopted sequentially. In line with Rostow's theory, societies like Liberia are still in the traditional stage. This is a stage where economic growth is not experienced because, the economy is dominated by subsistence agriculture farm produce with limited financial investment, use of crude implements, lack of institutional support, and modern technology to drive the economic growth.
This study believes that poor technological advancement, traditional methods of rice production, limited financial assistance, and ignorance from the societal structure to support and manage the post-production system are the causes of postharvest losses of rice. This has affected the economic benefit of farmers associated with the production of rice. This assumption, which is in line with Wang (2017) attributes postharvest losses of rice to subsistence-based rice production, which is primarily conducted using outdated post-production technology.

Due to this, the rate of postharvest losses in rice has increased, which has negatively impacted farmers' income, and self-sufficiency and restricted its availability for mass consumption. It has affected farmer's economic growth and this problem has made rice farmers not to generate profitable revenue from the production of rice. This is also in line with the report of the Rockefeller Foundation (2015) which states that, due to limited knowledge by smallholder farmers, limited technical know-how, and inability to access modern technology, limited access to credit and financing to expand and invest in large production of rice has made small farmers lose their income and become financially handicapped in the development of rice for mass consumption.

3.4. Description of PHL Along the Rice Value Chain

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 added to the high post-harvest losses along the value chain, limiting the availability of locally produced rice in the country.

To describe post-harvest losses along the rice value chain (harvesting, threshing, drying processing transportation packaging, and marketing), descriptive statistics were used. Specifically, the percent 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, complete primary, complete secondary, and no school). The goal of computing these percentages was to provide basic information about the influence of those categories on PHL.

The descriptive analysis was complemented by quantitative analysis and especially hypothesis testing through which we analyzed the differences of rice post-harvest losses along the various stages of the rice value chain. The Analysis of variance (ANOVA) test was used to determine if there are differences in losses between the various stages of the post-harvest value chain. The hypothesis being tested is:

H_0: PHL is equal in the various stages of the rice value chain.

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

This method was adopted by (Delphine Mapiemfu *et al.*, 2023; Sugri *et al.*, 2021; Upadhyay *et al.*, 2021) to evaluate the loss point of postharvest losses. Table 2 shows the ANOVA framework used in this study.

Table 2: Framework of ANOVA

Source of variation	Sum of Squares	Degree of Freedom	Mean Squares	F Value
PH-Stages	$SSB = \sum n_j (\bar{X}_j - X)2$	$df_1 = k - 1$	MSB = SSB / (k-1)	F = MSB/MSE
Error	$SSE = \sum\sum (X - \bar{X}_j)2$	$df_2 = N - k$	MSE = SSE / (N-k)	
Total	SST = SSB + SSE	$Df_3 = N - 1$		

Where **F** test used to evaluate the significance of various stages for the PHL, **k** is the PH-Stages (Harvest, Threshing, Drying, processing, Transportation, Packaging, Marketing), **MSB** is the Mean squares among the PH-Stages, **MSE** is the mean squares of errors, **df_1** is the degrees of freedom among the PH-Stages, **df_2** is the degrees of freedom of errors, **df_3** total degrees of freedom, **N** is the total number of observations, **SSB** = sum of squares among the PH-Stages, **SSE** = sum of squares of errors, **$\bar{X}$** = mean of each stage, **N_j** is the sample size of the j^{th} stage, **X** = each data point in the j^{th} stage (individual observation) and **SST** = Total sum of squares.

To validate the ANOVA results, a test for homogeneity of variances and normality was conducted. The Bartlett test of equal variances was used to test for homogeneity of variance between the percent 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:

H_o: there is no difference in the variances of post-harvest losses along the rice value chain.

H_1: there is difference in the variances of post-harvest losses along the rice value chain.

The test statistics for the Bartlett test is obtained with the following equations:

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

where s_i^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 S_p^2 is the pooled variance. The pooled variance is a weighted average of the group variances and is defined as:

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

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:**

$$HSD = q \frac{\sqrt{MSE}}{n} \quad \textbf{(3)}$$

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. Furthermore, post-harvest losses within the geographical regions of Liberia was also analyzed using the Tuckey HSD test. The hypothesis being tested is that PHL are equal in all geographical regions in Liberia[1].

Additionally, we 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 was also analyzed. The percentage of quantity loss at different stages was computed between males and females and within the fifteen counties of Liberia.

[1]*The regions are Bomi, Bong, Gbarpolu, Grand Bassa, Grand Cape mount, Grand Gedeh, Grand Kru, Lofa, Margibi, Maryland, Montserrado, Nimba, Rivercess, River Gee and Sinoe.*

3.5. Determinants of Post-Harvest Losses

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 (Basavaraja *et al.,* 2007; Omidiji, 2011; Ojotule, 2017). 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 it is coded as 0 and 1. [0= Framers 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:

$$ln\left\lfloor\frac{P}{(1-P)}\right\rfloor = \beta_0 + \sum_{i=1}^{n}\left(\beta_i\, X_{ij}\right) + \varepsilon j \qquad \textbf{(4)}$$

where $ln\left\lfloor\frac{P}{(1-P)}\right\rfloor$ is the log-odds (ratio of the probabilities of incurring post-harvest losses), X_j is the vector of independent variables, ε=error term, and $\beta_0\ and\ \beta_{\mathrm{j}}$ 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.

$$\frac{\partial PHL}{\partial Xj} = \left(\beta_i\, X_{ij}\right) \qquad \textbf{(5)}$$

The choice of explanatory variables used in this study is based on previous studies such as those in Table 1. 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 3 below presents the included variables as well as the respective definitions and expected signs.

Gender was represented as a dummy variable to clearly distinguish farmers’ participation as either male or female. Integrating a gender perspective is important because females play a significant role in rice production and post-harvest-related activities. The expected and positive sign agrees with (Nshimyumuremyi Vincent *et. al.,* 2023;) who argued that women may be more vulnerable to high post-harvest losses due to limited access to resources such as access to land, financing, markets, agricultural training, education, suitable working conditions, and equal treatment put female farmers at a significant disadvantage, they also have limited success to information, as well as a lower ability to implement loss-reduction technologies. They attributed the high PHL incurred by female farmers to gender discrimination.

Household size is a continuous variable and was used to determine the impact it has on post-harvest losses among rice farmers. It allows us to understand better the complexities and nuances associated with PHL and can have a significant effect on the amount of labor available for agricultural activities. 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, while a smaller number of members of households may have fewer workers available. It enables us to understand the dynamics of agricultural labor supply and demand. The negative sign is the expected sign and it is consistent (Maziku, P. 2019, Amentae T.k. *et al.,* 2016) who found that the amount of post-harvest losses decreases with the increase in family size by one person in Ethiopia. Furthermore, the negative sign is also in line with Robert Aidoo (2014) who found that Farmers who had larger household sizes tended to have lower levels of postharvest losses because they had a relatively high amount of family labor that helped with harvesting for the process to be faster and efficient.

This means family member makes decisions regarding their labor supply based on the overall welfare and economic interests of the household. For example, they may choose to allocate more labor to agricultural activities during peak seasons to maximize production and income. In many agricultural settings, family members play a crucial role in the production process. They often work together on the farm, with each member contributing their labor to various tasks. Understanding the theory of family labor supply in agricultural production is important for policymakers and researchers as it helps explain the dynamics of agricultural labor markets and the role of family units in agricultural production. It can also provide insights into the factors that affect productivity and welfare in rural areas, helping to inform policies and interventions aimed at improving agricultural outcomes.

Age is also a categorical variable with three dummies (1=25-54yrs and 0=otherwise, 1=55-64yrs and 0=otherwise, and 1=65yrs and Above and 0=otherwise) with 18-24yrs as a reference variable. It is important to understand the relationship between age and postharvest losses, and how different factors influence individual losses at different stages of life leading to more accurate and applicable findings. The positive sign is consistent with (Basavaraja et al., 2007; Nshimyumuremyi Vincent et. al., 2023) who found that older-aged farmers may face physical limitations that can affect their ability to handle and perform certain post-harvest operations. 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 post-harvest losses.

Education level is a categorical variable with four modalities (no education, complete primary, complete secondary, and complete college/university). It has three dummies (1 = complete primary 0= otherwise, 1= complete secondary 0= otherwise, and 1 = complete college/university 0= otherwise) with no education as a reference variable. Education level was used to identify patterns among different groups of farmers and provide insight into how it may impact postharvest losses. It was also used to understand smallholder farmer's ability to provide accurate responses and their overall perspective on post-harvest losses. The negative sign is concise with (Hodges *et al.*, 2011; Basavaraja *et al.,* 2007) who found that an increase in education leads to less loss. They argued higher level of education among farmers can lead to increased productivity and efficiency in farming practices thereby leading to high output. Education equips farmers with the ability to access and utilize information, such as market trends, weather forecasts, and better techniques on post-harvest management systems. Additionally, education can empower farmers to engage in value-added activities and institute good postharvest management practices. Overall, education is a key factor in enhancing agricultural productivity. It equips farmers with the necessary knowledge, skills, and mindset to adopt sustainable practices, embrace innovation, and maximize their potential in the agricultural sector thereby reducing PHL.

The number of harvest days is a continuous variable and it was used to identify its impact on post-harvest losses. By analyzing the number of harvest days, we can pinpoint areas where improvements can be made to reduce post-harvest losses. The positive sign is in line with a study conducted by Falola A. et al. (2021) who suggests that if the harvest is spread over a long period, there is a greater chance of spoilage and damage to the rice produced while being in the field, which will increase the risk of PHL. This is because, the longer the rice are left in the field, the more they are exposed to environmental factors such as pests, disease, weather conditions, and seeds shattering. Overall, the number of harvest days can have a significant impact on post-harvest losses, and it is important for farmers to carefully manage the timing of their harvest to minimize losses and maximize profits.

Post-harvest training is a dummy variable coded as 0 if acquired training and 1 otherwise. It was used to examine how post-harvest training influences post-harvest losses. It is important to understand its impact on postharvest losses because it plays a crucial role in the post-harvest management system. The positive sign is consistent with (Kagima et al. 2005; Changalima, I. A. 2019). They found that farmers who have not acquired postharvest training are less likely to reduce postharvest losses as post-harvest training has a significant impact on reducing post-harvest losses. The lack of training on the use of appropriate harvesting tools, proper packaging, and storage techniques, refrigeration, drying, and preservation could greatly increase PHL. By improving knowledge and skills in these areas, farmers can reduce the quantity of rice that is lost or damaged during the post-harvest period. This can result in increased yields, higher-quality produce, and greater profits for farmers.

Climatic season is also a dummy variable coded as 0 if dry season and 1 if rainy season. This variable was used to determine in which climatic season (rainy and dry) of Liberia the highest postharvest loss is incurred. Climatic season is important in post-harvest losses because it can affect the quality and quantity of rice produced. The expected and positive sign is in line with (Akar et al., 2004; Abass et al., 2014; Aulakh and Regmi 2013) who found that climatic conditions significantly increased rice harvest losses because, it increased the rice lodging area, thereby increasing the difficulty of harvesting suggests that Changes in temperature, precipitation, and extreme weather events can impact the growth and development of rice yield, making them more susceptible to pests and diseases. This can result in reduced yields and lower-quality produce, which can lead to post-harvest losses. Additionally, climate changes can also affect the storage and transportation of crops, making it more difficult to preserve them and transport them to market.

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. It was used because harvesting usually results in a huge amount of grain which is intended to be usable for a longer duration. Leaving large amounts of grain unattended leads to moisture contamination and insect or rodent infestation, which is why a need to take the right measures to store them. Therefore, it’s important to note the relationship between the storage method employed by smallholder rice farmers and PHL. The sign is negative and congruent with the stance of Suleiman and Kurt (2015) and Maziku, Petro (2019) who found that post-harvest losses were lesser for those farmers who were using modern storage facilities. This means proper storage methods can help reduce post-harvest losses by preserving the quality of the harvested produce, protecting it from pests and diseases, extending its shelf life, and reducing handling and transportation losses. This can be achieved by controlling temperature, humidity, and ventilation, using appropriate storage containers, fumigation, and other pest control measures.

Harvesting techniques is a categorical variable coded as 1 if manual and 0 otherwise. It was used in this study to understand and identify the factors that contribute to losses during the harvesting process. By studying harvest techniques, we can assess the efficiency and effectiveness of different methods used to harvest and identify any potential areas for improvement. Studying the impact of harvest techniques on post-harvest losses provides valuable insights into the factors that contribute to losses and helps identify strategies to minimize these losses, and improve quality and efficiency in the harvesting process. The positive sign is in line with (Bantayehu et al.2018; Rahiel et al. 2018; Parmar et al. 2017) who argued that inappropriate methods of harvesting cause high PHL due to the increased possibility of rough handling and inapt post-harvest handling and practices. This means a method of harvesting techniques used by smallholder rice farmers can result in physical damage to the rice grains. For example, using sharp sickles or knives can cause excessive cutting or bruising of the grains, leading to losses.

Table 3: Variables Description and Expected Signs on the Determinants of PHL

Variables Name	*Descriptions*	*Expected Signs*
1. *Post-Harvest Losses* [a]	Dummy variable equal to 0 if no PHL is Incurred and 1 if PHL is greater than 0	
2. *Gender*	Dummy variable coded as 1 if female and 0 otherwise.	+
3. *Household Size*	Continuous variable, Number of persons living in the household.	-
4. *Marital Status*	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.	
• *Widow(er)*		+
• *Divorced*		+
• *Single*		+
5. *Age*	Age is a categorical variable with three dummies, (1=25-54yrs and 0=otherwise, 1=55-64yrs and o0otherwise, and 1=65yrs and Above and 0=otherwise) with 18-24yrs as a reference variable.	+
6. *Education Level*	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 was set to be the reference variable	-
• *Complete Primary*		-
• *Complete Secondary*		-
• *Complete College/University*		-
7. *# of Harvest Days*	Number of days takes to harvest.	+
8. *Post-Harvest Training*	Post-harvest training for Respondents is coded as 0 if acquired training and 1 otherwise.	+
9. *Climatic seasons*	Major season PHL is incurred equal 0 if Dry season and 1 if rainy season.	+
10. *Storage Method*	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.	-
• *Bags*		-
• *Silo*		-
• *Warehouse*		-
11. *Harvesting Techniques*	Harvesting techniques used during harvest and it is coded as 1 if Manual and 0 otherwise.	+

Note: a: is the dependent variable for the regression analysis

3.6. Effect of PHL on Smallholder Rice Farmer Gross Margin

We begin the analysis of the effects of PHL on rice farmers' gross margins by testing if there is a difference in the average gross margins of farmers who incurred PHL and those who did not have PHL using the t-test. The hypothesis being tested is:

H_o: the average gross margins of farmers having PHL are the same as those with no PHL

H_1: there is a significant difference between the average gross margins of farmers having to those with no PHL.

The calculation for the t-test (the Student's t-test) is shown below:

$$t = \frac{\mu GM_{L} - \mu GM_{WL}}{\sqrt{\left[S^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right) \right]}} \qquad \textbf{(6)}$$

where t is the t value, S^2 is the standard error of the two groups, n_1 and n_2 are the number of observations in each group and was tested at ($\alpha = 0.05$).

If t calculated > t critical, the gross margins are significantly different, and that the null hypothesis will be rejected.

To conduct the t-test, the gross margin without PHL and the gross margin with PHL (value of PHL) were computed. The gross margins for the two groups of farmers are computed as the difference between total revenues and total variable costs.

3.7. Data

A secondary data from the Liberia Post-harvest and Food Security Assessment (LPFSA), 2021 conducted by the World Food Program was used to analyze the determinant of postharvest losses amongst smallholder rice farmers in Liberia. It contains data on socio-economic and demographic characteristics, Agriculture, including subject related to post-harvest losses, climatic and post-harvest factors. A Structured and semi- structured questionnaires were administered in gathering data on PHL from the 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 the central point. All eligible respondents found within this cluster were selected and a face-to-face interview 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 was subjected to analyses such as descriptive statistics, ANOVA, logistic regression analysis, gross margin computation.

3.8. Sampling Analysis

Table 4 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 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 18 and 45 years of age implying that a good number of the farmers in the area are in their economic active age. This fact can positively affect the development of the rice value chain as youth farmers are more willing to adopt and implement improved technologies. In addition, the study reveal that (86.51%) of the farmers were married and had household sizes of between 1 and 12 members accounting for 88.45% 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 Ayandiji (2011) and Ousman Sarlia Dorley *et al.* (2022) who found that the sector is dominated by farmers with low levels or no education. The dominance of illiterate farmers limits them to institute appropriate post-harvest practices that minimizes losses.

91.73% of farmers used manual harvesting methods while 8.63% used mechanical methods which include the use of machines. This is concise with Deepak Kumar *et al.* (2017) who reported that crop harvesting is performed manually using hand-cutting tools such as sickle, knife, scythe, and cutters in most developing countries. The dominance of the manual method of harvesting yields an increase in the level of post-harvest losses because manual harvesting takes a long time. The study has further disclosed that more than half, 58.81% of farmers experienced post-harvest losses during the rainy seasons while 41.19% of farmers incur losses during the dry season. It is expected that humidity and the development of diseases and pests, which can cause post-harvest losses are prevalent during the rainy season.

Major post-harvest constraints reported by respondents in Liberia as presented in Table 4 include pests and diseases including Birds, climatic conditions, and rodents. This is consistent with the findings of Seid *et al.* (2013) and Basappa *et al.* (2007) who found inadequate control of pests and diseases including birds are the major factors contributing to losses of cereal, maize, and commercial horticultural crops respectively.

Table 4 The Basic Demography and Socio-Economic Characteristics of Respondents

Characteristics	n=823	Description	Percent(%)	Mean	SD	Min	Max
Gender	522	Male	63.43		(0.488)	0	1
	301	Female	36.57				
	41	18-24	4.98				
Age (years)	663	25-54	80.56		(0.468)	0	3
	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 Coll./Univ.	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				
	377	Bag	45.81		(1.451)	1	6
	36	Silo	4.37				
	71	Warehouse	8.63				
Post-Harvest Loss	145	No	17.62		(0.804)	0	1
	678	Yes	82.38				

4. Results and Discussion

4.1. Description of Post-Harvest Losses 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). Losses 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 as presented in Table 5 show a statistical significance with Prob>F (0.000). This implies the rejection of the null hypothesis which states that PHL is the same at all stages of the rice value chain and the conclusion.

Table 5 **Analysis of Variance Post-Harvest Stages and % of Qty. Loss**

Source	SS	Df	MS	F	Prob > F
PH-Stages	33186.249	6	5531.041		
Residuals	1141693.5	5,754	198.417	27.88	0.0000
Total	1174879.8	5,760	203.972		

The ANOVA results were validated using the Bartlett test for equal variances. The results as shown in Appendix 2 implies that there is homogeneity in the variances of post-harvest losses for all stages of the rice value chain implying that the statistical test results are valid.

To analyze the differences of PHL at various stages of the rice value chain the Tukey's Honestly Significant Difference Test was used. The results as shown in Figure 4 indicated that there is 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 at 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 Priefer *et al.* (2013) suggested that rice harvest losses were increased by farmers' poor harvesting operation skills, pest and disease infestation, and a lack of relevant policies. Policy plays an essential role in minimizing postharvest losses, which can become a more pronounced basis following an increase in rice production. A lack of information on the scale of postharvest losses continues to challenge decision-makers and impede the deployment of resources. Liu (2014) found that inadequate infrastructure, poor awareness of grain saving and loss reduction, 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 categorized by the usage of primitive methods including poor infrastructures and 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 concise with Murthy et al. (2009) who found that most farmers experience losses during the harvesting stage.

A study carried out in Punjab also revealed that delays in harvesting caused losses to increase by approximately 67%, owing to high shattering losses (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 gather, and the harvesting implements: sticks, sickles, spades, hoes, and axes cannot preserve the appropriate quality of the produce (Emana *et al.*, 2015). Because of the greater likelihood of rough handling and improper post-harvest handling and practices, these harvesting techniques result in high PHL (Bantayehu *et al.,* 2018; Rahiel *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 usage 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 used the local method of packaging rice in tarpaulin, crib, silo, and bags. These methods lead to the contamination of packaged rice by rodents, buds, 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.[2]

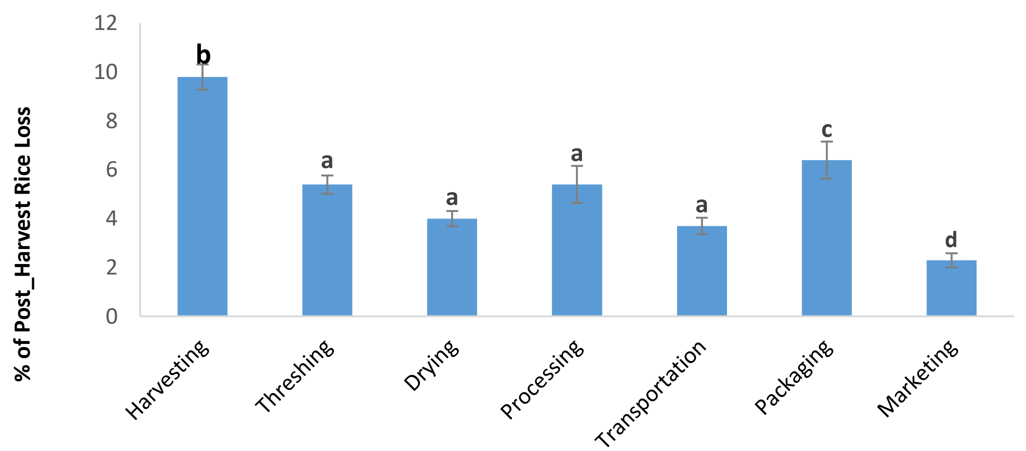

Figure 4: Loss Point of Rice PHL in Liberia

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) who found that rice farmers in Liberia were losing between 10-40% of production due to post-harvest losses.

4.2. Gender Dimension of PHL

Despite these losses, there has generally been limited investment in understanding and addressing gender-equity issues during various postharvest operations (Stella Nordhagen, 2021). Figure 5 shows the gender dimension of post-harvest losses 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 percent of quantity loss of 10.0% and 7.3% at the harvesting and packaging stages respectively of

[2] ***b****=1st highest PHL,* ***a****=equal PHL,* ***c****=2nd highest PHL* ***d****=lowest PHL*

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 SM, McDougall 2018; Chisule G. *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 consistent with a study conducted by (FAO 2018, Stella Nordhagen *et al.*, 2021, Valido A., *et al.* 2019, Palacios-López A., 2015) who found that Postharvest Losses among female farmers are influenced by access to technology, and market information, knowledge and 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.

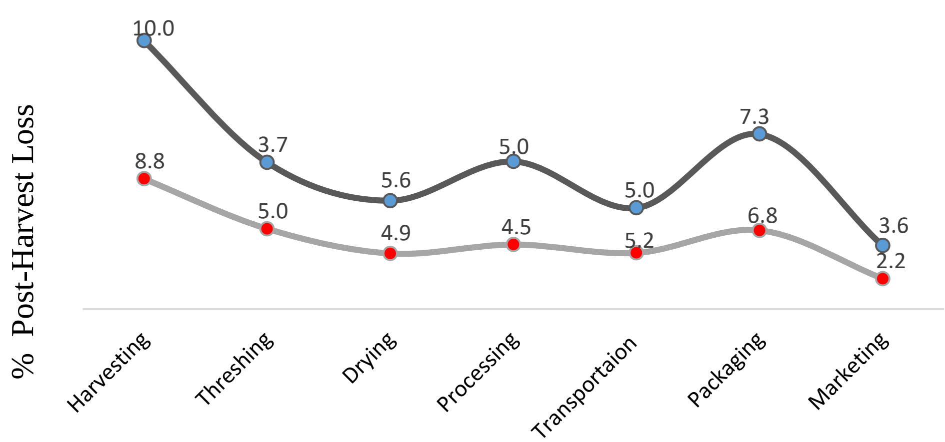

Figure 5: Gender Dimension of PHL in Liberia

The Tukey's Honest Significant Difference Test with α=0.05 significant level indicates that there is a significant difference in percent of quantity lose within the geographical regions of Liberia. Figure 6 presents the geographical distribution of post- harvest losses by counties in Liberia. The results show that Lofa County reported the highest percentage of quantity loss (18.13%) compared to Sinoe, Bomi, Rivercess, and Grand Cape Mount with the lowest PHL. This is because Lofa

County is the first highest rice-producing county in Liberia and is considered the bread basket of the country (Ousman Sarlia Dorley, 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.

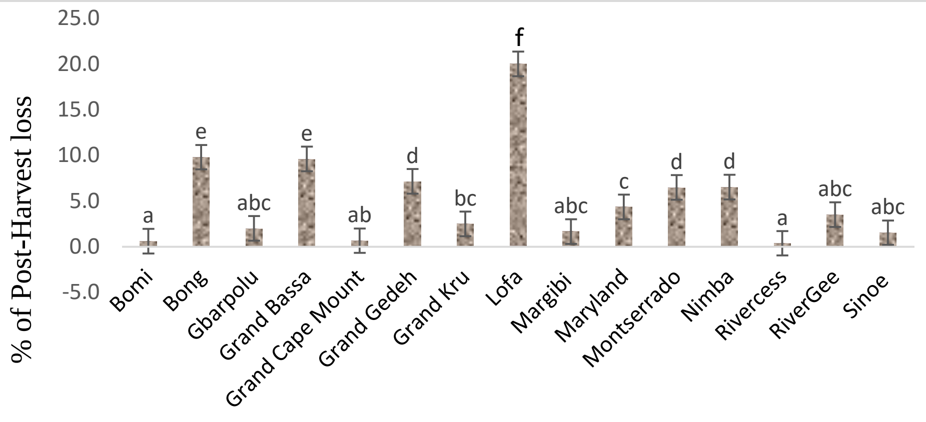

Figure 6: Geographical Distribution of Post-Harvest Loss in Liberia

Table 6 shows the per-county distribution of rice PHL at each stage of the post-harvest value chain. The results show that the bulk of postharvest losses in rice production mainly occur at the harvesting and packaging stages of the PH value chain. 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 harvesting stage. Again, at packaging, Lofa, Bong, Grand Gedeh, and Grand Bassa counties incur losses up to 25.7%, 16.1%, 13.3% and 13.0% as compared to Bomi, Rivercess, Sinoe, and Rivergee 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 wrapping packages, and damaged packaging material, such as torn or punctured wraps or damaged pouches, can lead to contamination of packaged rice by rodents, buds, insects, molds, etc. These results are concise with (M. K. Hasan 2015; Olayemi *et al.* 2011) who reported that most farmers still use traditional baskets and sacks as their packaging material and rice stored in these structures was susceptible to damage by natural disasters and attack of microorganisms, insects and rodents and caused considerable damage and loss. Per county distribution of rice post-harvest loss by gender in Liberia is also presented below.

Table 6 **Per County Distribution of Rice PHL at each stage of the value chain**

County	Harvesting (%)	Threshing (%)	Drying (%)	Processing (%)	Transportation (%)	Packaging (%)	Marketing (%)
Bomi	1.3	1.1	1.2	1.3	1.2	1.5	0.6
Bong	31.0	3.6	4.8	9.8	7.4	16.1	1.8
Gbarpolu	1.8	1.4	3.5	3.3	1.8	1.8	0.3
Grand Bassa	23.2	7.5	8.7	7.9	12.8	13.0	2.4
Grand Cape Mount	0.9	1.0	1.5	1.8	1.4	1.8	1.4
Grand Gedeh	7.4	5.2	5.2	6.8	8.1	13.3	3.2
Grand Kru	5.2	13.9	5.2	1.2	1.0	1.2	0.6
Lofa	33.6	9.4	14.1	9.8	28.2	25.7	11.0
Margibi	3.8	2.7	2.6	2.7	3.7	6.5	5.0
Maryland	4.4	4.3	4.2	3.9	2.2	2.6	3.4
Montserrado	6.1	8.0	6.5	5.3	10.0	10.7	0.8
Nimba	11.3	4.3	5.4	4.0	7.4	7.5	2.3
Rivercess	1.7	1.6	1.3	1.6	0.7	1.1	0.8
River Gee	1.0	8.5	7.5	1.2	1.4	0.9	1.7
Sinoe	2.1	1.1	1.8	2.3	1.6	2.2	2.1

The distribution of post-harvest losses in percentages

Table 7 ---------------------------- Rice Post-Harvest Loss By Counties and Gender In Liberia ----------------------------

County	Harvesting (%)		Threshing (%)		Drying (%)		Processing (%)		Transportation (%)		Packaging (%)		Marketing (%)	
	M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Bomi	1.5	1.1	1.2	1.12	1.1	1.3	1.1	1.5	1.1	1.4	1.4	1.5	0.1	0.1
Bong	29.5	33.2	4.4	2.3	5.8	3.2	12.3	6.2	8.8	5.5	13.1	20.6	1.3	2.5
Gbarpolu	2.3	1.2	1.1	1.7	3.6	3.3	3.1	3.6	2.4	1.2	1.1	2.7	0.5	0.1
Grand Bassa	20.6	12.8	5.9	16.6	8.5	15.5	6.6	0	11.8	20.6	12.3	5.9	3.0	8.5
Grand Cape Mount	0.8	0.9	1.2	0.8	1.5	1.5	1.8	1.8	1.3	1.6	1.7	1.9	1.4	1.3
Grand Gedeh	7.3	8.1	5.6	3.5	5.4	4.5	5.7	12	8.8	5.0	12.5	16.7	3.0	4.1
Grand Kru	3.5	8.3	17.7	0.7	5.9	3.9	1.2	1.3	1.3	0.5	0.7	2.3	0.5	0.8
Lofa	33.0	34.1	9	9.8	9.6	17.6	8.3	10.9	23.6	31.6	23.1	27.6	8.0	13.2
Margibi	4.0	3.3	2.5	3.1	2.3	3.2	2.8	2.5	3.7	3.7	6.5	6.6	5.0	5.0
Maryland	3.5	5.5	4.8	3.8	4.0	4.5	4.4	3.2	2.6	1.7	3.8	1.2	2.9	4.0
Montserrado	6.5	3.6	8.2	5.4	6.3	9.6	5.4	4.3	10.1	9.7	11.5	5.6	1.0	0.0
Nimba	12.9	9.0	5.5	2.6	6.9	3.2	4.6	3.0	7.7	6.8	8.3	6.1	3.1	1.0
Rivercess	1.6	2.0	1.7	1.6	1.3	1.2	1.4	1.8	0.5	0.9	1.1	1.1	0.3	1.3
RiverGee	0.9	1.1	14.0	1.2	10.2	4.1	1.4	1.0	1.5	1.33	1.1	0.6	1.5	0.60
Sinoe	3.4	1.6	1.1	1.1	1.8	1.8	2.6	1.9	1.6	1.6	2.2	2.1	1.5	3.0

4.3. Causes of Post-Harvest Losses in Rice Production

Postharvest losses can be caused by a wide variety of factors, ranging from harvesting to marketing. Not only are losses a waste of food, but they also represent a similar waste of human effort, farm inputs, livelihoods, investments, income, and scarce resources (Mrema, C. and Rolle, 2002). Table 8 shows the causes of postharvest losses in rice production by counties in Liberia. The results show that birds, climatic conditions, and rodents are major factors influencing postharvest rice loss with theft accounting for the lowest loss in Liberia. 40.92% of smallholder rice farmers in Liberia acknowledge that they incur post-harvest rice loss due to birds' infestation while 33.09% and 22.19% incur losses due to climatic conditions and rodents respectively. These causes exist because smallholder rice farmers do not have the available resources to institute appropriate bird and rodent control measures. When their farms are left exposed, birds and rodent infestation becomes a problem causing severe PHL during and after harvest.

On the other hand, unfavorable climatic condition significantly influences PHL in Liberia. Rice production is both a victim and a contributor to climate change. Traditional cultivation methods contribute approximately 10% of global man-made methane, a potent greenhouse gas (IRRI, 2022). Drought, flood, and extreme temperatures devastate crops and increase PHL each growing season (IRRI, 2022). The results further reveal that Bong, Sinoe, and Nimba incur PHL due to bird infestation, while, Lofa and Grand Gedeh incur losses due to climatic conditions, with Bong experiencing PHL due to rodents. The results are consistent with Taiwo (2016) who found that the causes of post-harvest losses are bird attacks and poor post-harvest management systems. The results also agree with a study conducted by BRRI/FAO (2019) which found that rice losses in post-harvest operations are due to heavy rainfall (climatic conditions) during harvesting.

Therefore, smallholder farmers could introduce a type of management system such as fencing, bird boys, exclusion netting, noisemakers, chemical repellents, and the use of flags, scarecrows, or bird kites while the government of Liberia through the Ministry of Agriculture can introduce smart and conservation agriculture to avoid cutting trees and enable farmers settle and farm to a particular place for many years.

Table 8 **Causes of Rice PHL by Counties in Liberia**

County	Birds(%)	Climatic Condition(%)	Insufficient Labor(%)	Lack of Storage(%)	Rodents(%)	Theft(%)	Cultural Practices(%)	Total(%)
Margibi	75.00	15.91	0.00	4.55	0.00	0.00	0.00	100
Grand Kru	21.25	50.00	0.00	0.00	27.50	0.00	1.25	100
Sinoe	67.39	16.30	2.17	3.26	10.87	0.00	0.00	100
Bomi	44.90	34.69	0.00	0.00	20.41	0.00	0.00	100
Grand Cape Mount	70.21	10.64	0.00	0.00	19.15	0.00	0.00	100
Bong	32.68	25.49	0.65	0.61	39.87	0.65	0.00	100
Grand Bassa	40.21	21.65	0.00	2.06	34.02	1.03	1.03	100
Lofa	22.88	50.98	1.31	1.96	21.57	0.65	0.65	100
Rivercess	59.09	13.64	13.64	0.00	13.64	0.00	0.00	100
Maryland	75.76	9.09	0.00	3.03	12.12	0.00	0.00	100
River Gee	60.00	15.00	0.00	0.0	25.00	0.00	0.00	100
Nimba	49.17	22.50	4.17	2.50	20.83	0.00	0.83	100
Gbarpolu	30.25	42.86	3.36	0.00	22.69	0.00	0.84	100
Grand Gedeh	27.96	56.99	0.00	0.00	15.05	0.00	0.00	100
Montserrado	30.88	52.94	1.47	2.94	11.76	0.00	0.00	100
Total	40.92	33.09	1.73	1.40	22.19	0.25	0.41	100.00

Percentage distribution of respondents in each county

4.4. Determinants of Postharvest Losses

Table 9 presents the results obtained from the Logistic regression analysis on the factors influencing post-harvest losses amongst 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 models fit the data quite well. Most estimated coefficients exhibit similar levels of statistical significance. The F-statistics 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 had a significant effect on postharvest losses in rice production. The results show that the age of smallholder rice farmers has a positive relationship with post-harvest losses. 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 level of age. This means the odds of incurring post-harvest losses for farmers between the ages 25-54 years increase by 8.8% whereas the probability of incurring post-harvest 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 post-harvest losses for a farmer between the ages of 55-64 years is increased by 15.31% compared to a farmer between the ages 18-24 years. Finally, farmers who ages are above 65 years are 2.278 times more likely to incur post-harvest losses. The study found that the probability of incurring post-harvest losses 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 aged farmers might not have the necessary or available 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 post-harvest losses. The findings disagree with Esmat Ara Begum *et al.* (2012) who found that post-harvest losses 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 who had 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 post-harvest losses decreases by (4.8%). An addition of one person to the family reduces rice post-harvest losses because, rice production is labor intensive, and therefore, an increase in the number of active laborers in the family is expected to reduce post-harvest losses. 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 that of Amentae *et al.* (2016) who found that the amount of post-harvest losses decreased by 3.75%, with the increase in family size by one person in Ethiopia. Furthermore, the results agree with those reported by Robert Aidoo (2014) who found that Farmers who had 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 for the process to be faster and efficient, ceteris paribus.

The results indicate the Climatic Season (Rainy) has a positive effect on the level of post-harvest losses 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 to incur post-harvest losses 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 them 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 post-harvest losses. This finding is similar to (Abass *et al.,* 2014; Yuan-Chih Su, 2023) who found that most farmers considered changes in weather and climate as a major factor that exacerbate post-harvest losses and most farmers experienced high postharvest losses during the rainy season. The studies further disagree with Ashish Raghuvanshi (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. Akar *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 *et al.,* 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 post-harvest losses (Zhang *et al.*, 2013).

On the other hand, *storage method* shows a negative relationship with post-harvest losses 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 silo, and warehouse 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 (Rugimamu, 2004; Suleiman and Kurt, 2015; Maziku and Petro, 2019) who found that post-harvest losses were higher for those farmers who were using traditional storage facilities. They argued that the traditional storing method facilitates insect and pest infestation, mole, 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 post-harvest losses 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 they are exposed to environmental factors such as pests, disease, weather conditions, and seeds shattering. This calls for the development and use of suitable harvest machinery, which can reduce harvest time to reduce post-harvest losses.

Post-Harvest Training was found to have 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 post-harvest losses 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; Ismail, J. and Changalima, 2019; Kagima, 2005) who suggested that associated postharvest losses could be reduced through the provision of training for farmer's postharvest management. They further stated that farmers were more likely to reduce postharvest losses as training on post-harvest management reduces rice loss.

Table 9 Logit and Logistic Estimate of the Determinants of Post-Harvest Losses

Variables	**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
# 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 R2	0.4099				
Log-likelihood	-229.55644				
Prob. > chi2(18)	0.0000				
Number of observations	823				

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

4.5. Effect of Post-Harvest Losses on Income

The quantity of rice loss reduces its economic value and makes it unsuitable for human consumption. These losses play a critical role by influencing and reducing the gross margins of smallholder rice farmers, while agricultural inputs used to produce are also wasted. Table 10 presents the results of the gross margin analysis for evaluating the effect of postharvest losses on smallholder rice farmers' gross margin in Liberia. The result of the t-test shows a P-value of (0.0000) indicating that there is a significant difference between the gross margin with postharvest loss and the gross margin without postharvest loss. The average gross margin with a post-harvest loss of LRD 3,512.475 was much lower than the average gross margin without a loss of LRD 8,826.114. This implies that post-harvest loss incurred by smallholder rice farmers reduced their gross margin by 39.79% valued over 2.8 million Liberian Dollars. The results further show that there is no significant difference between the gross margins for both males and females.

This result is in agreement with the findings of Robert Aidoo, (2014) who found that farmers incurred postharvest losses of up to 40% receiving only 60% of the potential revenue during the major production season in Offinso North District of Ghana.

Similarly, Emmy Owoicho (2022) also found the gross margin with losses (₦8,275,000/$18,658) for rice farmers to be lesser than the gross margin without losses (₦61,825,000/$139,498.40). This shows that post-harvest losses reduce smallholder rice farmer's income by 13.38% in Benue state.

Additionally, Omidiji D. Ayandiji (2011) also analyzed the impact of post-harvest on the income of smallholder farmers by computing the gross margin with loss and the Gross margin without loss. They found that the average Gross margin with loss (9,251.41) is lesser than the average gross margin without loss (72,251.41). the author found that post-harvest losses reduce the income of farmers in the Imeko-Afon local Government Area of Ogun State. The percentage loss incurred by the farmers is 87.3%. The effects of post-harvest losses lead to wastage of the products and tend to frustrate the efforts put into production and their income on the produce.

The results of the gross margins analysis and the respective percentage of losses for each county as shown in Appendix 1 below indicate that Nimba, Lofa, Bong, and Grand Bassa incurred reductions in their gross margins by 65.12%, 64.38%, 57.59%, and 55.68%, respectively compared to Bomi Grang Cape Mount Sinoe, and Grand Kru with the lowest reduction. These counties incurred a higher reduction in their gross margins because they are major rice-producing counties and contribute more than 50% of the total rice produced in Liberia (Ousman Sarlia Dorley, 2022).

Table 10 Gross Margin Analysis Results

Analysis	Total Variable Cost (LRD)	Total Revenue (LRD)	Total Gross Margin (LRD)	Average Gross Margin(LRD)
Without Post-Harvest Loss	828,962	8,092,854	7,263,892	8,826.114[a]
With Post-Harvest Loss		3,719,729	2,890,767	3,512.475[b]

Table 11 Gross Margin Analysis for Gender

Analysis	Total Variable Cost (LRD)		Total Revenue (LRD)		Gross Margin (LRD)		Average Gross Margin(LRD)	
	Male	Female	Male	Female	Male	Female	Male	Female
Without Post-Harvest Loss	471,000	357,962	5,096,202	2,996,652	4,625,202	2,638,690	8,998.447[a]	8,539.45[a]
With Post-Harvest Loss	471,000	357,962	2,328,319	1,391,410	1,857,319	1,033,448	3,613.461[b]	3,344.492[b]

5. Conclusion and Policy Implications

Postharvest loss reduction throughout the rice value chains is an important pathway to addressing food security in Liberia. However, a lack of understanding of losses and associated factors along the rice value chains remains a major challenge to operationalizing postharvest loss mitigation strategies. This study revealed that post-harvest losses 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, policy 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 with the use of poor-quality materials and improper handling of products. There is a need for increased financial investment by both the public and private sectors to provide inputs and opportunities for the integration of PHL interventions with key priority to these counties. Policy towards value addition and especially value chain development policies articulating good packaging practices for rice can be considered to reduce post-harvest losses.

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. These determinants significantly influence post-harvest losses because older-aged farmers may face physical limitations and might not be able to perform various post-harvest operations, whereas the lack of post-harvest training limits the farmer's ability to introduce improved harvesting techniques and measures to mitigate the infestation of pests and diseases that may be arising due to variation in climatic seasons. It is imperative to address the problem of postharvest losses through the promotion of postharvest management technologies, thereby providing training for smallholder farmers with technical knowledge on handling practices which could empower them to adopt new technology. Provision of up-to-date storage facilities and post-harvest handling tools such as hermetic storage and combined harvesters 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.

The study further revealed that post-harvest losses negatively impact the gross margin of smallholder rice farmers in Liberia. It shows that Lofa, Bong, Grand Bassa, and Nimba incurred higher reductions in their gross margins compared to other counties with an overall reduction of 39.79% valued at over 2.8 million Liberian Dollars. Reducing post-harvest losses with priority to these counties will not only increase rice outputs and productivity but also enhance the quality of grains produced for increased acceptability at the local market. Priority interventions should target improvements to market linkages and postharvest management practices. These may include further investments in road infrastructures to facilitate trade between producers and buyers, and training farmers in best postharvest management practices. The protection of domestically produced rice against imported rice could also be articulated to guarantee that producers can produce and sell their rice timely reducing post-harvest losses and at the same time having access to the domestic market at a fair price.

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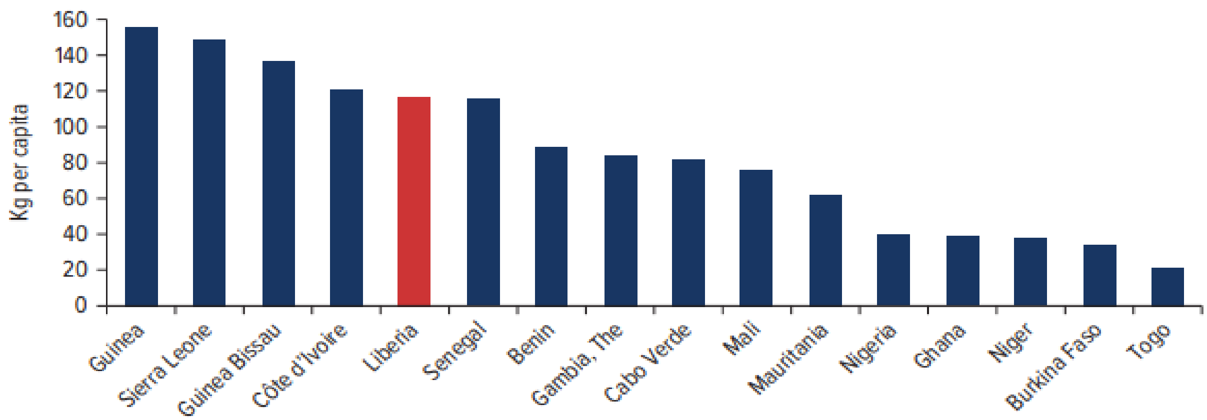
7. Appendices

7.1. Appendix 1: Income Distribution Per County and Percent Losses

Income Distribution per county and % Losses

Counties	*Average Gross Margin Without Loss*	*Average Gross Margin With Loss*	*% Loss*
Margibi	*6008.0356*	*3000.1606*	*49.9358*
Grand Kru	*4370.4082*	*1955.1021*	*44.735*
Sinoe	*11747.204*	*4513.061*	*38.4182*
Bomi	*23097*	*4275.75*	*18.5121*
Bong	*11512.82*	*6631.1538*	*57.598*
Grand Cape Mount	*12050.202*	*4729.1841*	*39.2457*
Grand Bassa	*2867.4348*	*4146*	*64.3781*
Lofa	*3844.8379*	*2140.8242*	*55.6805*
River Cess	*7110.9033*	*3724.1936*	*52.373*
Maryland	*8782.333*	*2678.7917*	*30.5021*
Rivergee	*9150*	*3823*	*41.7814*
Nimba	*3702.2656*	*2411*	*65.1223*
Gbarpolu	*10462.215*	*3122.9141*	*29.8495*
Grand Gedeh	*10709.68*	*2219.3396*	*20.7227*
Montserrado	*10513.982*	*3656.0876*	*34.7736*

7.2. Appendix 2: Annual Rice Consumption in West Africa.



Source: Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) and World Bank staff calculations.

7.3. Appendix 3: ANOVA Results.

Number of obs = 5,761   R-squared = 0.0228
Root MSE = 12.9031   Adj R-squared = 0.0218

Source	Partial SS	df	MS	F	Prob>F
Model	22323.856	6	3720.6426	22.35	0.0000
PH_Stages	22323.856	6	3720.6426	22.35	0.0000
Residual	957978.9	5,754	166.48921		
Total	980302.75	5,760	170.19145		

7.4. Appendix 4: Tuckey Pairwise Comparison for Losses along the Rice Value Chain.

Pairwise comparisons of marginal linear predictions

Margins : asbalanced

	Margin	Std. Err.	Unadjusted Groups
PH_Stages			
Harvest	9.344075	.4160117	
Threshing	4.574468	.4564778	A
Drying	5.188425	.4733677	A
Processing	4.730667	.4711535	A
Transportation	5.172216	.4372038	A
Packaging	7.046512	.419515	
Marketing	2.826087	.4912115	

Note: Margins sharing a letter in the group label are not significantly different at the 5% level.

7.5. Appendix 5: Homogeneity Test for Equal Variances.

Analysis of Variance

Source	SS	df	MS	F	Prob > F
Between groups	26.6162573	36	.73934048	3.17	0.0000
Within groups	1336.52521	5724	.233494971		
Total	1363.14147	5760	.236656505		

Bartlett's test for equal variances: chi2(26) = 20.9298 Prob>chi2 = 0.746

note: Bartlett's test performed on cells with positive variance:
5 single-observation cells not used
5 multiple-observation cells not used

7.6. Appendix 6: Tuckey Pairwise Comparison for Losses in Various Counties.

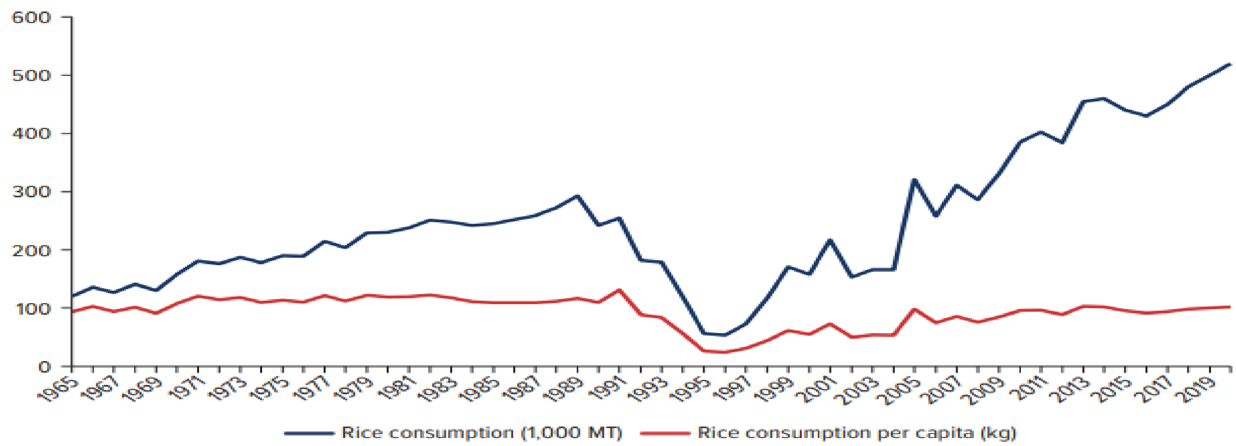
Pairwise comparisons of marginal linear predictions

Margins : asbalanced

	Margin	Std. Err.	Unadjusted Groups
Counties			
Margibi	3.379845	1.053577	ABC
Grand Kru	2.965753	.7002769	BC
Sinoe	2.022989	.5737419	ABC
Grand Bassa	10.71378	.7113249	E
Grand Cape Mount	1.449838	.6807411	AB
Rivercess	1.295964	.4626453	A
Lofa	18.13946	.4934834	
Bomi	1.188377	.5356868	A
Bong	12.11203	.7708195	E
Maryland	3.622318	.7839408	C
RiverGee	3.139535	1.053577	ABC
Nimba	6.794776	.516867	D
Gbarpolu	1.973129	.5242547	ABC
Grand Gedeh	7.481625	.5262789	D
Montserrado	7.036842	.6138601	D

Note: Margins sharing a letter in the group label are not significantly different at the 5% level.

7.7. Appendix 7: Trends in Rice Consumption and Consumption Per Capita (1965 – 2020).



Source: Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) and World Bank staff calculations.

7.8. Appendix 8: Logit Estimate

Logistic regression	Number of obs	=	823
	LR chi2(18)	=	314.07
	Prob > chi2	=	0.0000
Log likelihood = -226.11838	Pseudo R2	=	0.4099

PHL_loss	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
gender	.0331288	.2709886	0.12	0.903	-.4979991	.5642567
Age_02						
25-54	1.08836	.4898374	2.22	0.026	.1282966	2.048424
55-64	1.737522	.6055588	2.87	0.004	.5506488	2.924396
65-Above	2.278013	1.128896	2.02	0.044	.0654166	4.490609
Household_Size_01	-.0608827	.0235824	-2.58	0.010	-.1071034	-.014662
Marital_status						
Widow(er)	.2616004	.5163145	0.51	0.612	-.7503574	1.273558
Divorced	-.5055312	.6492815	-0.78	0.436	-1.778099	.7670371
Single	-.3570281	.5032871	-0.71	0.478	-1.343453	.6293966
Education_level						
Complete Primary	-.7754843	.8068523	-0.96	0.336	-2.356886	.8059172
Complete Secondary	-.4410725	.8254819	-0.53	0.593	-2.058987	1.176842
Complete College/University	-.7783797	.8629961	-0.90	0.367	-2.469821	.9130616
Harvest_Days_01	.0130121	.0052738	2.47	0.014	.0026757	.0233485
PH1_training	2.782153	.2626513	10.59	0.000	2.267366	3.29694
PH1_Season	1.787056	.3672758	4.87	0.000	1.067209	2.506904
Storage_Mothod						
Bags	-.9360191	.3000382	-3.12	0.002	-1.524083	-.347955
Silo	-.3890485	.5870077	-0.66	0.507	-1.539562	.7614655
Warehouse	.3072463	.5495992	0.56	0.576	-.7699483	1.384441
Harvest_Method_	.0218149	.0096195	2.27	0.023	.002961	.0406688
_cons	-6.260482	1.186485	-5.28	0.000	-8.585949	-3.935014

7.9. Appendix 9: Logistic Estimate

Logistic regression	Number of obs	=	823
	LR chi2(18)	=	314.07
	Prob > chi2	=	0.0000
Log likelihood = -226.11838	Pseudo R2	=	0.4099

PHL_loss	Odds Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
gender	1.033684	.2801165	0.12	0.903	.6077455	1.758141
Age_02						
25-54	2.969401	1.454523	2.22	0.026	1.13689	7.755667
55-64	5.683244	3.441538	2.87	0.004	1.734378	18.62297
65-Above	9.75727	11.01495	2.02	0.044	1.067604	89.17571
Household_Size_01	.9409336	.0221895	-2.58	0.010	.8984328	.9854449
Marital_status						
Widow(er)	1.299007	.6706963	0.51	0.612	.4721978	3.573545
Divorced	.6031851	.3916369	-0.78	0.436	.1689589	2.153377
Single	.6997528	.3521766	-0.71	0.478	.2609431	1.876478
Education_level						
Complete Primary	.4604807	.3715399	-0.96	0.336	.0947147	2.238749
Complete Secondary	.6433461	.5310706	-0.53	0.593	.1275831	3.244114
Complete College/University	.4591494	.3962441	-0.90	0.367	.0846	2.49194
Harvest_Days_01	1.013097	.0053428	2.47	0.014	1.002679	1.023623
PHl_training	16.15376	4.242806	10.59	0.000	9.653935	27.0298
PHl_Season	5.971847	2.193315	4.87	0.000	2.907254	12.26689
Storage_Mothod						
Bags	.392186	.1176708	-3.12	0.002	.2178206	.7061306
Silo	.6777014	.3978159	-0.66	0.507	.2144749	2.141412
Warehouse	1.359676	.7472767	0.56	0.576	.463037	3.992593
Harvest_Method_	1.022055	.0098316	2.27	0.023	1.002965	1.041507
_cons	.0019103	.0022666	-5.28	0.000	.0001867	.0195454

7.10. Appendix 10: Marginal Effects

```
. margin, dydx (*)

Average marginal effects                    Number of obs     =        823
Model VCE     : OIM
```

	Delta-method dy/dx	Std. Err.	z	P>|z|	[95% Conf.	Interval]
gender	.0027147	.0222039	0.12	0.903	-.0408041	.0462336
Age_02						
25-54	.1040792	.0532557	1.95	0.051	-.0003001	.2084585
55-64	.1531474	.0581863	2.63	0.008	.0391042	.2671905
65-Above	.1872649	.0780861	2.40	0.016	.0342189	.340311
Household_Size_01	-.004989	.0019083	-2.61	0.009	-.0087292	-.0012488
Marital_status						
Widow(er)	.0206285	.0393466	0.52	0.600	-.0564894	.0977464
Divorced	-.044274	.0606571	-0.73	0.465	-.1631597	.0746117
Single	-.0306401	.0451016	-0.68	0.497	-.1190377	.0577575
Education_level						
Complete Primary	-.0592611	.0552279	-1.07	0.283	-.1675059	.0489837
Complete Secondary	-.032048	.0565876	-0.57	0.571	-.1429577	.0788618
Complete College/University	-.0595079	.0610361	-0.97	0.330	-.1791364	.0601205
Harvest_Days_01	.0010663	.0004267	2.50	0.012	.0002299	.0019026
PHl_training	.2279822	.0155	14.71	0.000	.1976028	.2583615
PHl_Season	.1464395	.028401	5.16	0.000	.0907745	.2021045
Storage_Mothod						
Bags	-.0796773	.0248814	-3.20	0.001	-.1284439	-.0309108
Silo	-.0302786	.0478739	-0.63	0.527	-.1241097	.0635524
Warehouse	.0211455	.0366162	0.58	0.564	-.0506208	.0929119
Harvest_Method_	.0017876	.0007829	2.28	0.022	.0002532	.0033221

Note: dy/dx for factor levels is the discrete change from the base level.

7.11. Appendix 11: t-test Results for Gross Margin Analysis

```
. ttest profit=Vphl

Paired t test
```

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
profit	823	8826.114	1006.77	28882.21	6849.971	10802.26
Vphl	823	3512.475	151.9103	4357.999	3214.297	3810.653
diff	823	5313.639	1001.141	28720.7	3348.546	7278.733

```
    mean(diff) = mean(profit - Vphl)                          t =   5.3076
 Ho: mean(diff) = 0                          degrees of freedom =      822

 Ha: mean(diff) < 0           Ha: mean(diff) != 0            Ha: mean(diff) > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```