

Article

On-Farm Grain Storage and Challenges in Bagmati Province, Nepal

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Abstract: Farmers in Nepal lose up to one-third of stored grain to pests and diseases. This results in food insecurity and loss of income. To mitigate these losses, farmers use several approaches including pesticide applications on stored grains. We interviewed 241 farmers in Bagmati Province, Nepal, to assess the current on-farm grain storage practices and challenges to improve postharvest management. The results show that rice was the most stored crop (median 1150 kg). About half of farmers stored for at least nine months and grain was mainly used for home consumption. Grain was stored by 66.5 and 69.8% of farmers in granaries (rice) and plastic drums (legumes), respectively. Insects were the most important challenge during storage, and farmers used pesticides to control them. Farmers were more likely to use insecticide on grain ($p = 0.000$) if they stored rice, used traditional granaries, and had insect damage during storage. The use of improved storage methods (e.g., hermetic bags) was very low for rice (3.5%). There is a need to improve on-farm grain storage by disseminating storage innovations to address postharvest challenges in important crops such as rice.

Keywords: grain storage; insect pests; losses; hermetic storage; extension services; Dhading/Chitwan



Citation: Kandel, P.; Kharel, K.; Njoroge, A.; Smith, B.W.; Díaz-Valderrama, J.R.; Timilsina, R.H.; Paudel, G.P.; Baributsa, D. On-Farm Grain Storage and Challenges in Bagmati Province, Nepal. *Sustainability* **2021**, *13*, 7959. <https://doi.org/10.3390/su13147959>

Academic Editor: Riccardo Testa

Received: 25 May 2021

Accepted: 13 July 2021

Published: 16 July 2021

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1. Introduction

Nepal has an agrarian-based economy that contributes almost one-third to the country's GDP, and two-thirds of its population is engaged in agriculture [1]. The most cultivated staple crops in Nepal include rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.) [2–4]. Agriculture is mostly rainfed; thus, farmers produce a major portion of their crop during the monsoon season from June to September [5]. Most postharvest operations, including threshing, transportation (from field to house), winnowing, drying, storage, and milling, are done manually [3,6]. Storage losses range from 5.0 to 20% for several cereal crops and are mostly caused by insects and rodents [7–10]. These storage losses are exacerbated by prevailing hot and humid conditions during the monsoon season [11].

Farmers use several approaches to address storage losses, including traditional methods and synthetic pesticides [7,12]. Traditional storage methods and their variants include botanicals (plant parts or extracts), indigenous materials (e.g., maize stored with sheath intact on Thangros, which are vertical/or horizontal poles), and bamboo granaries [8,9]. Challenges for traditional granaries include their inability to protect grain from insect and disease attacks during storage [13]. Insecticides have been shown to be effective at mitigating insect-caused storage losses. When available, insecticides are used by farmers

to prevent storage losses because they tend to be affordable [14]. However, misuse and overuse may have adverse human health consequences, even death [12]. Incidences of pesticide poisoning have been reported in Nepal, particularly in Dhading district where 20 people were hospitalized and a family of six died after consuming food treated with pesticides [15].

Studies conducted to compare the efficacy of different storage methods reported a better performance of improved storage techniques (e.g., metal bins) compared to traditional structures in reducing insect damage and weight loss, as well as in preserving seed viability and germination [4,7,16]. Several efforts have been made to promote the use of storage methods to reduce postharvest losses, including botanicals, metal bins, granaries, insecticides, and traditional storage structures plastered with mud, cement, or plastics [7,8]. Hermetic bags (i.e., Purdue Improved Crop Storage- PICS bags, and SuperGrainbags™) were commercially introduced in Nepal as viable alternatives to pesticides, traditional structures, and other storage methods [17].

With the introduction of improved storage technologies in Nepal, there is a need to assess the status of postharvest practices to help improve their adoption. Therefore, the objectives of this study were to: (i) understand current storage management practices and challenges among farmers, and (ii) evaluate the use of improved storage technologies (i.e., hermetic bags). Results will be useful to government and development practitioners interested in disseminating improved storage technologies to reduce grain losses and health risks associated with chemical use.

2. Materials and Methods

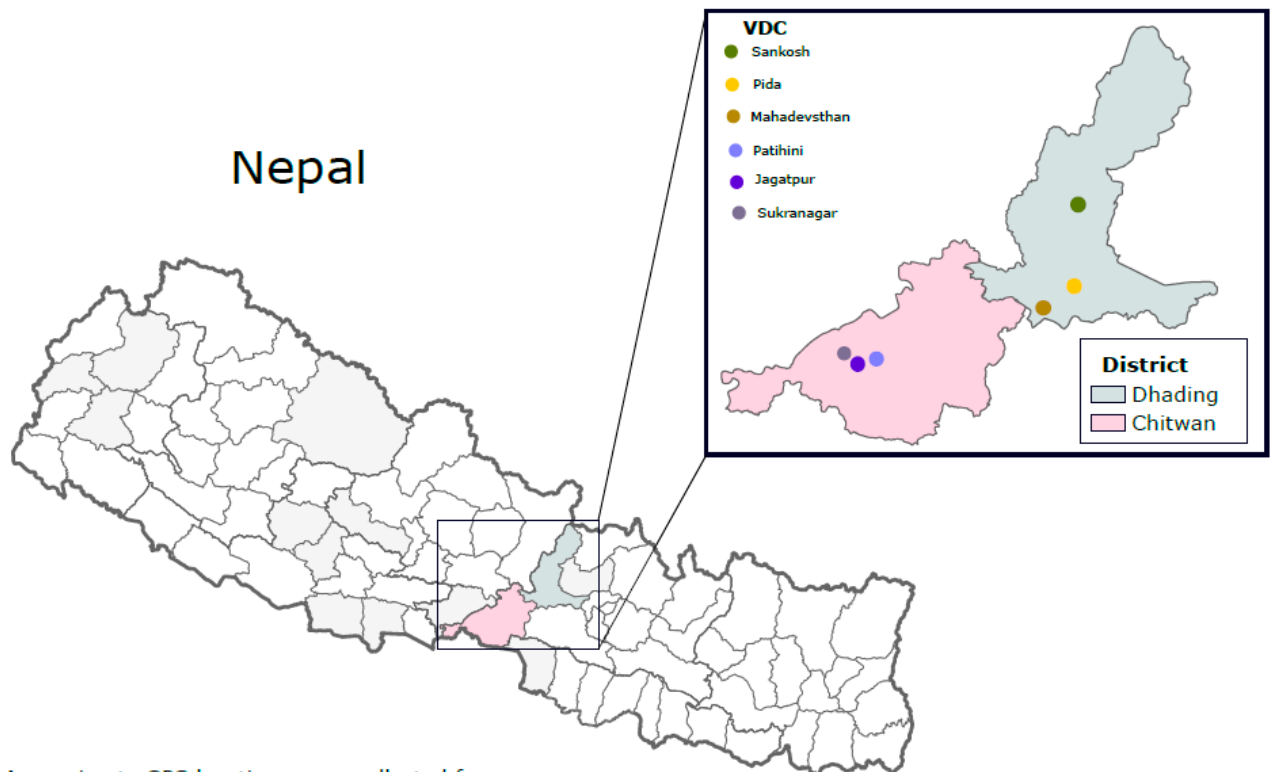
2.1. Site Selection

The study was conducted in December 2018 in two ecologically and socioeconomically diverse districts in the Bagmati Province of Nepal: Chitwan, and Dhading. Both districts were selected because of food poisoning linked to grain storage using chemicals. The agricultural characteristics of Chitwan and Dhading districts are markedly different. Farmers in Chitwan, a lowland area, practice commercial farming and have easy access to infrastructures (e.g., irrigation) and technologies [18]. Access to year-round irrigation allows these farmers to harvest rice twice a year—November/December and June/July [3]. Legumes such as beans (*Phaseolus vulgaris* L.) and lentils (*Lens culinaris* Medik) are grown in between rice seasons [19]. Dhading district, in contrast, is midland where most of the villages are in a rural setting and rice is grown in the wetland areas. Maize is the major cereal grown in unirrigated lands in both districts, and usually intercropped with soybean (*Glycine max* L. Merr.) and cowpea (*Vigna unguiculata* L. Walp) [20]. The survey was implemented in six Village Development Committees (VDCs), three in each district (Figure 1). Data were collected during the transition from VDCs to new administrative units called “Gaupalika” or “rural municipality” created under the recent political reforms in Nepal. The targeted VDCs were Mahadevsthan, Sankosh, and Pida in Dhading and Patihani, Jagatpur, and Sukranagar in Chitwan. These VDCs were selected based on crop production and issues related to excessive use of pesticides [21].

2.2. Sampling, Data Collection and Analysis

Survey data were collected using a semi-structured questionnaire with open and closed-ended questions. The questionnaire focused on understanding farmers’ demographics, storage practices and challenges of major cereal and legume crops, and storage loss mitigation approaches and limitations. The questionnaire was uploaded into KOBO toolbox (<https://www.kobotoolbox.org>, accessed on 30 November 2018) and answers were recorded using Android tablets. In each of the VDCs, 40 farmers were randomly selected from the farmers list provided by the local non-government organizations (NGOs). Interviews were conducted in farmers’ homes. Prior to each interview, a brief introduction to the study was provided, and oral consent was requested from the participant. If a farmer did not agree to participate, the interview was discontinued. We interviewed 241 farmers,

including 121 and 120 respondents in Chitwan and Dhading districts, respectively. Raw data from the KOBO toolbox were downloaded and cleaned before analysis for congruity. Some choices in questions were removed because no response was recorded, new categories were created based on the responses obtained, and several choices were combined into one category. After cleaning, the data were analyzed with SPSS 26.0 (IBM Corp., New York, NY, USA). Cross tabulations were constructed, and descriptive statistics were obtained to summarize the data. Correlation tests were used to ascertain the relationships between variables. Data on quantity of grain stored were visualized with boxplots.



Source: Approximate GPS locations were collected from Google maps and mapped using ArcGis-10.6 developed by ESRI

Figure 1. Map of Nepal showing area where the study was conducted. Each dot represents a Village Development Committee (VDC) surveyed in Chitwan or Dhading district in Bagmati Province.

2.3. Analytical Framework

The decision on whether or not to use pesticides depends on utility derived by users (farmers) [22]. Farmers use pesticides only if the expected utility (U_a) is greater with than without them (U_n), i.e., $U_a - U_n > 0$ [23]. The random utility models presume that the utility U_a derived by farmers from using pesticides is composed of a deterministic component that can be calculated based on farmers' observed attributes z_i and a stochastic error component, which is unobservable, such that:

$$Y_i^* = \beta z_i + \varepsilon_i, Y_i = 1 \text{ if } Y_i^* > 0 \quad (1)$$

where Y_i is a binary variable that takes a value of 1 if household i uses pesticides and 0 otherwise, β is a vector of parameters to be estimated, z_i is a vector of explanatory variables that determines farmers' pesticide use decisions, such as storage containers types, types of crops, duration of storage, damage by insects, and ε_i is the error term. The error component ε_i is unobservable, and therefore we do not have sufficient information to predict farmers' preference, but we can predict the determinants of households using pesticides from non-users. The conditional probability of farm household using pesticides

based on the observed farm attributes can then be estimated by using either binary logit or probit model as:

$$Pr(Y_i = 1) = Pr(Y_i^* > 0) = 1 - F(-\beta z_i) \quad (2)$$

where F is the cumulative distribution function for ε_i , which is assumed to have a normal distribution for the probit model, or logistic distribution for logit model.

3. Results

3.1. Demographic Characteristics of Farmers

Most of the respondents were female (66.4%), married (95.9%), and had basic to high school education (73.0%) (Table 1). About three-fifths of the respondents were 41 years or older. Among the respondents, 90% had farming as their main economic activity, 88.4% had ten years or more of farming experience, 95% had cellphones, and only 45% had a radio in their house.

Table 1. Demographics of farmers in Chitwan and Dhading districts, Nepal.

Variables	Categories	Chitwan (n = 121)	Dhading (n = 120)	Overall (n = 241)
Gender	Female	67.8	65.0	66.4
	Male	32.2	35.0	33.6
Age	18–30 years	8.3	15.8	12.0
	31–40 years	28.1	28.4	28.2
	41–50 years	26.4	18.3	22.4
	>50 years	37.2	37.5	37.3
Education level	None	9.9	21.7	15.8
	Basic Literacy	18.2	34.1	26.1
	Primary school	18.2	20.0	19.1
	High school	38.0	17.5	27.8
	College/Tertiary	7.4	5.0	6.2
	University	8.3	1.7	5.0
Years in activity	<5 years	5.0	0.8	2.9
	5–10 years	5.0	12.5	8.7
	>10 years	90.0	86.7	88.4

3.2. Grain Storage and Pest Challenges

The proportion of farmers storing grain varied by crop and district. The proportions of farmers storing crop in both districts were 97.4% for maize, 93.0% for soybean, and 75% for cowpea in Dhading; while in Chitwan it was 88.6% for lentils, 76.4% for beans, and 58.9% for rice. Quantity of cereal grains stored by farmers varied by crop and was significantly higher for rice than maize ($p = 0.0001$). Quantity stored ranged from 5 to 2800 kg for rice (median 1150 kg) and 80 to 2050 kg for maize (median 537.5 kg) (Figure 2A).

Quantities of legumes stored were smaller and significantly different ($p = 0.0006$) among crops. They varied from 5 to 600 kg for lentils (median 35 kg), 0.75 kg to 825 kg for beans (median 14.5 kg), 2.5 to 200 kg for soybean (median 26.5 kg), and 2 to 105 kg cowpea (median 17.5 kg) (Figure 2B). A few additional legumes were stored by a limited number of farmers, including Mung beans (*Vigna radiata*), Black gram (*Vigna mungo*), Pea (*Pisum sativum* L.). About half of the farmers who stored grain kept it for more than nine months and primarily stored for home consumption (Table 2).

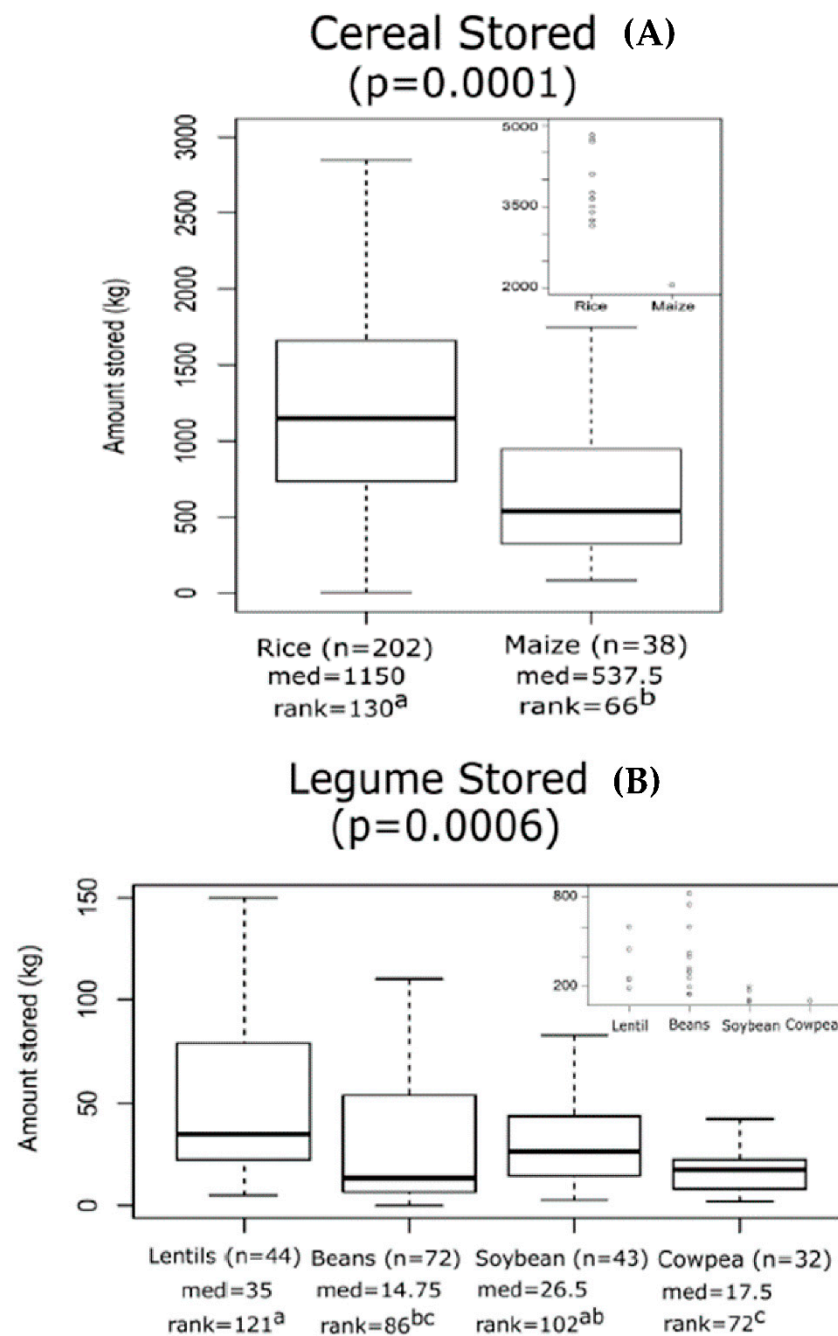


Figure 2. (A) Boxplots showing the quantity of cereals and (B) legumes stored by farmers in Bagmati Province, Nepal. The smaller graph embedded in the main plot contains the outliers of each data set, i.e., data points greater than the 75th percentile value plus 1.5 times the interquartile range. Within cereals or legumes, crop ranks followed by similar upper letters are not significantly different in quantity stored.

Grain storage methods varied by district and crops. Among farmers who stored cereals ($n = 240$), 87.1% used granaries and woven bags, while of those who stored legumes ($n = 215$), 95.3% used plastic drums and woven bags. Most farmers who used granaries (97.8%, $n = 139$) and woven bags (67.3%, $n = 70$) for cereal storage were in Chitwan. Granaries and woven bags were mostly used to store rice (67.3% of farmers), while maize was piled on the ground in a circular raised structure (68.4% of farmers). Granaries were significantly more likely to be used by farmers storing rice (Pearson correlation coefficient $r = 44.5\%$, $p = 0.000$). Insecticides were mostly applied to grain stored in

granaries and woven bags. Hermetic storage technologies (HSTs) were predominantly used to store legume crops: beans (75%), lentils (88.7%), and cowpea (64.5%) (Table 2). Farmers indicated that the benefit of using HSTs included effectiveness in protecting grain (93.5%), no chemicals (34.8%), and ease of use (15.9%). Among farmers who did not use HSTs ($n = 108$), the main reasons were lack of awareness (77.0%), unavailability (16.4%), and high price (6.7%).

Table 2. Storage practices, challenges, and protection methods for cereals and legumes among farmers in Chitwan and Dhading districts, Nepal.

Variables	Categories	Rice n = 202	Maize n = 38	Beans n = 72	Lentils n = 44	Soybean n = 43	Cowpea n = 31
Reason for storage	Consumption	99.0	73.7	69.4	97.7	86.0	93.6
	Sell	1.0	2.6	30.6	2.3	14.0	6.4
	Animal feed	0.0	23.7	0.0	0.0	0.0	0.0
Storage Duration	<3 months	11.9	21.1	31.9	34.1	34.8	19.4
	3–6 months	12.4	10.5	1.4	6.8	9.3	25.8
	6–9 months	7.4	5.3	8.3	9.1	4.7	3.2
	>9 months	68.3	63.1	58.4	50.0	51.2	51.6
Storage methods	Granaries ^a	67.3	7.9	2.8	4.5	4.6	3.2
	Woven bags	31.2	18.4	22.2	6.8	60.5	32.3
	Hermetic	1.0	5.3	75.0	88.7	34.9	64.5
	Hanging/piling	0.5	68.4	0.0	0.0	0.0	0.0
Storage challenges	Insects	49.7	52.2	25.0	36.4	16.3	64.5
	Rodents	42.4	43.3	2.8	2.3	13.9	0.0
	Decay/mold	7.9	4.5	0.0	0.0	0.0	0.0
	No damage	0.0	0.0	72.2	61.3	69.8	35.5
Primary method of protection	Chemicals	40.6	5.3	0.0	4.6	0.0	9.7
	Botanicals	18.3	18.4	13.9	6.8	18.6	22.6
	Hermetic	3.5	7.9	59.7	70.4	16.3	22.6
	Do nothing	33.2	68.4	26.4	11.4	65.1	41.9
	Others	4.4	0.0	0.0	6.8	0.0	3.2

^a Granaries refers to traditional storage structures of rolled bamboo mat or rolled paddy straw mat.

Insect damage was the major storage challenge for cereals but less so for legumes. About two-thirds of farmers reported no damage to most stored legumes, except cowpea. Farmers identified several pests of stored cereals including rice weevil (*Sitophilus oryzae* L.) (91.3%), rice moth (*Corcyra cephalonica* Stainton) (89.2%), sawtoothed grain beetle (*Oryzaephilus surinamensis* L.) (0.8%), lesser grain borer (*Rhyzopertha dominica* Fabricius) (1.3%), Indian meal moth (*Plodia interpunctella* Hübner) (0.8%), and Angoumois grain moth (*Sitotroga cerealella* Olivier) (0.4%). Farmers with infested cereals were more likely to have rice weevil (Pearson correlation coefficient $r = 60.4\%$, $p = 0.000$) and/or rice moth (Pearson correlation coefficient $r = 53.1\%$, $p = 0.000$) as the major pests. Stored rice infested by rice weevil was significantly likely to be attacked by rice moth as well (Pearson correlation coefficient $r = 79.4\%$, $p = 0.000$). Legume crops were mostly infested by bean weevils (*Bruchus* spp. and *Callosobruchus* spp.)

3.3. Grain and Seed Protection during Storage, and Use of HST

Among farmers using synthetic pesticides to protect cereals during storage ($n = 89$), 98% of them applied chemicals on rice. Most farmers storing maize (68.4%) did nothing to protect their grains. Ninety-six percent of farmers who used pesticides to store grain obtained them from Agroveter shops (Table 3). Farmers used different types of synthetic pesticides to protect cereals against insect/rodent attacks: 83.2% for Aluminum Phosphide, 9.0% for Dichlorvos (DDVP), 3.4% for Malathion, 2.3% for Methyl parathion, and 4.5% for rodenticides (Table 3). It is important to note that a small proportion of farmers (1.1%)

used a fungicide (Mancozeb) on stored cereal grains. Pesticides were significantly likely to be used by farmers in Chitwan (Pearson correlation coefficient $r = 53.8\%$, $p = 0.000$). Only a small number of farmers ($n = 7$) used pesticides (Aluminum Phosphide, Malathion, and Methyl parathion) to protect legumes against stored grain pests. Farmers preferred pesticides for several reasons, the major one being efficacy (61.1%). Among those applying pesticides, the majority of farmers (63.3%) noted that there were no issues with chemical use.

Table 3. Information on pesticides and hermetic storage technologies (HSTs) in Chitwan and Dhading districts, Nepal.

Variables	Categories	Chitwan	Dhading	Overall	
		(n = 57)	(n = 32)	(n = 89)	
Pesticides (%)	Pesticides used to protect cereals ^a	Aluminum Phosphide	98.3	56.3	83.2
		Dichlorvos (DDVP)	3.5	18.8	9.0
		Malathion	1.8	9.4	3.4
		Mancozeb	0	9.4	1.2
		Methyl parathion	0	3.1	2.2
		Rodenticides	0	6.3	4.5
	Source of pesticides	Agrovet shops	96.5	93.9	95.6
		Farmers' cooperatives	3.5	6.1	4.4
	Advantages of pesticides	Effective	57.9	66.8	61.1
		Easy to use	22.8	12.1	18.9
		Don't know	7.0	15.1	10.0
		Locally available	12.3	3.0	8.9
		Low price	0	3.0	1.1
	Disadvantages of pesticides	None	68.4	54.5	63.3
		Hazardous	17.6	27.3	21.1
Not effective		7.0	15.2	10.0	
Lack of knowledge		7.0	3.0	5.6	
		(n = 82)	(n = 55)	(n = 137)	
Hermetic Storage Technologies (HSTs) (%)	Source of HSTs	Agrovet shops	100 ^a	16.3	66.3
		Donation from NGO	0	76.3	30.7
		Government agencies	0	7.4	3.0
	HSTs used to protect grains	Plastic drum ^b	86.6	18.2	59.1
		PICS Bag	1.2	47.3	19.7
		SuperGrainbags™	2.4	29.1	13.1
		Metal Silos	9.8	5.4	8.1

^a The total is more than 100% because some farmers used more than one pesticide; ^b Commonly available plastic barrels on the market.

Among farmers using hermetic containers to store legumes, the majority used them to protect beans (59.7%) and lentils (70.4%). Most farmers storing soybean (65.1%) did not protect their commodity. About three-fourths of farmers were aware of HSTs but only 12.4% were trained in their use. A little over half of farmers (56.8%) had used HSTs including plastic drums, PICS bags, SuperGrainbags™, and metal silos. Plastic drums were the most used HSTs in Chitwan (86.6% of farmers, $n = 57$), and farmers purchased them from Agrovet shops. Most farmers in Dhading noted that flexible HSTs including PICS bags (47.3% of farmers) and SuperGrainbags™ (29.1% of farmers) were obtained through donations from NGOs and relief interventions after the 2015 earthquake (Table 3). Farmers using HSTs ($n = 108$) indicated that the benefits included effectiveness (93.5%), no chemicals (34.8%), and ease of use (15.9%). Farmers who were not using HSTs ($n = 104$) gave several reasons including lack of awareness (77.0%), unavailability (16.4%), high price (6.7%), lack of training on how to use (2.9%), and ineffectiveness (1.0%).

Seed storage was practiced by most farmers (77.2%, $n = 241$) in both districts. Farmers who did not store seed ($n = 55$) purchased it from Agrovet shops (60.8%), farmers' groups/cooperatives (35.3%), or community seed banks (3.9%). Among farmers who stored seed, 71.4% had insect damage. Farmers used a variety of seed storage methods

including hermetic methods (23.8%), botanicals (17.5%), synthetic pesticides (11.6%), ash (11.6%) and drying (2.6%). A third of farmers (31.2%) did not use any protection methods to maintain seed quality during storage.

3.4. Farmers' Decisions to Use Insecticides during Storage

To evaluate the factors that influence a farmer's decision to use pesticides for grain storage, we considered "district", "contact with extension agents", "storage container", "storage duration", "storage location", and "insect damage" as independent variables in the logistic regression model (L.R. test $p < 0.001$). The decision to use pesticides on grain was significantly influenced by the crop stored, storage method, and the incidence of insect damage. Farmers who stored rice (OR = 8.5) were more likely to use insecticides than those storing maize. Similarly, farmers who stored in granaries (OR = 1.0) were more likely to use insecticides than those who stored in woven bags. Additionally, farmers experiencing insect damage (OR = 9.8) were more likely to use pesticides (Table 4).

Table 4. Factors influencing farmers' decisions to use insecticides to protect grain during storage in Chitwan and Dhading districts, Nepal.

Variables	Categories	OR ^a	95% CI ^b	<i>p</i> Value	L.R. Test ^c
District	Chitwan	1.0	(referent)	0.4	$X^2 = 43.844$ $df = 6$ $p = 0.000$ $LogLik = 7.9388$
	Dhading	0.7	(0.4, 1.5)		
Stored crop ^d	Maize	1.0	(referent)	0.04	
	Rice	8.5	(1.4, 100.7)		
Storage containers ^e	Granaries	1.0	(referent)	0.56	
	Raised and piled up structures ^f	0.5	(0.05, 5.37)		
	Woven bags	0.4	(0.21, 0.79)		
Storage duration ^g	Less than six months	1.0	(referent)	0.15	
	More than six months	1.6	(0.84, 3.34)		
Insect damage	No	1.0	(referent)	0.03	
	Yes	9.8	(1.7, 183.4)		

^a OR = odds ratio; ^b CI = confidence interval; ^c L.R. = Likelihood Ratio test; X^2 = Chi-square value; df = degrees of freedom; p = probability value; $LogLik$ = model's log likelihood; ^d Wheat was excluded because of low percentage value; ^e Hermetic storage was excluded because of low value; ^f Traditional maize storage: maize cobs are tied together using their husks and then piled up; ^g Storage durations were grouped into less than six months and more than six months.

4. Discussion

4.1. Grain Storage and Pest Challenges

Rice is an important staple food in Nepal and grown by family farms to meet their household needs for consumption as well as for income generation [24,25]. This in part explains why rice was stored in larger quantities compared to other crops. Overall, in both districts, crop production was strongly focused on cereals, followed by legumes [3,9,20]. Cereals were often intercropped with legumes [26]. In Dhading, maize was mainly intercropped with soybean, while in Chitwan rice was grown together with beans. The storage duration of grains for six months or more in Nepal is in congruence with findings from other developing countries in sub-Saharan Africa and Latin America [27,28]. Though farmers in Chitwan who had access to year-round irrigation grew rice twice a year, they preferred to store fine rice (grown in the main season) for more than nine months because of its organoleptic traits [3]. Maize, on the other hand, a vital animal feed, was usually shredded and mixed with rice bran and given to lactating animals [29]. Legume crops were produced in smaller quantities and mostly used for home consumption. However, in recent years, farmers have increased the production and commercialization of legume crops such as lentils due to higher market demands [20].

Farmers in Dhading and Chitwan used a variety of storage methods but preferred traditional granaries and woven bags; just like farmers in other developing countries [28,30,31].

Traditional storage structures used by farmers in both the low and midland of eastern Nepal included Kunio and Thangros [30]. Maize is stored by piling up cobs on the floor/wooden platform or hanging on vertical poles and ropes inside the house [31]. This was a common practice in both districts and other parts of Nepal [10]. Because legumes such as cowpea and soybean were usually stored in small amounts, farmers often used small and portable containers such as woven bags and plastic containers [31].

Traditional structures and woven bags have higher losses due to pests, leading to grain damage and loss of germination [32,33]. Insects caused the most damage followed by rodents, as found in another study in Nepal [13]. Insect damage increased with the duration of storage with severe losses observed when grain was stored for more than six months, particularly during summer months (Ransom, 2000). Storage pests identified during this survey have been reported by other studies in Nepal [11,13,34]. Insect pests can cause losses ranging from 15% to more than 75.0% in maize and rice stored in traditional granaries without insecticides [9,30]. To control these pests during storage, farmers applied various types of insecticides [35]. Farmers have primarily used hermetic bags as alternatives to insecticides to manage storage insect pests [36]. Affordable technologies such as hermetic bags will help reduce these losses and hence improve food security and increase income of smallholder farmers [3,4].

4.2. Grain and Seed Protection during Storage

The distribution of pesticides in Nepal is done primarily through Agrovets shops and, to a lesser extent, cooperatives [21,35]. Our results support findings that pesticide use was higher in the lowlands (Chitwan compared with Dhading) [35]. Farmers used a variety of pesticides to control insects and rodents during grain storage. Most of these pesticides were misused, resulting in food poisoning, environmental pollution, and sometimes death [12,15,37]. Pesticide poisonings often occur from incidental and occupational exposures; this may be why only a few farmers reported pesticides as hazardous (Sharma et al., 2013). Inadequate awareness and training in safe and efficient application of pesticides have led to poisoning [38]. A limited number of farmers used a fungicide (i.e., Mancozeb) on stored grains. Other farmers used pesticides (i.e., Dichlorvos) that are no longer recommended for use on stored grain by the Plant Protection Directorate of Nepal [37]. Scaling up safe and affordable storage options (e.g., hermetic bags) would help address pesticide-related issues during postharvest management of grains.

Most farmers in both districts stored seeds for planting in the subsequent cropping seasons. Insect damage was quite common during seed storage. Farmers in Chitwan used hermetic containers (e.g., plastic containers and metal bins) to preserve their seed, while those in Dhading mostly used ash and botanicals (plant parts or extracts). Synthetic pesticide use for seed storage was low in both districts. Botanicals have been used to preserve seed during storage because they have been shown to be as effective as malathion in controlling insects [8]. Farmers (mostly those who did not store) purchased seed from Agrovets shops but community-based seed production by agricultural cooperatives is increasing in both districts in Nepal [39,40].

4.3. Farmers' Decisions to Use Insecticides during Storage

Farmers' decisions to apply insecticides to stored commodity varied by crop, storage methods, and the level of infestation. Farmers were more likely to treat their grain with insecticides if they stored rice, used traditional granaries, and incurred insect damage during storage. Similar findings were reported in Peru where farmers who experienced insect problems during storage were more likely to apply insecticides [28]. Because rice is a major staple crop and is important for food security, farmers are more likely to protect it from pests during storage. In addition, as reported in sub-Saharan Africa, farmers who stored longer tended to use pesticides [14]. Just like farmers in other countries, farmers in Bagmati Province clearly preferred pesticides to protect stored commodities because they are effective [41]. These results were in line with the technology adoption literature,

indicating that the innovative technologies can be useful to control insect pests and improve food security in developing countries [23]. However, pesticides can be harmful to humans if misused or overused [42]. Finding safer alternatives to insecticides will help reduce their impacts on human health and the environment [12,38]. Evidence from Uganda suggested that households that received hermetic bags were less likely to use storage pesticides [43]. Disseminating hermetic bags would help reduce the use of chemicals for grain storage and reduce the potential threat of pesticides on human health.

4.4. Hermetic Storage Use

Hermetic storage methods are viable chemical-free alternatives to traditional methods and pesticides used for grain storage among smallholder farmers [33,44]. They effectively control pests of stored products, maintain seed quality, improve food security, and increase the income of smallholder farmers [32,33,36,45]. Though farmers reported not having issues while using hermetic storage methods, some of the challenges associated with rigid containers such as silos and drums are cost, efficacy when not fully filled, and scalability [44,46,47]. Training and capacity-building in the use of these rigid containers may help to address some of these issues.

Flexible hermetic containers (e.g., PICS bags and SuperGrainbags™) are often attractive alternatives to airtight rigid storage containers among smallholder farmers. A recent study conducted in Chitwan, Nepal, showed that PICS bags and SuperGrainbags™ were effective at preserving stored maize [16,32]. Hermetic bags have been disseminated to millions of smallholder farmers in Africa [44]. Though there are suppliers of both PICS and SuperGrainbags™ in Nepal, the use of these technologies among farmers remains low due mostly to limited awareness and unavailability. Similar adoption constraints have been observed in sub-Saharan Africa [48]. A study conducted in Nepal identified education and access to savings as the main variables that influence the adoption of hermetic bags [17]. Only a small proportion of farmers complained about the price, which is about NPR 250 (Nepalese rupees, about USD 2.50) for a 50 kg hermetic bag. Farmers who produced enough to store seldom complained about the price of hermetic bags because they are affordable [44]. A cost-benefit analysis conducted in several districts in Nepal showed a positive gain when grains (e.g., rice) were stored in hermetic bags compared to traditional storage methods [17]. Creating awareness and developing a sustainable supply chain of hermetic bags will increase adoption among smallholder farmers in rural areas of Nepal. Increasing awareness of hermetic bags among farmers will increase their willingness to pay for these storage technologies [49].

5. Conclusions

This study found that rice was the most stored grain in Bagmati Province, Nepal. Cereal and legume crops were mostly stored for consumption. Insect pests were the major sources of losses during storage. Traditional storage structures such as granaries offered little or no protection to grain during storage unless pesticides were applied. Because most farmers stored grain for nine months or more, they often applied pesticides, which are often highly toxic or prohibited. These practices have resulted in food poisoning and sometimes loss of human lives. Cost-effective hermetic technologies (e.g., hermetic bags) provide alternatives to pesticides and traditional storage methods. Disseminating hermetic bags to store rice would significantly improve food security, safety, and the income of farmers in Nepal, given their importance in the production system (most stored), storage challenges, and high pesticide application.

Author Contributions: Conceptualization, K.K. and D.B.; methodology, K.K., A.N., B.W.S., R.H.T., G.P.P. and D.B.; software, K.K. and A.N.; validation, P.K., A.N., B.W.S., J.R.D.-V. and D.B.; formal analysis, P.K., A.N., J.R.D.-V. and D.B.; investigation, K.K., B.W.S. and R.H.T.; resources, K.K. and D.B.; data curation, P.K.; writing—original draft preparation, P.K.; writing—review and editing, K.K., A.N., B.W.S., R.H.T., G.P.P., J.R.D.-V. and D.B.; visualization, P.K. and D.B.; supervision, D.B.; project administration, K.K., B.W.S. and D.B.; funding acquisition, K.K. and D.B. All authors have read and agreed to the published version of the manuscript.

Funding: We thank the Conservation, Food and Health Foundation (CFHF, Grant # 41000414) and the Bill and Melinda Gates Foundation (BMGF, grant# INV-006972) for providing support to this research.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Purdue University (protocol code 1405014885; on 6 November 2018).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Raw data are not publicly available, though the data may be made available on request from the corresponding author.

Acknowledgments: We thank all the organizations (local NGOs and private sector partners) and individuals for providing support during the field survey, including those who supplied the lists of farmers to be interviewed in the different VDCs, and the enumerators for collecting data. Our deepest gratitude to all farmers who spared their valuable time to answer the questions.

Conflicts of Interest: The authors declare the following financial interest/personal relationships, which may be considered as potential competing interest: Dieudonne Baributsa is a co-founder of PICS Global Inc., a social enterprise that commercializes postharvest technologies (including PICS bags) to smallholder farmers around the world and hence declares a conflict of interest. The other authors declare no conflict of interest. The funders (Conservation, Food and Health Foundation and the Bill and Melinda Gates Foundation) had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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