

Adoption Dynamics of Hermetic Storage Technology and Post Harvest Quality Outcomes in Maize Production

Karthikeyan K

Department of Computer Science and Engineering, SNS College of Engineering, Coimbatore, Tamil Nadu, India.
sns.cse.karthik@gmail.com

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Corresponding author(s):

Karthikeyan K, Department of Computer Science and Engineering, SNS College of Engineering, Coimbatore, Tamil Nadu, India.
sns.cse.karthik@gmail.com

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Abstract – Post-harvest loss forms a significant challenge to productivity of smallholder maize farmers especially those found in the developing nations, where lack of adequate storage technologies means that the grain is prone to pest infestations and thus deterioration. Two randomized encouragement design is used in this study where farmers were given a full-coverage (100%), or partial-coverage (50%), subsidy on the use of Purdue Improved Crop Storage (PICS) bags. Instrumental-variable estimation on the 543 household data shows that the level of adoption is significantly increased by the incentives that come as subsidies. The experimental results support that adding one PICS bag to the storage increases the maize storage by about 39 to 43 kg. Additionally, the adoption with the 100 % subsidy leads to the reduction in post-harvest losses by about 10 kg, but the 50 subsidy brings weaker effects, which can be explained by the low adoption rates, thus, emphasizing the importance of strong financial incentives.

Keywords – Post-Harvest Losses, Hermetic Storage, PICS Bags, Randomized Encouragement Design, Instrumental Variables, Maize Storage, Agricultural Technology Adoption.

I. INTRODUCTION

Maize (*Zea mays* L.) is an essential staple grain in sub-Saharan Africa and is simultaneously utilized both industrially as well as in animal feed in the region. In the tropical areas that experience two harvests of maize per year, it is standard practice that one of the harvests coincides with the start of the rainy season. Since most of the smallholder farmers rely on the use of solar drying before the storage of the grains, the practice increases a significant threat of worsening the quality of the grains. Storing grains in moisture and warm conditions may hasten the quick deterioration of the grains as the growth of molds and infestation of insect pests may occur [1]. Considering the demand of consumers of high quality and safety of food, it is necessary to take certain measures to preserve and safeguard grains of maize weakness to attacks by insects and fungi.

The post-harvest losses (PHL) are a significant issue to the extent of 36% of yield. Loss due to insect activity is mostly because of poor drying but in most cases, fungal degradation and possible mycotoxin contamination could occur. Most of the small holder farmers still use traditional post-harvest management and storage methods. Solar drying is energy efficient but it is not possible to achieve the intended moisture level in unfavorable weather scenarios. An alternative that is more cost-efficient is the use of woven bag storage that demands the usage of the pesticides. This means that farmers are becoming more conscious of the dangers of having such insecticides particularly when storing their grains indoors.

Farmers should be provided with economical, easy to use, popular and safe storage technologies. Another possible solution to traditional pesticide-based solutions is the development of sophisticated hermetic storage technologies (HSTs), such as hermetic bags and silo systems. Containment systems are known as hermetic storage in which the exchange of oxygen is restricted thus preventing the survival of pests and fungal growth. HSTs integrates hermetic liners (e.g., the Purdue Improved Crop Storage (PICS) bags), silos with a seal and containers. PICS bags have a triple-sealed hermetic design and are widely employed in Latin America and Africa. PICS liner is made of 2 interior layers of 80-thick bags made of high-density polyethylene (HDPE), which prevents the permeation of oxygen, which are surrounded by an outer layer of woven

polypropylene. This is an outer layer that serves as a protective shell to the two interior polyethylene liners and provides the entire mechanical integrity of storage package [2].

Yewle et al. [3] shows that hermetic and conventional methods of maize storage are relatively effective in preserving maize. The technologies of hermetic prevent heavy dependence on the use of chemical pesticides, which increases food safety and contributes to environmental sustainability. They are affordable, scalable and would be applicable in smallholder settings and therefore, should be embraced in nations like Nigeria, Kenya and India. Besides, technical support to such farmers is necessary in order to enhance productivity and bring in cost-efficient options.

Researchers note that there is imperative to create instruments which would assist farmers to have sustainable practices. These mechanisms can be in form of policies and subsidies on businesses that are committed to sustainable agriculture. Scholars agree that the multidimensional issues facing sustainable agriculture need a holistic approach that incorporates a combination of different dimensions and different stakeholders as well as simultaneously appeal to the social, economic, and environmental issues. In that regard, sustainability shifts have to be holistic regarding agri-food systems in order to enable the introduction of sustainable production methods [4].

Government institutions have the holistic view in determining the conditions and plans on the application of sustainable agricultural practices. Since attaining economic development at the same time as being socially and environmentally sustainable has been identified as a significant policy goal, the role of the government has played a critical part in putting into consideration the environmental issues. Government funding is regarded as a highly important external resource because of its ability to impact the business ecosystem in a vast way and encourage entrepreneurship and innovation. Such support also covers public-policy tools that have been put into place to subsidize and guarantee the roles and functions of enterprises. The empirical data reveals the fact that the governmental support has a positive impact on the innovative power and performance of the enterprises [5].

We aim to determine the causal impact of the adoption of airtight storage technology on the outcome of maize storage among the smallholder agriculturalists. In particular, the research examines the impact of varying subsidies incentives on the levels of PICS bags adoption and evaluates their impact on the level of storage and subsequent losses during post-harvest processes based on instrumental-variable framework.

The rest of this research paper is structured in the following way: Section II is the literature review. Section III outlines the materials and methods, including the experimental design and subsidy treatment, data collection and measurement of the variables and econometric estimation plan. In Section IV, the results and discussion are provided, which focuses on effects of subsidies on adopting PICS bags, effects on maize storage time and losses after harvesting, and a comparison of 100% and 50% subsidy effects. Section V provides the conclusions of the study and presents the findings on the causal ordering of hermetic storage technology on the grain storage behavior of the smallholder farmers.

II. RELATED WORK

Aripong et al. [6] have shown that storage is the worst place to experience the most post-harvest losses (PHL) that is often explained by insufficient or poor storage facilities. Redman and Redman [7] pointed to the need to spread knowledge on how to better store the food and control the food system that can result in a major decrease in food waste up to 98%.

According to Bradford et al. [8], it is important to counter abiotic factors especially moisture content and climatic conditions to minimize storage losses. Commodities in the agricultural sector are also sensitive to moisture hence when they are stored enough, they have to be dried to attain an appropriate moisture content. Based on this, it is advised that the moisture value should be kept to less than 13% extended storage, and below 15% when the time to be stored is not more than six months (see **Table 1**). Furthermore, moving grain out of small farms to large, well monitored consolidated storage facilities is an effective approach of reducing PHL.

As described by Bendinelli et al. [14], post-harvest grain losses refer to all the losses incurred after the grain has been harvested until the grain is eventually used either to be utilized as food or otherwise. The productivity of agriculture in most of the developing countries, mostly in SSA (sub-Saharan Africa) is still lower than that of wealthy countries. The low crop yield is further aggravated by PHL of legumes and cereals that usually amount to 20- 30% in many low-income nations around the globe.

Tong et al. [15] describes that these losses may be in the quality or quantity of the grain thus majorly reducing the value of the grain. Losses would be quantitative due to scattering and spillage of grain, immediate infestation of insects and the birds, contamination by mycotoxins or mechanical damage, and would be qualitative due to the infestation of the mold, mycotoxins, and mechanical damage. Depending on the nature and the extent of losses, a variety of causative factors are linked to the PHL in the entire cereal supply chain (see **Fig. 1**).

As depicted by MacPherson et al. [16], digitalization in agriculture will improve the technical performance of agricultural production systems and value chains as well as food systems. Ogunyiola and Gardezi [17] have also focused on clarifying the connection between digital agriculture and its economic, environmental, and social effects, particularly with regard to how technology has transformed the values, practices, and identities of farmers. Additionally, there are shared concerns such as food traceability and provenance, animal welfare in livestock business and environmental effect of different farming initiatives.

Gumbi, Gumbi, and Twinomurizi [18] also points to some possible opportunities of digital agriculture technologies that are yet to be utilized in LMICs. These prospects integrate enhancing financial inclusion and market access by integrating farmers to insurance, credit, and markets, enhancing precision agriculture and climate resilience through AI-oriented weather prediction and IoT-based local monitoring, agronomic advisory service, and ensuring equitable compensation and reduction of losses through blockchain and smart contracts. The increase of digitalized technology in the agricultural field is quite

gradual and a number of essential elements of technology, including equal access to it, mobile connections, and energy has to be put in place before the sector can actually achieve its potential.

Table 1. Storage Loss Mitigation Strategies and Technologies

Practices	Technology/Technique	Significant Results	References	
Management	Water content	Below 13%	Long-term storage	
		Less than 15%	Short, < 6 months	
		Above 16%	Few weeks	
	Aeration	Airflow 2–20 L/s/tonne	Bulk storage	Lukasse, De Kramer-Cuppen, and Van Der Voort [10]
	Chemical fumigation	Methyl bromide Phosphine	Commonly employed in developing nations Control enormous grain borer insects for cereal crops.	Daglish et al. [11]
		Actellic Super	Commonly employed in Africa (Tanzania/Kenya)	
		Nitrogen or ethyl bromide	Safe for humans and environment	
	Natural insecticides	Chenopodiaceae herbs/leaves	Appropriate for smallholders	Nath et al. [12]
		Crude cottonseed oil Pure soybean oil Crude rice bran oil Crude palm kernel oil	Expensive, unsuitable for business use Good for grain borers and weevils	
	Storage structure/system	Hermetic system	PICS bags Super Grain Plastic bag	PHL < 1% Typically employed in smallholders
Silo		Local/FAO metallic silo	Affordable expense Typically employed in African/Asian nations	
Plastic/steel drum		Small-Medium farm	Easy and cost-effective to handle Typically employed in South Asia	
Grain harvest bag		Medium-Large scale farm	Large- and medium-scale (shipment) usage Typically employed in developed nations	

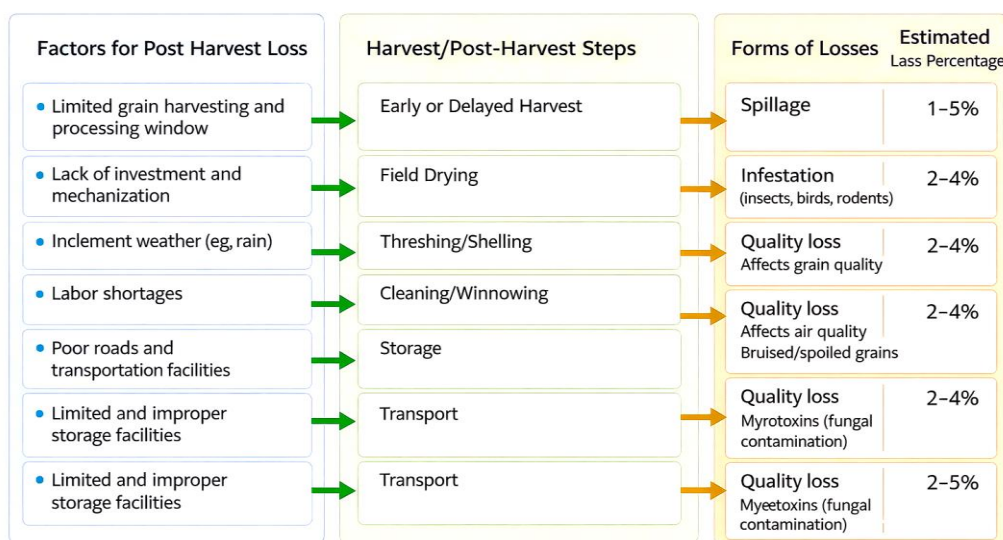


Fig 1. Predictors of Losses on Different Post-Harvest Cereal Supply Chain in Developing Nations.

In SSA, as reviewed by Karekezi and Kithyoma [19], only half of the population can access electricity and mobile connections are not yet on critical mass in many regions. In low-/middle-income nations, like the SSA, the Pacific and Southeast/East Asia, small-scale farmers occupy many of the farms with their livelihood depending on the small-scale farming activities. These nations are facing challenges related to the application and availability of farm technologies. Informing agriculturalists about novel opportunities and assisting them to adopt farm technology is, therefore, a necessary strategy in increasing farming output and enhancing livelihood of the small-scale farmers.

Omotilewa, Ricker-Gilbert, and Ainembabazi [20] evaluate the application of an economic policy instrument, which is a unique subsidy to Ugandan smallholders to establish incentives that increase their activity in commercial markets or use hermetic storage bags. This was checked on the basis of a RCT (randomized controlled trial) aimed at determining the direct impacts of subsidies and informational influences on the business adoption of this novel product, which provides unique empirical and experimental data, which can be fully evaluated in a developing-nation scenario.

The evaluated hermetic method, although similar in their cultural background to the traditional woven polypropylene (PP) storage bags that most families use before the intervention, show a higher level of effectiveness in deterring the infestation of insect pests in stored cereals without using chemicals to combat the problem. It is however five times the price of a regular woven bag which does not offer any protection against insects; thus, smallholders might be hesitant to embrace the technology because of the initial price and the lack of knowledge about its effectiveness or their abilities to properly apply it to benefit.

III. MATERIALS AND METHODS

Experimental Design and Treatment of Subsidies

The research design is a randomized encouragement design (RED), to determine the causal effect of adoption of hermetic storage technology on the outcomes of maize storage among the smallholder farmers. The innovative idea that the intervention aims to introduce is the implementation of Purdue Improved Crop Storage (PICS) hermetic bags as a form of storage technology designed to limit the amount of oxygen and prevent insects that are able to destroy grains stored in bags. The direct randomization of technology adoption is not feasible because the choices of technology adoption are self-determined by farmers. To that effect, the experiment constitutes subsidy-based promotion that alters the purchase price of PICS bags and does not interfere with the farmers determining whether to or not to use the technology.

There were two levels of subsidy incentives used to create differences on the adoption behavior. The first treatment condition was in which the farmers were given a subsidy of 100%, which implied that they could obtain PICS bags at no cost. Under the second treatment condition, farmers were under a 50% subsidy and hence, they had to make a half-price payment on the market price existing. The rationale behind the introduction of these two subsidy levels was to induce differing rates of adoption that would be exploited to identify the cause-and-effect relationship. The assignment of treatment was also achieved by a randomized allocation process that was implemented on the sample of maize-producing households. Randomization makes subsidy assignments statistically independent of observable and unobservable farmer attributes, which ensures that any observed systematic difference in the adoption behavior of treatment groups can be credited to the subsidy incentives and not to any pre-existing variation in the heterogeneity of the farmers.

In this experimental design, subsidy incentives can be applied to influence the adoption behavior to the economic cost of the purchase of PIC bags. Farmers that have lower costs of acquisition are projected to embrace more bags as compared to those who are faced with a high cost of acquisition. Nevertheless, the subsidy is not a direct determinant of adoption since farmers will be left at liberty to adopt or not to adopt the technology and the number of bags to employ in the storage season. **Fig. 2** shows the conceptual framework of the experimental framework.

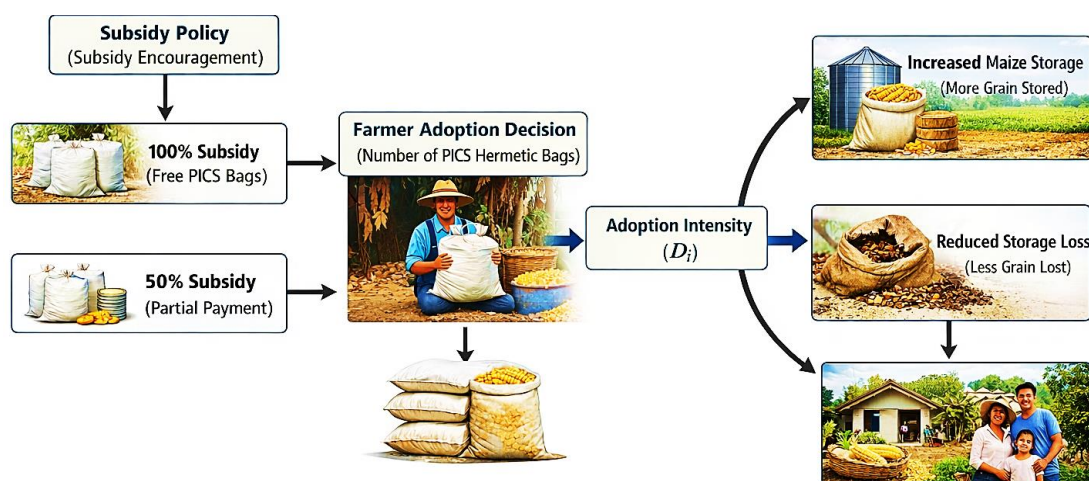


Fig 2. Experimental Encouragement Design of The PICC Bag Adoption and Storage Results.

The figure is used to show the sequential connection between subsidy assignments, decisions on adoption and storage outcomes. In this context, subsidy encouragement is a type of exogenous policy intervention, which changes adoption

choices, but does not directly influence the result of maize storage. This instrumental property enables the use of subsidy incentives as instrumental variables in the econometric estimation plan.

Data Acquisition and Measurement of Variables

Primary data was collected through household structured household surveys that were conducted on the maize-producing farmers during the post-harvest storage period. The survey instrument was designed in a manner that would draw detailed information on the socio-economic characteristics of the households, the volumes of maize produced, how it is stored, and its adoption of hermetic storage technologies. The methodology employed in the study was a face-to-face interview by trained enumerators using standardized questionnaires thus assuring consistency in methodologies and accuracy of data.

The data includes the observations of 543 maize producing households. The Survey answers were on demographics of the head of the household, the quantity of maize they produce, their mode of storage during the storage period, and the results of their storage within the season. In addition to the survey data, field visits were conducted to chosen cases to determine whether the hermetic storage bags were used and to increase the validity of the reported storage results. **Table 2** represents descriptive statistics of the key variables included in the analysis. These statistics would sum up the socio-economic features of the involved farmers and their maize production and storage status.

Table 2. Descriptive Data of the Important Variables

Variable	Mean	Std. Dev.	Min	Max	Observations
Age (years)	46.21	12.38	21	78	543
Education (years)	6.84	3.92	0	16	543
Family size	5.12	2.03	1	11	543
Maize production (kg)	723.45	288.67	120	1480	543
Storage quantity (kg)	118.67	64.52	0	340	543
Storage losses (kg)	24.31	16.44	0	82	543
Number of PICS bags adopted	1.63	0.98	0	4	543

Intensity of PICS bag adoption which is measured by the number of bags employed by individual farmers in the storage season is the primary explanatory variable in the analysis. The fact that the adoption is an operationalized count variable rather than binary indicator enables the analysis to measure the scale of technology adoption among households.

Table 3. Balance Test at Baseline Between Subsidy Groups

Variable	100% Subsidy Mean	50% Subsidy Mean	Difference	p-value
Age	45.98	46.42	-0.44	0.72
Education	6.91	6.77	0.14	0.64
Family size	5.10	5.14	-0.04	0.83
Maize production	728.13	719.24	8.89	0.61
Storage quantity	119.87	117.54	2.33	0.48

In this study, two outcome variables are utilized in order to measure storage performance. The first outcome variable, which is storage quantity of maize, is the mass of maize that has been preserved in PICS bags during the storage period, and is measured in kilograms. The second outcome measure, the post-harvest store losses, can be described as the amount of maize that will be lost during store keeping through infestation by pests, or spoilage among other causes of degradation.

In order to guarantee the validity of the randomized design, baseline balance test of socio-economic characteristics among the subsidy treatment groups was carried out. Results in **Table 3** justify the conclusion that all the differences in treatment groups are not statistically significant. The fact that no statistically significant differences are observed shows that the treatment assignment was effective in creating similar groups, therefore proving that internal validity of the experimental design is achieved.

Econometric Estimation Strategy

The innovative technology of hermetic storage has endogeneity in the adoption choices and therefore requires a strict method of estimating the causal link between the adoption of hermetic storage initiative and the outcome of storing maize. Adopters of PICS can systematically be different, in ways that affect the outcome of storage in a complex and multi-faceted way that simultaneously affects the non-adopters. These systematic discrepancies can be due to some unobservable factors including competence in management, riskiness, access to the market, or access to data.

In order to address this endogeneity challenge, the study uses an instrumental variable estimation model that is based on a randomized subsidy encouragement. The subsidy incentive only changes the probability of using PICS bags but does not have any direct impact on storage results other than via the channel of adoption (see Eq. 1).

$$Y_{it} = \alpha + \beta D_{it} + \theta' X_{it} + \lambda_i + \tau_t + \varepsilon_{it} \tag{1}$$

where variable Y_{it} is the outcome of the storage of the farmer i and D_{it} is the number of bags implemented. The vector X_{it} includes the household attributes that are observed; and, the factor, λ_i reflects the exclusive heterogeneity of farmers; τ_t

reflects the effects of the storage time and, ε_{it} reflects the idiosyncratic error model. Formulation of the decision on adoption uses a latent demand function in Eq. (2) and (3), which identifies the strength of the adoption of PICS bags.

$$D_{it}^* = \delta_0 + \delta_1 Z_i + \delta_2 P_t + \delta_3 X_{it} + \delta_4 W_i + v_{it} \quad (2)$$

$$D_{it} = \max(0, [D_{it}^*]) \quad (3)$$

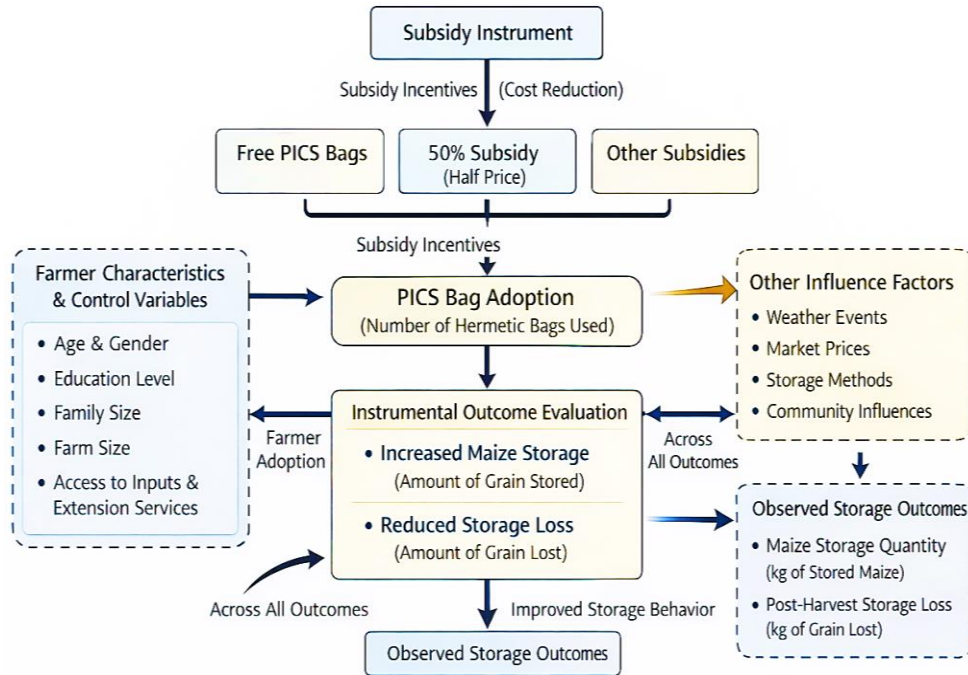


Fig 3. Instrumental-Variable Identification Model to Determine the Causal Estimates PICS Bag Adoption on Maize Storage.

Where D_{it}^* represents the latent demand of hermetic storage bags, Z_i refers to the subsidy incentive received by farmer i , P_t refers to the market price of storage inputs in the market, W_i refers to farm-specific characteristics of technology adoption, and v_{it} refers to the unobserved determinants of technology adoption. The causation of adoption can take the form of Eq. (4) in the potential-outcomes model of causality.

$$ATE(d) = E[Y_i(d) - Y_i(0)] \quad (4)$$

where $Y_i(d)$ represent the storage result by having farmer i use d PICS bags. The endogenous nature of adoption means that the study reveals the local average treatment effect which is brought about by encouragement of subsidies. The instrumental variable estimate may be defined through the ratio in Eq. (5).

$$\beta_{IV} = \frac{\frac{1}{N} \sum_{i=1}^N Y_i Z_i - (\frac{1}{N} \sum_{i=1}^N Y_i)(\frac{1}{N} \sum_{i=1}^N Z_i)}{\frac{1}{N} \sum_{i=1}^N D_i Z_i - (\frac{1}{N} \sum_{i=1}^N D_i)(\frac{1}{N} \sum_{i=1}^N Z_i)} \quad (5)$$

The ratio refers to the percentage of the covariance of the outcomes and the instrument to the covariance of adoption and the instrument. The estimator will then determine the marginal causal impact of an increase in the uptake of PICS bags by those farmers, the uptake actions of which are affected by the encouragement created by subsidies. Practically, the estimation is conducted using two-stage least squares estimation, which involves the anticipated levels of adoption based on the first stage regression included on the second stage structural outcome model. **Fig. 3** provides the conceptual framework behind this estimation strategy, which shows the causal pathway between the effects of subsidy incentives, adoption behavior and storage outcomes. All regressions have robust standard errors (SE), which are used to address the heteroskedasticity and provide credible statistical inference.

IV. RESULTS AND DISCUSSION

Subsidy Effects on the PICS Bag Adoption

PHLs are also a significant obstacle to food security in the world. The existing estimates show that the rates of losses lie between 10% and 50%, based on the crop type, and geographical location, with the highest rates recorded in developing nations because of the infrastructural inadequacies and environmental pressures. The most negatively affected crop groups are cereals, roots, tubers, fruits and vegetables.

Table 4. World Average Percentages of Post-Harvest Losses Per Type of Crop

Crop Type	Cereals	Roots & Tubers	Fruits & Vegetables
Average Post-Harvest Loss (%)	15–30	20–40	30–50
Primary Causes	Insect pests, moisture, poor storage	Microbial spoilage, physical damage	Mechanical damage, rapid respiration, fungal infection

Table 4 outlines the percentage averages of various types of crops globally on the losses incurred on them. These losses lower the availability of food and cost small-holder farmers a significant economic burden since they depend on how their produce will be sold. The main causal factors are insufficiency in the drying processes, poor storage facilities, pest attacks and variations in temperature and humidity.

Hermetic storage technology is of great significance since the technology acts as a solution to smallholder farmers to minimize PHLs, increase the storage lifespan, and improve the value of the harvested grain, hence improving the socio-economic environment, and food sanctuary of such agriculturalists. This suggestion is substantively supported by reciprocal empirical evidence of our experiment. This is due to the fact that it is a priority to overcome the socio-economic barriers to the implementation of innovative agricultural technologies by policy makers and scholars.

Table 5. The Effects of Subsidy Provisions in the Initial Usage of PICS Bags

Model	100% Financial Incentives	50% Financial Incentives	Constant	Observations	R ²	Covariates
(1)	0.76*** (0.08)	-	0.00*** (0.00)	496	0.29	No
(2)	0.76*** (0.08)	-	-0.21* (0.11)	496	0.30	Yes
(3)	-	0.41*** (0.04)	0.00 (0.00)	543	0.19	No
(4)	-	0.41*** (0.04)	-0.10* (0.06)	543	0.20	Yes

Notes: Covariates are reported (age, educational attainment (in years), family size, and gender) and with strong SE and p-values of less than 0.01, less than 0.1, and **, respectively.

As shown in **Table 5**, the number of PICS bags used can be a strong predictor of the performance of the first stage incentive schemes which provide either full or half subsidy. As models (1) and (2) in the table demonstrate, the value of the coefficient indicating the promotion of a 100% financial incentives, without covariates and with control variable, is 0.761 at the level of significance of 1% ($p < 0.01$).

Similarly, the coefficient of the promotion of a 50% subsidy, which is calculated in the specifications of both models that exclude and introduce covariates, is calculated as 0.41; it is statistically significant at 1 percent ($p < 0.01$). Both the 100% and 50% subsidy forms of encouragement can thus be considered as appropriate instrumental variables since the coefficients estimated are highly distinct other than zero. The results of the initial phase thus emphasize the effect of various levels of subsidy on the level of adoption of hermetic bags.

Effects of PICS Bags to the Maize Storage Extent

Table 6 shows the LATEs (local average treatment effects) of two levels of incentives 50% and 100% subsidy offer on the outcome of storage-quantity. Our findings show that farmers with 100% subsidy store more maize by 42.84 kg in the absence of covariates and 42.86 kg with covariates by an extra bag of PICS used. On the same note, we can use a 50% subsidy which would stimulate more maize that is stored leading to an increment of 39.20 kg without covariates and 44.20 kg with covariates. **Table 6** also indicates that the regulating of the variables does not reduce the significant and positive effect of adoption of PICS-bag on the amount of storage ($p < 0.001$).

Table 6. Impacts of Using PICS Bags on the Capacity of Storage

Model	No. of PICS bags	Constant	Observations	R ²	Covariates
(1)	42.84*** (2.64)	-0.00*** (0.00)	496	0.85	No
(2)	42.86*** (2.67)	2.61 (5.41)	496	0.85	Yes
(3)	39.20*** (1.38)	0.00*** (0.00)	543	0.92	No
(4)	39.20*** (1.36)	0.97 (1.12)	543	0.92	Yes

Notes: Significant SE are provided in parenthesis, the covariates included in the analysis are: age, years of education, gender, and family size.

The individuals in the 100% incentive class who used 1 bag saved 36.591 kg as compared to those who used 2/3 bags saving 82.51 and 122.01 kg, correspondingly. In the same way, among the group to whom 50% subsidy was applied, the average mass of bags used by 1 bag was 35.441 kg, and by 2-3 bags were 81 kg and 130 kg, correspondingly. The fact that it is increasing the volume of storage significantly shows a significant behavioral change towards using more advanced forms

of storage using PICS bags. The findings show the changes in storage behavior of small holding farmers after the introduction of PICS bags.

Effect of PICS Bags on the PHL

Table 7 shows LATE estimates of the outcomes of loss of post-harvest storage due to two incentive schemes, a 100% subsidy and 50% subsidy. The table was used to model (1) and (2) showing LATEs with and without covariates respectively used in encouraging farmers who had 100% financial incentives. Models (3) and (4) show LATEs both with and without covariates of farmers who were given a 50% subsidy incentive. The findings suggest that, when there is an extra offer of a PICS bag, the PHL are reduced by 10.051 kg and 10.021 kg with and without covariates by a 100% subsidy offer to the farmers. These findings are statistically significant at approximately 5.5% level (with p-value that is less than 0.05).

Table 7. Influence of Implementation of Hermetic Bag on PHL of Storing

Model	No. of PICS hermetic bags	Constant	Observations	R ²	Covariates
(1)	-10.05** (4.08)	30.53*** (1.73)	496	0.02	No
(2)	-10.02** (4.56)	9.89 (7.50)	496	0.02	Yes
(3)	-11.93 (7.31)	30.67*** (1.75)	543	0.05	No
(4)	-9.37 (7.12)	5.61 (6.95)	543	0.05	Yes

Notes: Strong SE are presented in citations; the level of significance is symbolized by the symbols ***p < 0.01 and **p < 0.05. The control variable quantity integrate age, number of years in education, size of the family and gender.

The results of the analysis will indicate that a subsidy of 50% did not have a statistically significant impact on PHL. This is the null result that could be explained by the low level of uptake of storage bags by the treatment group. As addressed in the analysis of storage-loss results, reduced adoption is related to an increased storage loss.

Comparison of 100% and 50% Subsidy Effects

Table 8 shows stage one and instrumental variable estimates of the 100% subsidy on farmers, as compared to the 50 percent subsidy on farmers. Model (1) and (2) highlight the effect of a 100% funding on the adoption of storage bags with and without adding covariates on the adoption model, respectively.

Table 8. Impacts of Storage Bag Implementation and Associated Findings

Model	100% funding offer	No. of PICS bags	Observations	R ²	Covariates
(1)	0.35*** (0.09)	-	345	0.04	No
(2)	0.33*** (0.09)	-	345	0.06	Yes
(3)	-	47.15*** (6.36)	345	0.82	No
(4)	-	47.68*** (5.39)	345	0.82	Yes
(5)	-	-8.24 (10.06)	345	-	No
(6)	-	-10.94 (10.33)	345	-	Yes

Notes: *** p < 0.01; Parenthesis show strong SE.

The coefficients are 0.351 and 0.332; the two coefficients are statistically significant where p < 0.01 (at a 1% level), which means that 100% subsidy is a powerful tool of determining the causal effect of adopting bags on the identified findings. The results of models (3) and (4) depict the estimated effect of storage bag usage on the amount of maize that agriculturalists with 100% subsidy will store as compared to farmers with 50 percent subsidy with and without covariates.

The coefficient values signify that; the maize storage increases by 47.15 kg and 47.68 kg when an extra PICS bag units is used in both the no covariates and covariates models, respectively. These effects are significant at 1% level (p-value = 0.01) as well as they remain consistent in different model specifications. The impact on the PHL is depicted in model (5) and (6) with coefficient estimates of -8.241 and -10.940 in model (5) and (6) without and with covariates, correspondingly. The findings indicate that the effect of adoption of PICS bags on PHL is not significant among the farmers having 50% subsidy against those having 100 percent subsidy.

V. CONCLUSION

We explore the causal implication of the hermetic storage technology on grain storage performance of smallholder farmers. High subsidy inducement exerted by offering 100% and 50% subsidies on PICS bags created exogenous changes in the intensity of adoption and reduced possible endogeneity in the decision to adopt PICS through an instrumental-variable design. Findings indicate that stimulation of subsidies significantly increases the levels of PICS bag adoption. Increased adoption yields huge improvements in the performance of maize storage, including increasing the amount of storage and reducing post-harvest losses. These results posit that full subsidy incentives have greater impacts, which can be explained by higher adoption rates as compared to partial subsidies. The findings highlight the importance of specific policy measures aimed at minimizing the barriers to the use of technology due to financial aspects. Post-harvest losses, smallholder farming households, and the economic resilience of these households can be reduced, and food security strengthened through the promotion of hermetic storage technologies through subsidy programs.

CRedit Author Statement

The author reviewed the results and approved the final version of the manuscript.

Data Availability

The datasets generated during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interests

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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Competing Interests

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