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Post-Harvest Losses and Food Stability Among Groundnut and Rice Farmerzs in Benue State: The Moderating Role of Storage Technology Adoption

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Abstract

This study examined the effects of post-harvest losses (PHL) and storage technology adoption (STG) on food stability among 395 groundnut farming households in Benue State, Nigeria, using Structural Equation Modelling (SEM). Results indicate that PHL significantly reduced food stability (β=-0.135,p<0.001),, while STG had a strong positive effect (β=0.574,p<0.001). The interaction term (PHL × STG) was also significant (β=-0.045,p=0.012), confirming a moderating role. However, the negative interaction coefficient reveals that storage technology alone cannot fully neutralize losses accumulated prior to storage during harvesting, drying, and handling. Additionally, food accessibility enhanced stability (β=0.260,p<0.001), whereas climate change reduced it (β=-0.156,p<0.001). The study concludes that improving food stability requires integrated post-harvest management and recommends investments in modern storage, capacity building, and climate-resilient infrastructure across the entire value chain.

Keywords: *Post-harvest losses, Food stability, Storage technology, Structural equation modelling, Benue State*

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Background to the Study

In the agrarian landscape of North-Central Nigeria, the paradox of "plenty amidst scarcity" remains a persistent challenge for smallholder households. Benue State, recognized as the nation's "Food Basket," contributes significantly to the total output of rice and groundnut production. However, the seasonal nature of these crops, combined with high perishability and inadequate post-harvest management, often translates into a precarious state of household food security (Kughur et al., 2015). While substantial academic and policy attention has been directed toward increasing agricultural yields, the critical question of how households maintain food stability—the consistent availability of and access to food across seasons—remains largely tied to the efficacy of storage systems (Denny et al., 2018). Post-harvest losses (PHL) in rice and groundnut value chains are not merely physical waste; they represent a significant economic shock that erodes household resilience. Omobowale et al. (2021) attribute these losses to chemical changes, microbial attacks, and poor handling during distribution. When farmers experience high losses due to pests, moisture, or mold, they are often forced into "distress selling"—the practice of disposing of produce immediately after harvest at depressed market prices to avoid total loss (Ogunjobi, 2024). This cycle prevents households from utilizing their harvest as a buffer during the lean season, thereby undermining the stability dimension of food security.

Theoretically, storage technology is conceptualized as a "technological ladder". At the base are traditional storage systems, such as mud granaries and earthen pits, which are culturally rooted but offer limited protection against the biological and climatic drivers of PHL (Asom, 2016). At the higher tiers are improved and modern technologies, including hermetic (PICS) bags, solar-powered dryers, and metal silos, which create a resilient barrier against environmental stressors (Abraham et al., 2023). Despite extensive literature on agricultural post-harvest management in Nigeria, existing studies suffer from significant conceptual and methodological limitations. Most empirical investigations (e.g., Agboola & Williams, 2023; Ogundele, 2022; Ojiya et al., 2021) focus primarily on physical loss volumes, economic revenue loss, or general food security, largely ignoring food stability—the temporal capacity of households to sustain food access without seasonal disruptions. Furthermore, prior studies rely predominantly on basic regression techniques that treat post-harvest factors in isolation, failing to examine the complex structural pathways and moderating role of storage technology adoption within holistic household food systems. Consequently, it remains unclear whether modern storage adoption can effectively "buffer" households against loss-induced instability when crop decay occurs earlier in the post-harvest value chain. To bridge these empirical and analytical gaps, this study utilizes Structural Equation Modeling (SEM) to evaluate the interactions between post-harvest losses, storage technology adoption, and food stability among farming households in Benue State. Specifically, the study seeks to:

1. Evaluate the direct effect of post-harvest losses on household food stability.
2. Assess the direct influence of storage technology adoption on household food stability.
3. Investigate the moderating role of storage technology adoption in the relationship between post-harvest losses and food stability.

The remainder of this paper is organized as follows: Section 2 outlines the theoretical framework, conceptual definitions, and empirical literature review. Section 3 details the research methodology, sampling design, and Structural Equation Modeling (SEM) specification. Section 4 presents the empirical results and discusses the key statistical findings. Finally, Section 5 concludes the paper with policy implications, actionable recommendations, study limitations, and directions for future research.

Literature Review

Conceptual Clarification

Post-harvest Losses: The definition of Post-Harvest Loss (PHL) has transitioned from a simple measurement of physical waste to a comprehensive, multidimensional framework: Foundational definitions emphasize the measurable decline in both the physical volume and the nutritional/aesthetic quality of food from harvest to consumption (Kader, 2002; FAO, 2011). Modern perspectives expand the concept to include the environmental and institutional causes of loss, such as inadequate infrastructure and technological obsolescence (Aulakh & Regmi, 2013). Recent discourse incorporates a behavioral dimension, suggesting that loss is influenced by the management choices and individual characteristics of the practitioners involved (Hu, Wang, & Zhu, 2017). Synthesizing these perspectives, this study adopts the framework of Bendinelli et al. (2019) but introduces the concept of "economic death" to prioritize food security. PHL is operationally defined as the volume of crops measured in bags, basins, and mudus lost to spoilage or contamination to the extent that they are unfit for human consumption. Crucially, any produce diverted for secondary use as animal feed is still recorded as a total loss, as its primary value as a human staple has been extinguished.

Food Crop Production: The definition of food crop production has evolved from a botanical classification based on human sustenance (Britannica, 2021) to a process-oriented view focusing on the farmer's labor and planting intent (Asuakoh et al., 2018). However, for empirical measurement, this study synthesizes the volumetric approach of scholars like Ogundari (2013) and Chikezie et al. (2019), defining production as a time-bound result rather than an ongoing process. Operationally, this research treats food crop production as the total harvested yield of rice and groundnuts within a single cropping cycle in Benue State. By prioritizing the final volume quantified through local units like bags, basins, and mudus the study establishes a precise baseline to measure subsequent post-harvest losses and assess their impact on regional food security and economic stability.

Food Security: The paradigm of food security has evolved from a macro-level focus on national stocks to a household-centered, multidimensional approach. Rooted in the FAO (1996) definition, food security is achieved only when all individuals have consistent physical and economic access to safe, nutritious food. This study evaluates the impact of post-harvest losses (PHL) on food Stability.

Food Stability: Food stability addresses the temporal dimension of food security, the assurance that availability, access, and utilization remain consistent over time without disruption by shocks. Chambers and Conway (1992) link stability to the concepts of resilience and vulnerability, noting that a household may be secure today but insecure tomorrow due to unexpected negative events. In the context of Benue State, stability is threatened by insecurity and the unpredictable effects of climate change, such as irregular rainfall patterns leading to crop failure. Maxwell and Smith (1992) clarify that food insecurity in such regions is often transitory, manifesting as a stability crisis where food is abundant during the harvest but scarce during the lean season. Stability is conceptually dependent on the other three dimensions; a stable system must possess consistent availability and reliable access. Consequently, this study views effective storage technology as a proactive measure for smoothing the supply of food across seasons, thereby transforming a volatile harvest into a stable food system (FAO, 2014).

Farming Households: In agricultural economics, the farming household is conceptualized as a unified socio-economic unit where production, consumption, and labor decisions are inextricably linked (Low, 1986). Moving beyond the individual practitioner, this study views the household as a coordinated group that pools resources, manages shared land, and shares meals from a common pot (Ellis, 1993; Meeker & Meekers, 1997). Operationally, the farming household in Benue State is defined as a co-residential unit making joint decisions on the disposal of rice and groundnut harvests. By adopting this collective framework, the research ensures that food security is measured by the household's total capacity to manage risk and preserve its harvested volume to meet the nutritional and economic needs of all its members.

Storage Technology Adoption: This refers to the use of improved storage technology (e.g., PICS bags, silos).

Theoretical Framework

This research adopts a triangulated theoretical architecture by synthesizing three theories. First, the Theory of Constraints (TOC) pioneered in 1984 by Eliyahu M. Goldratt, positing that any complex system, be it a manufacturing plant or an agricultural value chain is governed by a singular binding constraint that prevents the system from achieving more of its goal (Goldratt, 1984). Goldratt's framework introduces a paradigm shift from local efficiencies to system throughput**.** The theory contends that traditional management often fails by attempting to optimize individual segments of a process in isolation. The second theory is the Entitlement Theory of Famine (ETF) developed in 1981 by Amartya Sen, the theory represents a paradigm shift from Food Availability Decline (FAD) to Food Entitlement Decline (FED), the theory contends that hunger is a characteristic of some people not having enough food to eat, rather than there being not enough food to eat (Sen, 1981). It is built on the concept of the entitlement set, the range of all possible commodity bundles that a person can command given their endowments (land, labor, assets) Sen identifies four categories of entitlement relations:

First, is the endowment vector, which represents all the resources an individual or household owns, this includes land, labour, seeds, and the physical harvest. The Second is the entitlement set which is the collection of all possible commodity bundles (food and non-food items) that a person can command using their endowments, this means the household can access any bundle of goods that their resources allow through production, trade, or transfers. Third is the exchange entitlement mapping (E-mapping), the function of the mapping) is the most critical part of this thesis. It represents the exchange rate at which endowments are converted into food access. These include; production-based entitlement: converting land and labour into crops, trade-based entitlement: selling the crop to buy other food and then the own-labor entitlement**:** Selling labour for wages to buy food. Lastly, is the inheritance/transfer entitlement: command over food given by others or the state**.** The third theory is the High Payoff Input Model (HPIM) articulated by Theodore W. Schultz in his 1964 landmark book, transforming traditional *a*griculture. Schultz's work was a direct challenge to the prevailing peasant irrationality myths of the time. He argued that traditional farmers in developing nations are poor but efficient. They are rational economic agents who have optimized their resources within the limits of their traditional technology; however, they have reached a technological ceiling where the marginal return on additional labour or traditional land use is near zero. The model posits that agricultural transformation and economic growth cannot be achieved by merely reallocating traditional factors of production. Instead, it requires the introduction of high-payoff inputs (Schultz, 1964).

These three theories ensure that the subsequent Structural Equation Modelling (SEM) is not merely a statistical exercise but is grounded in established economic logic. The relationship among the three theories is complementary, sequential, and centered on the achievement of food stability through the reduction of post-harvest losses. The Theory of Constraints (TOC) identifies post-harvest loss as the major bottleneck limiting stable food supply in the agricultural system. Although farmers in Benue State produce substantial quantities of food, weak storage and preservation systems interrupt the continuous flow of food from harvest to consumption. This creates instability in food availability across seasons. The Entitlement Theory of Famine (ETF) explains the socio-economic consequences of this bottleneck. Once post-harvest losses occur, households lose part of their food stocks and income, thereby weakening their entitlement to food. The result is unstable household food access, seasonal hunger, and increased vulnerability during periods of scarcity. And the High-Payoff Input Model (HPIM) provides the corrective mechanism for overcoming these problems. The theory argues that adoption of improved post-harvest technologies can significantly reduce spoilage, preserve food quality, stabilize household income, and ensure continuous food availability throughout the year. Collectively, the three theories establish that food stability is not determined solely by agricultural production, but by the efficiency of post-harvest management systems, the strength of household food entitlements, and the adoption of modern storage and preservation technologies. The theories therefore provide a strong conceptual basis for examining how reductions in post-harvest losses can improve food stability, among groundnut and rice farming households.

Empirical Review

Abubakar and Smith (2025) evaluated the effectiveness of government agricultural inputs in mitigating food insecurity among cereal farmers in north-central Nigeria. The findings revealed that although government agricultural inputs boosted initial output, gains were largely neutralized by post-harvest spoilage. Musa and Ibrahim (2024) explored the nexus between communal insecurity and household food entitlements among grain farmers in Benue

State. The results indicated that insecurity significantly restricts land access leading to an entitlement failure. Okoro, Yusuf, and Bello (2024) investigated the influence of climate volatility on groundnut value chains and household stability in the middle belt region of Nigeria. The research found that erratic rainfall resulted in mean post-harvest losses that exceeded safety benchmarks.

Agboola and Williams (2023) examined the impact of post-harvest loss management on the food security status of rice farmers in north-central Nigeria, specifically focusing on Benue and Nasarawa States. Employing descriptive statistics and a probit regression model, the findings revealed that inadequate storage technology and poor transportation networks were the primary binding constraints significantly increasing losses. An empirical study by Obayelu, Dairo, and Olowe (2022) investigated postharvest loss (PHL) in the orange value chain, employing a logit regression technique to determine key factors and correlation levels. The research noted a distinct gender distribution, with men dominating farming and women dominating marketing. Findings showed PHL levels were generally 6–10% for farmers and wholesalers, dropping to under 5% for nearly half of the retailers (46.79%).

Debebe (2022) utilized a national agricultural survey data from the Central Statistical Agency of Ethiopia using descriptive statistics and a Tobit model, to assess the magnitude and determinants of all crop post-harvest losses (PHL) in the country. The analysis revealed a significant variation in PHL across different crop types and an overall average annual loss rate. Key factors identified as barriers to PHL (meaning they increased losses) included larger adult family sizes, higher education and wealth status, large landholding sizes, and damage caused by insect or rodent infestation due to the use of traditional storage equipment. A recent study conducted by Ibrahim, et al. (2022) in Katsina State explored the effects of post-harvest loss (PHL) on household food security, analysing data from 240 farming households across the state. Their results showed that the principal food crops with significant PHL were sorghum, millet, maize, and cowpea. Specific loss stages included sorghum during threshing and storage; cowpea during storage; maize during drying and storage; and millet during threshing and harvest. The primary causes of loss were spillage and inadequate storage for millet, and theft and spills for maize. A study conducted by Bamikole, Tahirou, and Richardson (2022) investigated cassava post-harvest losses (PHL) in South-West Nigeria, gathering data from farming households on their experience with PHL in cassava production and processing. The researchers found that 96% of farmers reported PHL from harvest through selling, with the average loss of farmed cassava being 13%. Interestingly, improved varieties suffered more losses than local varieties, and more cassava was lost during the dry season than the wet season. Research by Acheampong et al. (2022) conducted an unbiased assessment of food security and identified its influencing factors in Ghana. Findings showed that while the majority of farm households in Ghana had appropriate levels of food consumption, a significant portion remained threatened by food insecurity, with approximately 19% falling into the borderline consumption category and 6% falling into the low food consumption category.

Research by Ogundele (2022) studied post-harvest loss (PHL) and food security in Nigeria, with the underlying assumption that PHL reduction would improve food security. The researcher utilized descriptive statistics for analysis and found that crop loss is typically caused by farm-to-market transportation, packaging, repackaging, and storage and warehousing activities. Specific losses included rice and maize suffering the highest losses during transportation, cowpea experiencing the greatest loss from packaging and repackaging, and yam suffering the highest percentage loss due to inadequate storage. Odeyemi, et al (2021) analyzed the costs and benefits of improved post-harvest techniques and technologies aimed at reducing losses in the tomato value chain in Nigeria, Rwanda, and India. In Rwanda, using a colour chart as a maturity indicator better protected tomatoes from mechanical damage during handling, resulting in an immediate profit increase of US$170 per 1000 kg cargo compared to fully ripe harvesting. In Nigeria, using a Zero Energy Cooling Chamber (ZECC) reduced tomato loss to 5%, a significant improvement over the current practice of immediate sale, which incurred a 40% loss. The use of Reusable Plastic Crates (RPC) and the simple ZECC technology in Rwanda enhanced the farmer/trader income by reducing loss from 30 to 10%. Conversely, India frequently used maturity indices and RPCs for harvesting and transportation, leading to decreased PHL during marketing.

A study conducted by Strecker, et al. (2021) aimed to pinpoint loss hotspots, causes, and impacts throughout the value chains of nightshade and bush beans in eastern Uganda. Using descriptive statistical techniques, the study found that the bush bean value chain incurred severe physical and qualitative losses during post-harvest handling by farmers, leading to high economic losses at this stage. A study conducted by Ohagwu, et al. (2021) focused on the post-harvest technological evaluation of various tomato storage environments/media for the home preservation of fresh tomato quality to increase its shelf life in Nsukka, Nigeria. They found that the Refrigerator (FR) and Room Freezer exhibited higher quality and longer shelf lives based on physicochemical parameters over seven days, with FR storage particularly effective at inhibiting/delaying ripening and achieving the least weight loss, often by inducing "cold stress." Goka et al. (2021) assessed the factors that contribute to post-harvest losses (PHL) in the production of tomatoes in Togo. The research revealed exceptionally high seasonal losses, with 42% of tomatoes lost during the major season and a dramatic 90% lost during the minor season. The regression analysis found that PHL was strongly correlated with female farmer gender, farm size, and the number of days in storage. The nature of postharvest losses of rice in Makurdi local government area of Benue State was explored by Okadonye, et al (2021). The study looked primarily at the stages of rice postharvest losses. The results of the study showed that rice postharvest losses are natural and occur at every stage, from harvest to consumption, with threshing recording the largest loss. The overall losses, however, range from 37% to 40% for all stages.

Employing a survey research design on a sample of 204 yam farming households in Benue State, Agba, Nwafor, and Lamin (2021) assessed the determinants of yam post-harvest losses (PHL). Data, gathered using semi-structured questionnaires and focused group discussions, were analysed with descriptive statistics and inferential multiple regression analysis. The research established that PHL is fundamentally caused by a combination of mechanical and environmental factors. Specific issues highlighted were pest and disease attacks, inappropriate storage practices, poor handling, lack of adequate transportation, theft, political crisis-related destruction, and exposure to intense sunlight. In Ukum local government area of Benue State, Nigeria, Ojiya, Andohol, and Doki (2021) assessed post-harvest losses and their consequent impact on the welfare of yam producers. The study discovered that inadequate storage facilities for farmers, insufficient measures to control pests and diseases, and other factors are the main obstacles facing farmers in their attempts to reduce post-harvest losses. The empirical findings also showed that post-harvest losses had a negative impact on farmers' welfare and revenue. This study also fails to link post-harvest losses to food security.

Assane and Komarek (2020) investigated the extent of on-farm post-harvest losses (PHL) for three vegetables in Senegal; onion, tomato, and pimento. Their findings indicated that about 30% of vegetable production is typically lost on the farm, and mitigating these losses could result in a significant 45% (US $72 million) annual boost to the overall value of the vegetable supply and a 22% (127,000 tons) annual drop in vegetable imports; furthermore, they emphasized that successful investment prioritization in loss reduction requires accounting for both the private costs to farmers and the public costs to the government associated with these decreases. The reviewed empirical studies revealed that post-harvest losses (PHL) remain a major challenge affecting agricultural productivity, household welfare, and food security across developing economies. However, despite the extensive literature on post-harvest losses, significant conceptual and methodological gaps still exist regarding the relationship between post-harvest losses and food stability. Conceptually, most of the reviewed studies focused on the effects of post-harvest losses on agricultural output, farmer income, welfare, or general food security without specifically examining their implications for food stability. Studies such as Agboola and Williams (2023), Ogundele (2022), and Okadonye et al. (2021) concentrated mainly on storage challenges, transportation constraints, and stages of post-harvest losses, while Ojiya, Andohol, and Doki (2021) emphasized welfare effects among yam farmers. Similarly, Acheampong et al. (2022) focused on food consumption patterns, and Musa and Ibrahim (2024) examined insecurity and household entitlements. Although these studies discussed food security broadly, they failed to explicitly analyze food stability, which concerns the ability of households to maintain continuous access to adequate food over time without seasonal shortages or disruptions. This creates a conceptual gap because food stability remains a critical but underexplored dimension of food security in agrarian economies where high harvest volumes often coexist with seasonal hunger due to poor post-harvest management.

Methodologically, most of the reviewed studies employed descriptive statistics, probit regression, Tobit models, logit regression, and multiple regression techniques. While these approaches are useful for identifying determinants of post-harvest losses, they are limited in explaining the complex and interconnected pathways through which post-harvest losses affect food stability. Studies such as Debebe (2022), Obayelu, Dairo, and Olowe (2022), and Agboola and Williams (2023) analyzed relationships in isolation and did not adequately capture the interactions among storage constraints, market access, household food reserves, seasonal shortages, and food stability outcomes. The present study fills these gaps by specifically examining the effect of post-harvest losses on food stability among farming households. The study further adopts Structural Equation Modelling (SEM), which enables simultaneous analysis of the direct and indirect relationships between post-harvest losses and food stability while accounting for the multidimensional and interconnected nature of household food systems.

Methodology

Research Design: The study adopted a cross-sectional survey design. This design was chosen because it allowed for the collection of data on all variables; various levels of post-harvest losses, socio-economic characteristics, and food security status from a representative sample of farming households in Benue State at a single point in time, that is the 2023/2024 agricultural cycle. This approach was effective for describing the prevalence of PHL and assessing its relationship with food stability.

The Study Area: Benue State, popularly known as the "Food Basket of the Nation," is situated in the Middle Belt region of Nigeria between Longitudes 7^∘ 47'"E" and 10^∘ 00'"E" , and Latitudes 6^∘ 25'"N" and 8^∘ 08'"N". It is bordered by Nasarawa State to the North, Taraba State to the North-East, Kogi State to the West, and Ebonyi, Enugu, and Cross River States to the South. Notably, the state shares an international southeastern boundary with the Republic of Cameroon. The state's landscape is dominated by the River Benue and its principal tributary, the Katsina-Ala River. While the region boasts a high drainage density, many smaller streams are seasonal, leading to localized water supply fluctuations during the dry season. However, extensive riverbanks, seasonal swamps, and ponds provide significant potential for dry-season fadama farming, irrigation, and aquaculture (Benue State Economic Empowerment and Development Strategy [BENSEEDS], 2004).

Sample Size Determination: The population size for rice and groundnut farming households in Benue State was considered unknown and infinitely large for the purpose of statistical calculation. Consequently, the appropriate sample size for the study was determined using Cochran's (1963) formula for estimating a proportion in a large population.

$$n = \frac{Z^2\ PQ}{e^2}$$

Where:
n = the calculated sample size.
Z = the standard normal deviate corresponding to a 95% confidence level, valued at 1.96
P = the estimated proportion of the population exhibiting the characteristic (maximum variability), set at 0.5.
Q = 1-P = 1- 0.5 = 0.5
e = sampling error at 5%

Substituting these values into the formula yielded the required statistical sample size:
Thus, the study sample size is as:

$$n = (1.96)^2 (0.5 * 0.5) / 0.05^2$$
$$= 0.9604 / 0.0025$$
$$= 384.16$$

The minimum calculated sample size was approximately 384 farming households. To ensure the statistical power of the analysis, account for potential non-response or poorly completed questionnaires during the field survey, and facilitate equal proportional allocation across the sampling units, a deliberate buffer margin of 24 was added to the calculated size.

$n = 384 + 24 = 408$

Therefore, the final sample size for the study was set at 408 farming households. This size was conveniently divisible by the twelve (12) council wards selected from six LGAs of the state- Ukum, Kwande, in zone A, Buruku and Guma in zone B and Agatu and Obi in zone C, a multi-stage sampling was used ensuring that each council ward was allocated an equal number of 34 respondents (408 / 12 = 34). However, only 395 were completely filled and retained for empirical estimation.

Method of Data Collection: Primary data was collected from 395 rice and groundnut farming households (68 per LGA) using a structured questionnaire and the recall method for the 2023/2024 season. To ensure high internal validity and minimize measurement error, this study avoids forcing farmers to estimate weights in kilograms, which are rarely used in local transactions. Instead, following Ani et al. (2013), it utilizes a local volumetric index (Vi**)** based on the standardized measurements mandated by the 2023 Benue State Executive Directive (Aar, 2024). The study utilized local unit of measurement, farmers output and losses were collected using the standard Benue bag size (28 x 47) containing 3 basins and each basin containing 30 Nigerian mudus as the base unit for the volumetric index, following the industrial specifications currently advocated by the Benue State Ministry of Industry, Trade, and Investment (Aar, 2024). Trained enumerators captured data across six specific stages: harvesting, threshing, winnowing, drying, transportation, and storage. By adopting these contextually accurate units, the research aligns with current legal standards and eliminates the "measurement noise" typical of field-level conversions.

Method of Data Analysis: The analytical framework for this study employs a multi-staged statistical approach designed to bridge field-level observations with systemic theoretical modelling. This process begins with data cleaning and volumetric standardization to harmonize local measurement units, followed by descriptive statistics of the respondents to establish their socio-economic and production profile. Following these preliminary assessments, the research employs Structural Equation Modelling (SEM) to evaluate the complex, interlinked relationships between post-harvest drivers and food stability. By integrating descriptive profiling, and SEM path analysis, the study ensures a rigorous evaluation of the theory of constraints, identifying both the magnitude of losses and the specific systemic bottlenecks that impede household entitlements.

Structural Equation Modelling (SEM): The study employs Structural Equation Modelling (SEM), specifically a path analysis, to estimate the complex and simultaneous relationships among the post-harvest losses, selected control variables, and food stability.

Model Specification: The structural model specifies the hypothesized causal pathways between the latent variable as follows:

$$FST= \lambda_0+\lambda_1\ PHL+\lambda_2\ STG+\lambda_3\ PHLSTG+\lambda_4\ UMP+\lambda_5\ STG+\lambda_6\ FAC+\lambda_7\ FUT+ \lambda_8\ HHS+ \lambda_9\ COF+\varepsilon_4$$

Where:
FST =Food Stability, PHL= Post-harvest Losses, FAC = Food Accessibility, FUT = Food Utilization, COF = Food Prices, HHS = Household size, STG = Storage Technology Adoption, CLC = Climate Change and UMP = Unemployment,
λ_0 = Intercept
$\lambda_1 + \lambda_7$ = parameters to be estimated

The Food Stability (FST) equation serves as the temporal stress test for household resilience against systemic shocks and leaks. Grounded in the Theory of Constraints (TOC) and Entitlement Theory, the model posits that stability is a function of consistent access (FAC) and nutritional quality (FUT). It treats market volatility (COF) and unemployment (UMP) as economic entitlement shocks while identifying climate change (CLC) as a primary external constraint. Crucially, the model tests the central hypothesis: that adopting high-payoff storage technology (STG) can successfully "elevate" the post-harvest loss (PHL) constraint, transforming a seasonal harvest into a stable, year-round food supply. This is depicted on the SEM diagram in Figure 1.

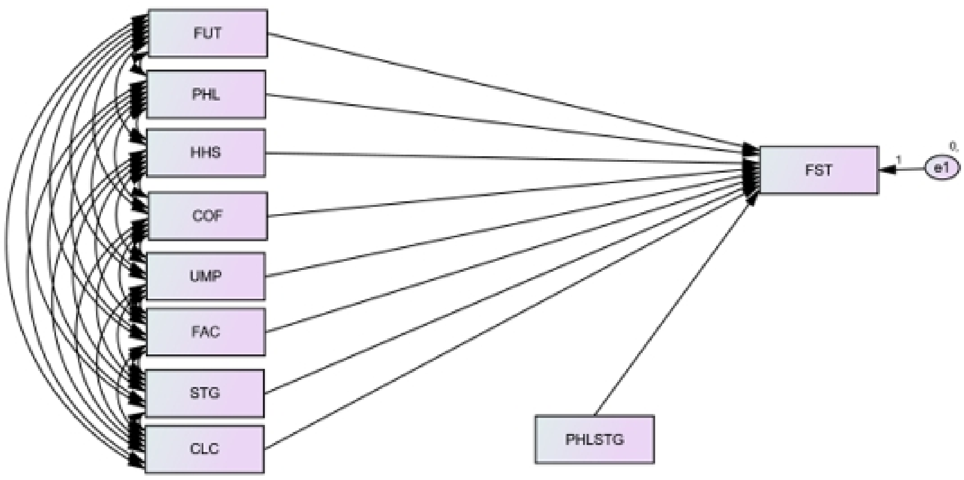

Figure 1: SEM Diagram

Operationalization of Variables
The variables in the model are operationalized in Table 1

Table 1: Operationalization of Variables

Variable (Symbol)	**Operational Definition**	**Measurement Unit / Scale**	**Theoretical Mapping**
Post-harvest Loss (PHL)	Volume of rice and groundnut lost after harvest.	Bags /Basins/ Mudus across all phases	TOC: The Binding Constraint.
Food Accessibility (FAC)	Meal Frequency: A proxy for the household's economic ability to command food daily.	Number of daily meals consumed by the household.	Entitlement theory of famine: reflects the household's exchange mapping and economic power.
Storage Technology Adoption (STG)	Use of improved storage (e.g., PICS bags, silos).	Binary (1=Improved, 0=Traditional)	HPIM: High Payoff Input.
Food Prices (COF)	Average daily per capita cost of meals.	Naira (₦) per person	TOC: Economic Bottleneck.
Unemployment (UMP)	Number of non-earning household dependents.	Ratio / Count	Sen: Entitlement Failure.
Household Size (HHS)	Total number of persons in the household.	Number of Persons	Logic: Labor Availability.
Climate Change (CLC)	Impact of erratic rainfall or temperature shifts.	An index on weather experience 0-1	TOC: External Constraint.
Food Utilization (FUT)	Nutritional quality: The degree to which the diet meets healthy standards.	WHO healthy diet compliance index (0–1): composite score based on 8 nutritional recommendations	Sen's capability theory measures functioning, the ability to convert food into health/well-being.
Food Stability (FST)	Systemic Resilience: The consistency of healthy access over time.	Composite Resilience Index (0–2): Calculated as the sum of FAC score (0–1) and FUT score (0–1).	TOC & Resilience: Measures the ultimate stability of the system and its ability to elevate seasonal constraints.

Source: Author's computation

Results and Discussion

This section presents the detail analysis and interpretation of the data collected to address the objectives of the study. The chapter includes the description of the socio-economic characteristics of the respondents, the selected farming households, the presentation and the interpretation of the Structural Equation Modelling (SEM) results.

Table 2: Socio-economic Characteristics of Respondents

Variable	Mean	Maximum	Minimum	Std. Dev	Frequency	Percentage
AGE	48.18	81.00	20.00	12.51		
HHS	8.61	30.00	2.00	4.35		
EXP	21.32	61.00	1.00	12.09		
LED	10.57	18.00	.00	4.40		
SEX	MALE				297	75.2%
	FEMALE				98	24.8%

Source: Field Survey, 2024

From Table 2, The mean age (AGE) of 48.18 years indicates that the study population is generally composed of middle-aged farmers. This group is typically experienced and in their productive prime, suggesting a strong capacity for farming activities. The relatively large standard deviation of 12.51 years shows a considerable spread in age. This is a common characteristic among farmers in Benue State as indicated in Uza et al. (2024), Obayelu et al. (2018) and Tarla et al. (2025). An indication from the table shows that, the respondents are highly experienced in farming with an average experience of 21.32 years. This high level of experience suggests a deep knowledge of local farming practices for crops like rice and groundnuts. This is also in line with the findings of Abah & Abah (2025).

The mean household size (HHS) of 8.61 persons confirms the prevalent pattern of large family sizes among rural farming households in Benue State This large size is often cited as an economic factor influencing both labor availability and food consumption as also indicated in Biam & Tav (2020). Table 1 also revealed a mean of 10.57 years of schooling. This suggests a relatively high level of formal education among the sampled farmers, with at least half completing secondary education. This is also reported in Agada *et al.* (2025) that, the majority of farmers in Benue State have basic education. The finding also shows that, majority of the respondents are Male (75.2%), this is a common feature of socio-economic studies conducted on farming households in Nigeria, where the male head is typically the primary respondent and decision-maker on farm matters. (Ogah & Akwubo, 2020).

Table 3: Descriptive Statistics of Volumetric Output and Stage-Specific Post-harvest Losses for Groundnut and Rice

Variable	Obs	Mean	Std. dev.	Min	Max	Obs	Mean	Std. dev.	Min	Max
	Groundnut Production (Output and Losses)					Rice Production (Output and Losses)				
FCP	345	12.25217	12.31031	1	75	347	15.32334	19.27202	1	170
PHL	345	1.471401	1.456757	0.088889	9.888889	347	1.840538	2.114172	0.011111	17.77778
HAP	345	0.22071	0.218514	0.013333	1.483333	347	0.184054	0.211417	0.001111	1.777778
THRP	345	0.14714	0.145676	0.008889	0.988889	347	0.460135	0.528543	0.002778	4.444444
WINP	345	0.102998	0.101973	0.006222	0.692222	347	0.220865	0.253701	0.001333	2.133333
DRP	345	0.36785	0.364189	0.022222	2.472222	347	0.092027	0.105709	0.000556	0.888889
TRP	345	0.044142	0.043703	0.002667	0.296667	347	0.055216	0.063425	0.000333	0.533333
STP	345	0.58856	0.582703	0.035556	3.955556	347	0.828242	0.951377	0.005	8

Note: The total sample for the study comprised 395 farmers. Of these, 48 farmers cultivated only groundnut, 50 farmers cultivated only rice, while 297 farmers cultivated both groundnut and rice. Consequently, the groundnut production analysis was based on 345 observations (48 + 297), whereas the rice production analysis was based on 347 observations (50 + 297). The overlap in observations reflects farmers who engaged in the production of both crops during the study period. FCP= Food Crop Production (in bags), HAP= Post-Harvest Losses during Harvesting Phase, THRP= Post-Harvest Losses during Threshing Phase, WINP= Post-Harvest Losses during Winnowing Phase, DRP= Post-Harvest Losses during Drying Phase, TRP= Post-Harvest Losses during Transportation Phase, STP= Post-Harvest Losses during Storage Phase, PHL=Post-harvest Losses.

Table 3 shows that rice production (Mean = 15.32 bags, SD = 19.27) is generally higher and more variable than groundnut production (Mean = 12.25 bags, SD = 12.31), indicating wider disparities among rice farmers in terms of farm size, input use, and production capacity. Post-harvest losses are also slightly higher for rice (Mean = 1.84 bags, SD = 2.11) than groundnut (Mean = 1.47 bags, SD = 1.46), suggesting that rice is more vulnerable to spoilage and handling inefficiencies. Harvesting losses are relatively similar for both crops, but rice records substantially higher losses during threshing, winnowing, transportation, and storage. In particular, threshing and storage constitute the major loss points for rice, reflecting challenges associated with grain handling, moisture content, and pest infestation. Conversely, groundnut experiences its highest losses during drying and storage, likely due to inadequate drying conditions and susceptibility to mold.

Overall, rice exhibits greater production variability and higher losses across most post-harvest stages, while groundnut losses are more concentrated in drying and storage. Despite these differences, the overall post-harvest loss ratio is approximately 12% for both crops, indicating similar levels of post-harvest efficiency but different patterns of vulnerability across the value chain.

The Food Stability Status of Groundnuts and Rice Farming Households in Benue State

As earlier indicated in the conceptual clarification section of this study, food stability is operationalised as the stability of food availability, accessibility, and utilization over time, specifically during the study period. To this end, it is measured here as the sum of food accessible and food utilized by a farm household within the period of study. The availability aspect is also captured in this context, as it is assumed to be inherently integrated into food accessibility, recognizing the fact that the number of times a farm household eat per day also defines the food that is available to them. Farm households are therefore assessed and scored accordingly. Measuring food stability (FST) as a composite index of accessibility (FAC) and utilization (FUT) provides a highly customized and robust indicator of holistic household food stability status. This section thus, presents the summary statistics and the categorical classification of farm households composite food stability score (FSS). The total sample size for this analysis is 408 farming households. The score ranges from a minimum of 0.25 to a maximum of 2.00, where a score of 2.00 signifies a fully food-stable household. The Statistics of the Composite Score is presented in Table 4.

Table 4: Composite Food Stability Score (FSS)

Statistic	Value
N (Sample Size)	408
Mean	1.25
Median	1.00
Mode	1.00
Standard Deviation	0.51
Minimum Score	0.25
Maximum Score	2.00

Food Stability is treated as a quasi-continuous variable ranging from 0.25 (lowest observed stability) to 2.00 (highest stability). The statistics showed a mean FSS of 1.25, which confirms that the average farm household is positioned in the lower-middle range of the scale. The Minimum Score of 0.25 indicates the presence of severely vulnerable farm households, while the Mode and Median of 1.00 confirms that the largest cluster of farm households experiences the critical state of moderate food instability.

Table 5: The effect of Post-Harvest Losses of rice and groundnut and other control variables on food stability among farming households in Benue State

Variables	Unstandardized Estimates	Standardized Estimates	S.E.	C.R.	P	Lower Critical Value	Upper Critical Value	Bias Corrected P value
FST<---COF	.038	.050	.026	1.465	.143	-.025	.115	.184
FST<---HHS	-.003	-.027	.002	-1.504	.132	-.068	.013	.170
FST<---CLC	-.186	-.156	.030	-6.231	***	-.201	-.115	.001
FST<---UMP	.026	.022	.021	1.197	.231	-.010	.059	.164
FST<---STG	.648	.574	.036	17.911	***	.515	.639	.001
FST<---FAC	.185	.260	.019	9.674	***	.189	.316	.002
FST<---FUT	-.005	-.041	.004	-1.214	.225	-.098	.028	.238
FST<---PHL	-.018	-.135	.003	-7.181	***	-.169	-.095	.002
FST<---PHLSTG	-.012	-.045	.005	-2.516	.012	-.094	.001	.053

Source: Extracts from SPSS Amos. Explained Variables *** (indicating P<0.001).

Note: FAC = Food Accessibility, FST= Food Stability, PHL= Post-harvest Losses, STG = Storage Technology Adoption, COF = Food Prices, UMP = Unemployment, CLC = Climate Change, HHS = Household Size, and PHLSTG=Interaction effect term of storage adoption technology and postharvest losses on Food stability in Benue State.

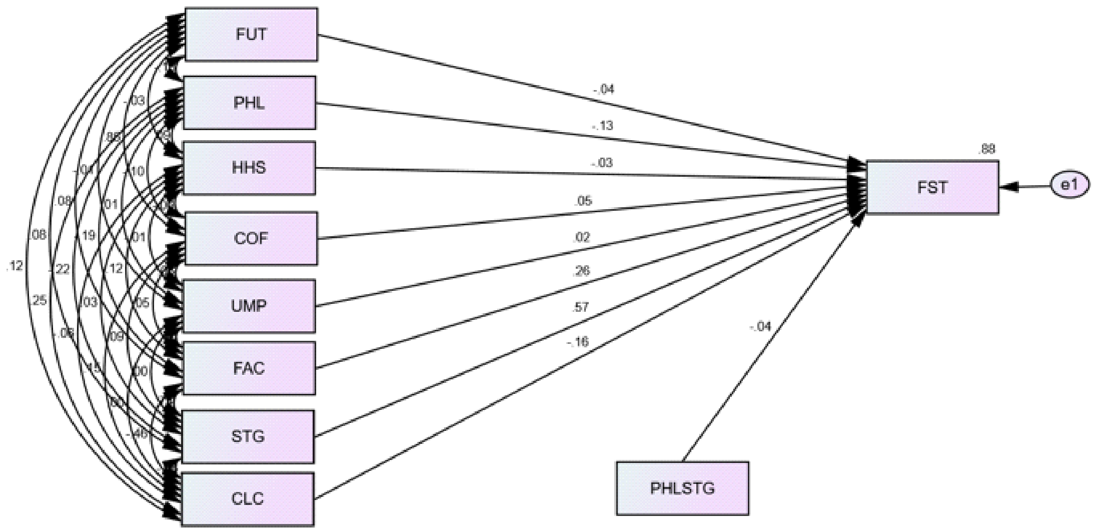

Figure 2: SEM Results

The first objective of the study examined the effect of post-harvest losses on food stability among groundnut farmers in Benue State. The Structural Equation Modelling (SEM) results presented in Table 4 indicate that post-harvest losses have a significant negative effect on food stability ($\beta = -0.135$, $B = -0.018$, C.R. = -7.181, $p < 0.001$). This implies that an increase in post-harvest losses significantly reduces the level of food stability among groundnut farming households. Specifically, a one-unit increase in post-harvest losses decreases the food stability index by 0.018 units, holding another factors constant. The standardized coefficient (β = -0.135) further suggests that higher post-harvest losses are associated with lower household food stability. This finding supports the argument that losses occurring during harvesting, drying, transportation, processing, and storage reduce the quantity of food available for household consumption and market sales, thereby weakening households' ability to maintain a stable food supply throughout the year. This finding is consistent with the World Bank (2011), which reported that post-harvest losses diminish food reserves, reduce market availability, and increase households' vulnerability to seasonal food shortages and external shocks.

The second objective examined the effect of storage technology adoption on food stability among groundnut farmers in Benue State. The results reveal that storage technology adoption exerts a strong positive and statistically significant influence on food stability ($\beta = 0.574$, B = 0.648, C.R. = 17.911, $p < 0.001$). This indicates that a one-unit increase in storage technology adoption increases the food stability index by 0.648 units, making it the strongest predictor of food stability in the model. The finding suggests that farmers who adopt improved storage technologies are better able to preserve harvested groundnuts, minimize storage losses, maintain food stocks during lean periods, and improve household food availability throughout the year. Consequently, storage technology adoption enhances households' resilience against seasonal shortages and market fluctuations. This finding corroborates Ibrahim et al. (2019), who observed that improved storage technologies contribute significantly to sustained food availability by reducing quantitative and qualitative post-harvest losses.

Regarding the third objective, the study investigated whether storage technology adoption moderates the relationship between post-harvest losses and food stability. The interaction term between post-harvest losses and storage technology adoption (PHLSTG) is negative and statistically significant ($\beta = -0.045$, B = -0.012, C.R. = -2.516, $p = 0.012$). This finding indicates that storage technology adoption significantly moderates the relationship between post-harvest losses and food stability. However, the negative interaction coefficient suggests that as storage technology adoption increases, the negative relationship between post-harvest losses and food stability becomes slightly stronger rather than weaker. In other words, although storage technology adoption independently improves food stability, its interaction with post-harvest losses does not offset the adverse effect of post-harvest losses. This result implies that storage technologies alone may not be sufficient to eliminate the detrimental effects of post-harvest losses if losses occur at earlier stages of the post-harvest value chain, such as harvesting, handling, transportation, or processing. Therefore, complementary interventions targeting the entire post-harvest management system are required alongside storage technology adoption to achieve substantial improvements in food stability. Among the control variables, food accessibility has a positive and statistically significant effect on food stability ($\beta = 0.260$, B = 0.185, $p < 0.001$), indicating that improved household access to food significantly enhances the stability of food consumption over time. Likewise, climate change exerts a significant negative influence on food stability ($\beta = -0.156$, B = -0.186, $p < 0.001$), implying that increased exposure to adverse climatic conditions significantly reduces households' ability to maintain stable food supplies. These findings are consistent with FAO (2021), which emphasized that climate-related shocks reduce agricultural production and disrupt food systems.

Conversely, food prices (COF) ($\beta = 0.050$, $p = 0.143$), household size (HHS) ($\beta = -0.027$, $p = 0.132$), unemployment (UMP) ($\beta = 0.022$, $p = 0.231$), and future uncertainty (FUT) ($\beta = -0.041$, $p = 0.225$) do not have statistically significant effects on food stability since their probability values exceed the conventional 5% significance threshold. Therefore, although some of these variables exhibit positive or negative relationships with food stability, there is insufficient statistical evidence to conclude that they significantly influence food stability among groundnut and rice farming households in Benue State. The findings demonstrate that post-harvest losses significantly undermine food stability, while storage technology adoption substantially enhances food stability. Furthermore, the significant interaction effect confirms that storage technology adoption moderates the relationship between post-harvest losses and food stability. Nevertheless, the negative moderation coefficient suggests that storage technology adoption, in its current form, does not completely neutralize the adverse consequences of post-harvest losses, highlighting the need for integrated post-harvest management strategies that address losses across all stages of the value chain rather than focusing solely on storage.

Discussion of Findings

The socio-economic characteristics indicate that the majority of the respondents are middle-aged farmers with considerable farming experience. This suggests that groundnut production in Benue State is dominated by farmers who possess substantial indigenous knowledge and practical experience in crop production and post-harvest handling. Farming experience is often associated with improved managerial ability and better decision-making regarding harvesting, storage, and marketing practices. This finding agrees with Okoye et al. (2020), who argued that experienced farmers are better able to manage production risks and reduce post-harvest losses through accumulated knowledge. However, the predominance of older farmers may also constrain the adoption of innovative post-harvest technologies because older farmers are generally more risk-averse than younger producers, as observed by Tarla et al. (2025).

The study also reveals relatively large household sizes among farming households. Large households provide an important source of family labour for labour-intensive agricultural activities, including harvesting, drying, sorting, and storage. Nevertheless, they simultaneously increase household consumption requirements and place greater pressure on available food stocks, particularly when post-harvest losses are high. This finding supports the observations of Biam and Tav (2020) and Abah and Abah (2025), who noted that while large rural households provide labour advantages, they also increase household dependency burdens. The empirical findings demonstrate that post-harvest losses significantly and negatively affect food stability among groundnut farmers. The negative and statistically significant coefficient indicates that increases in post-harvest losses reduce households' ability to maintain stable food availability throughout the year. This finding supports the theoretical expectation of the Theory of Constraints, which identifies post-harvest losses as a critical bottleneck limiting continuous food availability. It also reinforces Sen's Entitlement Theory, which argues that losses reduce households' food stocks and income, thereby weakening their entitlement to food and increasing their vulnerability to seasonal shortages.

The result is consistent with several previous empirical studies. Agboola and Williams (2023) found that poor storage facilities and inadequate transportation significantly increase post-harvest losses among cereal farmers in North-Central Nigeria. Similarly, Ogundele (2022) identified storage, transportation, packaging, and warehousing as major sources of post-harvest losses across major food crops in Nigeria. Okadonye et al. (2021) further reported that post-harvest losses occur at every stage of the rice value chain in Benue State, with overall losses ranging between 37 and 40 percent. Likewise, Ojiya, Andohol, and Doki (2021) concluded that inadequate storage facilities and poor post-harvest practices substantially reduce farmers' welfare. While these studies concentrated primarily on production losses, farmer welfare, and food security, the present study extends the literature by providing empirical evidence that post-harvest losses directly undermine the stability dimension of household food security.

Another major finding is that storage technology adoption exerts the strongest positive influence on food stability. Farmers who adopt improved storage technologies experience significantly higher levels of food stability because improved storage minimizes quantitative and qualitative losses, preserves food quality, extends shelf life, and allows households to maintain food stocks during lean periods. This finding strongly supports Schultz's High-Payoff Input Model, which argues that investment in modern agricultural technologies generates substantial productivity and welfare gains. The finding corroborates Odeyemi et al. (2021), who demonstrated that improved storage technologies such as Zero Energy Cooling Chambers and reusable plastic crates substantially reduced post-harvest losses and increased farmers' incomes. Similarly, Ohagwu et al. (2021) reported that improved storage environments significantly prolonged shelf life and maintained product quality, while Agboola and Williams (2023) identified improved storage facilities as one of the most effective interventions for reducing post-harvest losses. These studies collectively support the conclusion that investments in storage infrastructure are fundamental to improving household food stability.

The study further finds that storage technology adoption significantly moderates the relationship between post-harvest losses and food stability. However, the interaction coefficient is negative, indicating that although storage technology independently improves food stability, it does not completely offset the adverse effects of post-harvest losses. This suggests that losses occurring before the storage stage, including harvesting, handling, drying, and transportation, continue to reduce household food stability even where improved storage technologies are adopted. The finding implies that storage technology should be viewed as one component of an integrated post-harvest management system rather than a complete solution to post-harvest losses. This finding extends previous studies, which primarily examined the direct effects of storage technology without considering its moderating influence.

Among the control variables, food accessibility significantly improves food stability. This finding suggests that households with better physical and economic access to food are more capable of maintaining stable food consumption throughout the year. The result agrees with Acheampong et al. (2022), who observed that improved household access to food significantly enhances food security outcomes among farming households in Ghana. Conversely, climate change significantly reduces food stability, indicating that adverse climatic conditions continue to threaten sustainable food availability among groundnut farmers. Climatic variability reduces agricultural productivity, damages harvested produce, and disrupts storage conditions, thereby increasing households' exposure to food shortages. This finding is consistent with Okoro, Yusuf, and Bello (2024), who reported that climate variability significantly increased post-harvest losses within groundnut value chains in Nigeria.

Finally, food prices, household size, unemployment, and future uncertainty do not exert statistically significant effects on food stability after controlling for post-harvest losses, storage technology adoption, food accessibility, and climate change. This suggests that their influence may be indirect or mediated through other factors rather than exerting an independent effect on household food stability. Thus, the findings reinforce the argument that food stability is determined not only by agricultural production but also by the efficiency of post-harvest management systems. While reducing post-harvest losses remains fundamental, sustained improvements in food stability require complementary investments in improved storage technologies, enhanced food accessibility, and climate-resilient agricultural systems.

Conclusion and Policy Recommendations

Conclusion

This study set out to evaluate the structural relationship between post-harvest losses, storage technology adoption, and food stability among groundnut farmers in Benue State, Nigeria. By deploying a Structural Equation Modelling (SEM) framework, the study empirically disentangled the direct and moderating pathways through which post-harvest management shapes the temporal dimension of household food security.

The empirical findings confirm that post-harvest losses exert a direct, negative drain on household food stability, depleting food reserves and exposing farming households to severe lean-season vulnerabilities. Conversely, storage technology adoption proved to be the single strongest positive driver of food stability, highlighting the vital role of improved preservation infrastructure in smoothing household food consumption and income across seasons. Crucially, while storage technology adoption significantly moderates the relationship between losses and stability, the nature of this interaction demonstrates that modern storage alone cannot fully neutralize the adverse impacts of losses when they originate in earlier, pre-storage phases. Furthermore, while physical food accessibility reinforces stability, climate variability acts as a significant external shock that accelerates post-harvest decay and disrupts household food supply chains.

Contribution to Knowledge

This research advances the empirical literature by moving beyond conventional evaluations of post-harvest losses that treat storage technology merely as a physical waste reduction tool. By integrating Amartya Sen's Entitlement Theory, Goldratt's Theory of Constraints, and Schultz's High-Payoff Input Model within an SEM path model, this study conceptually establishes storage technology adoption as an explicit structural mechanism that buffers household entitlements against post-harvest shocks. Methodologically, it demonstrates the utility of SEM in capturing complex, multi-stage interaction effects within agrarian food systems in Sub-Saharan Africa.

Policy and Practical Implications

Addressing food instability requires a fundamental shift from standalone storage distribution toward systemic post-harvest intervention. Because significant volume loss occurs during harvesting, threshing, drying, and handling prior to storage, policy interventions that focus solely on distributing storage bags or silos will yield sub-optimal results. Agricultural development initiatives must adopt an end-to-end value-chain approach that pairs storage technologies with improved harvesting machinery, proper moisture management, and climate-resilient rural infrastructure.

Policy Recommendations

1. The Benue State Ministry of Agriculture and Rural Development (BNARDA) should transition from isolated storage projects to comprehensive post-harvest programs that address losses at harvesting, threshing, drying, and transportation stages.
2. Government agencies and development partners should expand smallholder access to proven storage technologies (e.g., hermetic PICS bags, improved metal silos, community grain banks) through subsidized extension schemes and rural credit lines.
3. Agricultural extension agents should receive specialized training to educate smallholders on pre-storage practices, including optimal harvesting timing, proper moisture testing, and post-harvest sanitation.
4. Investments should be prioritized for climate-adapted post-harvest infrastructure, such as solar-powered communal drying decks and improved rural feeder roads, to mitigate climate-induced spoilage during transport and drying.

Study Limitations and Suggestions for Future Research

While this study provides robust cross-sectional insights across Benue State, it is subject to notable limitations. First, relying on cross-sectional survey data captures household responses at a single point in time, limiting the ability to track long-term inter-annual storage dynamics. Future research should adopt longitudinal panel designs to track post-harvest behavior and food stability across multiple cropping cycles. Second, while this study focused predominantly on groundnut value chains, future studies should extend this structural framework to compare perishable horticultural crops with major staples to identify crop-specific post-harvest bottlenecks across diverse ecological zones.

Closing Statement

Ultimately, achieving sustainable food stability in Benue State depends not merely on increasing crop yields, but on fortifying the post-harvest management systems that safeguard those harvests. By bridging the gap between harvest and consumption through integrated post-harvest strategies, policy-makers can transform seasonal agricultural surpluses into lasting household food security and rural resilience.

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