Determinants of smallholder farmers' maize grain storage protection practices and understanding of the nutritional aspects of grain postharvest losses

Short title: Grain protection practices and postharvest nutritional loss

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Abstract

Poor storage methods lead to high postharvest losses in maize, an essential staple in sub-Saharan Africa. Smallholder farmers' knowledge and awareness of postharvest nutritional losses (PHNLs), practices regarding maize grain storage, and factors influencing use of improved storage protection practices were investigated in two districts in Zimbabwe through a cross-sectional field survey of 331 households randomly selected from lists of farmers' names kept by local extension staff. A multistage sampling technique was used involving purposively selecting the study districts then randomly selecting the study wards, the villages and the households. Twenty eight key informant were purposively selected being officers and stakeholders working or residing in the two districts and involved in postharvest and nutrition issues. The most commonly used storage practices were the admixture of maize grain with synthetic grain protectant pesticides followed by storage of untreated grain in polypropylene bags. Highly toxic pesticides, such as Cabaryl 85 WP and Acetamiprid 20 SP, which are not registered for stored food grain treatment, were being applied by 14.6% of the farmers to protect their grain from insect attack. We developed a PHNL knowledge index that measured farmers' nutritional knowledge and awareness of PHNL. Level of education and district positively correlated with farmers' PHNL knowledge ($p<0.05$), whereas the opposite was found for farmers' age ($p<0.05$). Multinomial logistic regression analysis showed that use of grain storage protection practices was positively related to farmers' age, total maize grain production, education level and PHNL knowledge ($p<0.05$). Older farmers were less likely to use non-recommended chemicals to protect their maize grain during storage. Farmers' education level and total maize grain production were positively associated with higher use of synthetic pesticides, while PHNL knowledge was associated with the use of traditional grain protectants ($p<0.05$). Training on grain storage management, especially safe grain storage protection practices and PHNLs, is essential to contribute towards household food and nutrition security.

Key words: Grain storage, Improved storage practices, Nutritional losses, Postharvest nutrient loss index, Nutrition security

1. Introduction

Maize is a staple food crop in sub-Saharan Africa (SSA) and forms a substantial part of most meals. Maize grain plays a key role as a food security crop and supplies most of the calories for millions of people across SSA (Afzal et al., 2009; Nuss and Tanumihardjo, 2010). As maize proteins are deficient in several amino acids (e.g., lysine and tryptophan) (Nuss and Tanumihardjo, 2010), maize-based diets need complementing with other foods. Where quantitative and qualitative postharvest losses (PHLs) occur, the nutritional value of the grain can be reduced (Garbaba et al., 2017; Stathers et al., 2020). Despite being the main producers of food on the sub-continent, smallholder farmers in SSA often grapple with poverty and food insecurity (Sheahan and Barrett, 2017). The majority of smallholder farmers in SSA live below the poverty line of US$2 per day (FAO, 2019). Effective postharvest practices and technologies can help minimise both quantitative and qualitative losses of maize grain.

The average annual PHLs of maize in SSA range from 10-20% (World Bank et al., 2011; APHLIS, 2020). High PHLs contribute to food and nutritional insecurity, especially losses incurred during storage when insects, rodents or fungi consume various components of kernels leading to a loss in weight and ultimately nutrients. Additionally, studies in Zimbabwe have found a high occurrence of mycotoxins (AFB_1 and FB_1) in maize (Hove et al., 2016; Murashiki et al., 2018), respectively. Murashiki et al. (2018) investigated the effectiveness of different types of storage containers in limiting aflatoxin B_1 (AFB_1) and fumonisin (FB_1) in stored maize grain in Zimbabwe. Occurrence of AFB_1 was lower in grain stored in hermetic storage containers than conventional stores, whereas occurrence of FB_1 was not affected by the type of storage container used (Murashiki et al., 2018).

Postharvest quality loss due to fungal infestations and associated mycotoxins is a well-recognised global issue (Ayalew et al., 2016). Comparatively little work has focused on measuring the value of insect-mediated PHLs in quality (Hodges, 2013; Affognon et al., 2015). Although fungal infestations can be difficult to determine due to the invisibility of mycotoxins; a Kenyan study found farmers placed a large premium on maize they had grown themselves relative to that available for purchase on the market without knowing the mycotoxin contamination status (Hoffman and Gatobu, 2014). Another study in Kenya found farmers producing maize for the market under-invested in quality relative to farmers producing for home consumption (Hoffman, 2018). Although visible quality losses do lead to price discounts at market (Kadjo et al., 2016; Jones et al., 2016), and can thus impact on household income as well as nutrition (Stathers et al., 2020).

Many smallholder farmers focus on reducing the quantitative PHLs but do not pay attention to qualitative losses that can further reduce the nutritional value of maize (Sheahan and Barrett, 2017; Garbaba et al., 2017; Stathers et al., 2020). The invisibility of some indicators of postharvest nutrient loss can make it challenging to identify. For example, grain kernels may be whole and physically undamaged, but with reduced nutritional value (e.g. loss of fat and lipophilic vitamins such as vitamins A and E) due to oxidation during long-term storage at ambient temperatures (Golob, 2002; Dubale et al., 2012). A decrease in carbohydrates and fats in insect-infested maize due to consumption of the endosperm of the grain by storage insect pests was observed by Garbaba et al. (2017) in Ethiopia. In the same study, dietary fibre and minerals increased in infested grain as these nutrients are mostly concentrated in the bran and germ of the grain. A knowledge gap exists with regards to many of aspects of postharvest nutrient loss as some indicators of quality loss such as bad taste, discolouration, insect grain perforations, mould growth and bad smell are easily discernible but are difficult to correlate directly with nutritional loss. Improper storage facilities may lead to insect infestation and oxidation of grain, causing postharvest losses in the nutritional value as well in other quality loss parameters (Shee et al., 2019).

Awareness is defined as the ability to directly know and perceive, to feel, or to be cognisant of events (Rogers, 2003). Awareness influences decision-making; for instance, farmers who are aware of the need to maintain grain quality to conserve its nutritional value may adopt improved storage practices to mitigate losses. However, the adoption or use of improved practices will also depend on the availability, affordability, appropriateness of the technologies, and ability to apply the practices, among other factors.

Optimal crop production aims to address many factors, including, germination, tolerance to field drought and pest and disease damage, maximizing of grain yield, maturity periods, taste and minimizing of environmental damage and PHLs. To minimise PHLs, it is important to evaluate farmers' knowledge regarding PHLs and identify where interventions are needed (Amponsah et al., 2018). In studying rice farmers in Ghana, Amponsah et al. (2018) found that most farmers (98%) were fully aware of the causes and opportunities to reduce PHLs, yet they continued to sustain high losses. This suggests other factors, beyond knowledge, contribute to postharvest loss (Barham et al., 2004; Bokusheva et al., 2012). Smallholder farmers in Zimbabwe reported obtaining their agricultural knowledge from their own experiences and that of their friends and family, and through training by government agricultural extension staff, different research institutions and Non-Governmental Organisations (NGOs) (Nyabako et al., 2020). Measuring farmers' knowledge levels regarding postharvest nutrient loss (PHNL) is complex, and there is a dearth of data on this topic. The development of a PHNL knowledge index - building on other nutritional knowledge indices such as those described by Yahia et al. (2016), Asakura et al. (2017), and Valmórbida et al. (2017) - could help in obtaining estimates of this knowledge-base.

While significant effort has gone into the development and dissemination of PHL reduction technologies, high losses continue to be recorded in SSA, prompting the need to review factors affecting the adoption and use of postharvest technologies (Mvumi and Stathers, 2003; Atibioke et al., 2012; Bokusheva et al., 2012; Villane et al., 2012; Gbénou-Sissinto et al., 2018). In a project that facilitated the manufacture and dissemination of metal silos, a post-project adoption analysis showed that regional policies, age of the head of household, land ownership and production self-sufficiency were the main determinants of adoption (Bokusheva et al., 2012). The objectives of the current study were: (i) to examine the knowledge and practices of smallholder farmers with regards to maize grain storage and postharvest nutrient losses; and (ii) to identify the factors influencing the use of improved grain storage protectant practices in the Zambezi Valley of northern Zimbabwe.

2. Materials and Method

2.1 Study sites

The survey was conducted in October 2017 in two purposively selected districts of Zimbabwe, Guruve (16.6609° S, 30.7034° E) and Mbire (20°43'60" S and 30°34'60" E) (Figure 1), which differ with respect to agro-ecologies and socio-economies. Selection of the two districts capitalized on previous postharvest management activities that had been implemented in the districts, upon which rapport had already been built with the district leadership. Therefore, it was easy for the research team to mobilise and organise the communities for the study with the help of the local leadership. Guruve represents a cooler climate with temperatures between 10 and 32°C and is within the relatively wetter zone with average annual rainfall of 775.5 mm (Moyo, 2000). Mbire is characterised by low annual rainfall (below 450 mm) and high temperatures between 32 and 42°C (Mugandani et al., 2012). Mbire is a relatively remote area about 250 km from the capital city of Harare, with mostly dirt roads. Guruve has better access to road networks, markets and information than Mbire district (Nyabako et al., 2020).

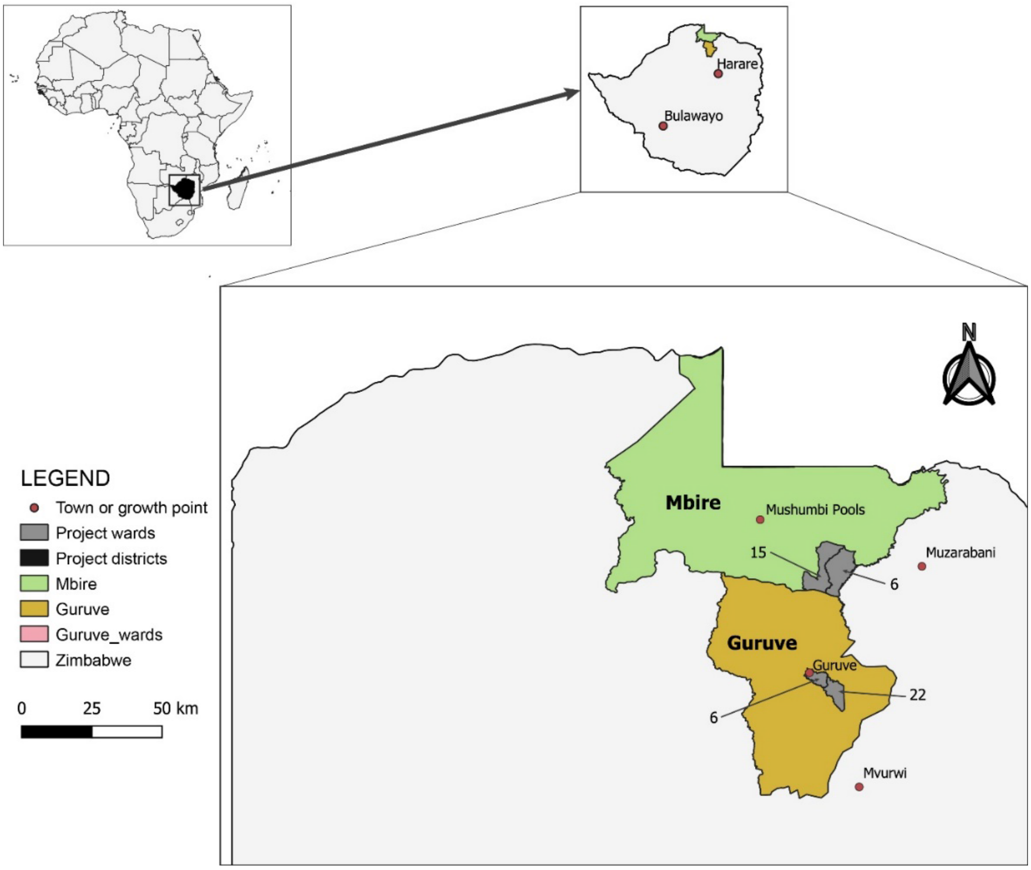

Fig. 1 Location of study districts and wards, Guruve (Ward 6 and 22) and Mbire (Ward 6 and 15), Zimbabwe

2.2 Target population, sample size and sampling techniques

A multi-stage sampling procedure with three levels (ward, village and household) was used to select household participants. A ward is an administrative division of a district. In each district, two wards were randomly selected using stratified random sampling technique with assistance from the district extension officers and District Development Coordinator (DDC) taking into consideration agro-ecological regions and socio-economic characteristics. Guruve and Mbire districts have 12 and 17 wards, respectively. A list of all the villages and households in the selected wards was obtained from the local agricultural extension officers and eight villages from each of the four wards were randomly selected using random numbers generated in Microsoft Excel (2016). The same procedure was used to select 12 households per village to give a total sample size of 96 households per ward i.e. 384 households between the two districts. However, due to non-response and inaccessibility of some households, it was only possible to interview 331 households (171 in Guruve district and 160 Mbire district).

2.3 Data collection methods

The survey was conducted through face-to-face individual interviews with household heads and with key informants using a structured questionnaire, and focus group discussions (FGDs) using a checklist. The survey tools were jointly developed by the team from the University of Zimbabwe and the Natural Resources Institute of the University of Greenwich and implemented by the former. In each district, four FGDs were conducted with each group comprising either 15 women or men. Men and women were separated to capture gender differences and facilitate more open discussion and sharing of views. A total of 331 farming households were interviewed by trained enumerators who spoke the local language and knew the study areas well. The questionnaires were administered in the local vernacular (Shona). Fourteen key informant interviews (KIIs) were conducted in each of the two districts giving a total of 28 KIIs. The key informants were selected based on their designation, working experience in the district, area of specialisation, link to farming activities, and knowledge of nutrition and public health – medical and public health practitioners. The informants included officers from Government of Zimbabwe departments (Health, Agriculture, Education and Social Welfare), local leadership, Non-Governmental Organisations (NGOs), quasi-state organisations and local agro-dealers. The selected key informants included agricultural extension officers (4), nutritionists (1), environmental health practitioners (2), nurses (6), social workers (2), agro dealers (3), agronomists (2), councilors (2), village heads (4) and NGOs representatives (agronomist and nutritionist) (2) per district.

The survey tools (structured and semi-structured) questionnaires were pre-tested before conducting the actual survey as a means of validation. Five enumerators participated in the pre-testing of the tools in each of the two districts. The enumerators' experiences and feedback were used to adjust the tools before the actual survey was conducted.

2.4 Data management and analysis

Household survey data were collected and entered into the CS Pro 7.3.1 application (2019), while statistical analysis was performed using IBM SPSS version 16 and Stata 14 software. Descriptive statistics (means, frequencies and percentages) were generated for all variables. The analysis included cross-tabulations, calculation of frequencies and Chi-square tests of association. Qualitative variables from KIIs and FGDs were analysed by summarising responses from different respondents and grouping the information into thematic areas.

To evaluate the PHNL knowledge of farmers, a PHNL knowledge index was computed based on the response from farmers. Farmers may acquire PHNL knowledge from their own postharvest handling experience or in some cases, through training events organised by different research and extension institutions and NGOs working in both the technical and geographical areas. To our knowledge, no information on the construction of a PHNL knowledge index or score was available, and so we borrowed from the literature on index construction from other disciplines. Following work by Earnest et al. (2015) and Australian Bureau of Statistics. (2006), a knowledge index was constructed by combining different components relating to knowledge about aspects of the focal topic, which in this case was PHNL. A structured and iterative process was used to identify and include important variables on PHNL for inclusion in the final PHNL knowledge index (Parmenter and Wardle, 1999; Singh and Hensel, 2014; Earnest et al., 2015; Yahia et al., 2016; Asakura et al., 2017; Valmórbida et al., 2017; Zhibing et al., 2021).

We considered the following factors and numerical scores:

(1) Farmer's general knowledge on nutrients, the respondents able to explain what nutrients are would get a score of 1, otherwise a 0 score was given; (2) Knowledge and ability to name any of the specific nutrients present in maize grain. The sum of correct nutrients known by the

farmer was scored from 0 to 5, with a maximum score of 5 given if five or more nutrients were named; (3) Knowledge of any indicators of postharvest nutrient change in produce. The sum of nutrient change indicators known by the farmer was scored from 0 to 6. Such indicators included, bad smell, strange colour, insect feeding noise, physical loss of part of the grain, bad taste and grain floating in water; and (4) Knowledge and ability to name the life-stage group most affected by nutrient deficiencies in the community. The maximum score of 3 was given when the following three groups were identified: children, pregnant women, and the elderly.

The weighted score (w_w) for each factor was calculated by dividing the attained score by the range as shown in Equation 1. The PHNL knowledge index weighted score was computed by multiplying each score in the set by its weight, then adding up the products as shown in equation 2.

$$w_w = \frac{actual\ score}{range} = \frac{actual\ score}{maximum\ score - minimum\ score} \qquad \text{(Equation 1)}$$

Where w_w = weighted score for each factor

$$PHNLS_i = \sum(w_w W_i + w_x X_i + w_y Y_i + w_z Z_i) \qquad \text{(Equation 2)}$$

where $PHNLS_i$ = Postharvest nutritional loss knowledge score, W_i = (0,1) knowledge of farmers on nutrition, X_i = (0, 1,…,5) sum of nutrients known, Y_i = (0, 1, ..., 6) knowledge of indicators of postharvest nutrient change, and Z_i = (0, 1, 2, 3) knowledge of life-stage groups most affected by nutrient deficiencies. w_w = weighted score for knowledge of farmers on nutrition, w_x = weighted score for sum of nutrients known, w_y = weighted score for knowledge of indicators of postharvest nutrient change, w_z = weighted score for knowledge of life-stage groups most affected by nutrient deficiencies.

The weighted PHNL knowledge score was used as a continuous variable in the analysis of data. Ordinary least squares (OLS) regression was performed to evaluate the determinants of PHNL knowledge (Zdaniuk, 2014). To evaluate the factors influencing farmers' use of different storage practices, a multinomial logistic regression analysis model was used following Mustapha et al. (2017), Bandara and Thiruchelvam. (2008) and Ojo et al. (2013). Multinomial regression is used to model nominal outcome variables, in which the log odds of the outcomes are modelled as a linear combination of the predictor variables (Acock, 2012; Peng et al., 2002).

This model was appropriate to test the hypothesis behind the aforementioned objective given the nature of the dependent variable which has four categories of farmers. The basal group was farmers who did not use any treatment to protect their grain, and the other categories were those using synthetic grain protectant pesticides, those using traditional storage protectant practices, and those using chemicals not recommended as grain protectants or for use by smallholder farmers.

Synthetic grain protectant pesticides are registered chemicals formulated to kill storage insects and they require investment. Directions for using the synthetic pesticides e.g., application rates and methods, are given on the label and should be followed carefully to ensure safety and efficacy. The traditional storage protectant practices included the mixing of ash or indigenous pesticidal plants with grain, sunning of the grain, and rodent trapping. The chemicals not recommended as grain protectants or for use by smallholder farmers included fumigants and highly toxic chemicals typically used in cotton production, such as Carbaryl 85 WP. The no treatment category referred to farmers who do not apply anything to their maize grain prior to loading it into a polypropylene bag. Farmers using hermetic grain storage technologies, such as hermetic bags or metal silos were excluded as only 1% of farmers utilise these methods. The potential explanatory variables included district, sex, age, farm size/land holding, total grain production, education and PHNL knowledge.

Multinomial logistic odds and marginal effects were computed in STATA as described by Ojo et al. (2013) and Danso-Abbeam and Baiyegunhi. (2018). The farmer's PHNL knowledge, farm size, maize production level and age were treated as continuous variables in the model. The education level of respondents was segmented into three groups: high (secondary education and above i.e., 8 and above years of education), medium (standard, primary education and Zimbabwe Junior Certificate i.e., less than 8 years of education) and low (no formal education). This classification was adapted from that of the Organisation for Economic Co-operation and Development (OECD) classification of educational level in which pre-primary = 0; primary = 1; lower secondary level of education = 2; upper secondary level of education = 3; post-secondary non-tertiary = 4; first stage of tertiary education = 5 (OECD, 1999). However, our study considered the education classes such as no formal education, primary, Zimbabwe Junior Certificate (ZJC), secondary and tertiary education according to the classification of the Zimbabwean government (OECD, 1999). Our study merged some classes i.e. high (secondary and tertiary, medium (standard, primary and Zimbabwe Junior Certificate) and low (no formal education).

For a dummy variable, the effect of switching from the designated zero group to the exposed 1 group was used. For example, for the female dummy variable, the computed marginal effect shows the effect of switching the sex of household head from male (0) to female (1) and also district dummy shows the effect of changing of the district from Guruve (0) to Mbire (1).

3. Results

3.1 Maize storage protection practices

Synthetic grain protectant pesticides were the most commonly used storage insect pest control practice, and were used by 76.5% and 63.0% of households in Guruve and Mbire districts, respectively (Table 1). Only 1% of the farmers in Guruve and Mbire used hermetic technologies, such as hermetic grain storage bags or metal silos.

There was low usage of traditional storage protectant practices in Guruve and Mbire districts, 2.9% and 11.3%, respectively (Table 1). The traditional methods included the use of maize cob ash, cow dung ash, *Eucalyptus* leaves, use of indigenous pesticidal plants and sunning on a prepared area of ground (mud-plastered) or on plastic sheeting for storage insect pest control and cats or traps for rodent control. Chemicals not recommended for maize grain storage were being applied to stored grain by 17.7% and 11.3% of farming households in Guruve and Mbire, respectively. These chemicals included Cabaryl 85 WP and Acetamiprid 20 SP (Acetamark) - both of which are pesticides intended for use on cotton during the field growth stages - and the phosphine fumigant (Aluminium Phosphide 57%). Smallholder farmers do not have appropriate equipment or training to ensure safe application of the phosphine fumigant, which requires for example, airtight facilities, personal protective equipment such as a respirator and gloves, knowledge of how to apply and use fumigants, including understanding that fumigation must never be done within a 100 m radius of any human habitation. Among the respondents, 2.9% and 14.4% did not add any treatment to their grain to protect it during storage in Guruve and Mbire, respectively (Table 1).

Table 1 Use of different maize grain storage protection practices by smallholder farmers in Guruve and Mbire districts, Zimbabwe

Storage protection practice	**Percentage of farmers using each storage practice** Guruve (n=171)	Mbire (n=160)	Total (n=331)
Synthetic grain protectant pesticides[a]	76.5	63.0	70.0
Traditional[b]	2.9	11.3	6.9
Not recommended chemicals[c]	17.7	11.3	14.6
No treatment[d]	2.9	14.4	8.5

Key: [a]Synthetic grain protectant pesticides are registered chemicals formulated to kill storage insect pests and they need to be purchased; [b]Traditional includes ash, indigenous pesticidal plants, sunning and traps; [c]Not recommended chemicals, are those not registered for use as food grain protectants; [d]No treatment refers to grain that is loaded into polypropylene bags without first applying anything to protect it

3.2 Socioeconomic attributes of farmers using different maize storage practices

The proportions of those farmers using synthetic grain protectant practices or those using chemicals not recommended for stored-grain protection, were higher (56.3% and 62.5%, respectively) for Guruve district than in Mbire district (43.7% and 37.5%, respectively). Of the few farmers using traditional grain protectant practices or applying no treatment at all, a much higher proportion were in Mbire district (78.3% and 82.1%, respectively) than in Guruve district (21.7% and 17.9%, respectively) (Table 2).

The majority of the farmers using synthetic grain protectant pesticides had medium or high levels of education, 47.6% and 38.1%, respectively; while 37.5% and 43.8% of the farmers who were using chemicals not recommended as grain protectants had medium or high levels of education, respectively. Amongst the few farmers using traditional grain protectant practices, 43.5% had a low level of education. With regards to the farmers who did not treat their grain with a protectant prior to storage 53.6% had a medium level of education, while only 14.3% had a high level of education.

The age of respondents in the household interviews ranged from 20 to 95 years, with a mean age of 48 years. No significant difference in age ($P>0.05$) was observed among users of the four different storage practices (Table 2).

The mean total cropped land area of the respondents ranged from 1.55 to 1.89 ha. No significant difference in farm size was recorded among users of the four different storage practices. The respondents using synthetic pesticides or chemicals not recommended as grain protectants produced a significantly higher quantity of maize grain (1176 and 1199 kg, respectively)

($P<0.05$) than those using traditional storage protectant practices or not treating their grain (524 and 455 kg, respectively). The farmers using traditional storage protectant practices produced significantly ($P<0.05$) more grain (524 kg) than those not treating the grain (455 kg).

The mean weighted PHNL knowledge score ranged from 1.94 to 2.47 among the farmers using the four different storage practices. No significant difference in PHNL knowledge was observed among the farmers belonging to the four different storage practice groups ($P>0.05$) (Table 2).

3.3 Determinants of farmers' PHNL knowledge

Ordinary Least Squares (OLS) regression estimated the determinants of PHNL knowledge using explanatory variables such as age, education, location and gender. The model was statistically significant ($F = 4.791$). The model had three significant variables correlated with farmers' PHNL knowledge namely age, district and education. Farmers' age was negatively correlated with farmers' PHNL knowledge, as age of farmer increased, the level of farmers' PHNL knowledge decreased. The district dummy was significant, and positively correlated with farmers' PHNL knowledge. The farmers residing in Guruve district were more likely to have higher PHNL knowledge than those in Mbire district. Education had a significant and positive association with PHNL knowledge, the farmers with high level of education had high level of PHNL knowledge. The farmers' sex had no significant correlation with farmers' PHNL knowledge (Table 3).

Table 2 Socioeconomic attributes and maize storage grain protection practices of farmers in Guruve and Mbire districts, Zimbabwe

	Maize storage grain protection practice			
	Synthetic pesticides[a] (N=231)	Traditional[b] (N=23)	Not recommended[c] (N=48)	No treatment[d] (N=28)
District (%)				
Guruve	56.3	21.7	62.5	17.9
Mbire	43.7	78.3	37.5	82.1
Sex (%)				
Male	57.1	56.5	58.3	64.3
Female	42.9	43.5	41.7	35.7
Education (%)				
Low	14.3	43.5	18.8	32.1
Medium	47.6	39.1	37.5	53.6
High	38.1	17.4	43.8	14.3
Age (mean years)	47	52	43	51
	(20)	(20)	(16)	(20)
Farm size (mean hectares)	1.79	1.89	1.55	1.85
	(0.29)	(0.34)	(0.73)	(0.17)
Grain production (mean kg)	1176	524***	1199	455***
	(1192)	(541)	(910)	(583)
PHNL knowledge score (mean)	2.07	2.47	2.04	1.94
	(1.29)	(0.92)	(1.09)	(1.27)

Notes: *** $p<0.01$

Figures in parenthesis are standard deviations

Key: [a]Synthetic grain protectant pesticides are registered chemicals formulated to kill storage insect pests and they require investment; [b]Traditional includes ash, indigenous pesticidal plants, sunning and rodent trapping; [c]Not recommended chemicals are those not registered for food grain protection; [d]No treatment refers to grain that is loaded into polypropylene bags without first applying anything to protect it.

*Education: **Low** (no formal education), **Medium** (standard, primary education and Zimbabwe Junior Certificate i.e., less than 8 years of education) and **High** (secondary education and above i.e., 8 and above years of education).*

PHNL knowledge score – Postharvest nutrient loss knowledge score

Table 3 Determinants of farmers' PHNL knowledge on Ordinary least squares (OLS) regression

	Dependent variable:
	PHNL knowledge
Age	-0.008^{**}
	(0.004)
District – Mbire	0.274^{**}
	(0.138)
Education _High	0.546^{**}
	(0.218)
Education_Medium	0.217
	(0.193)
Sex – Female	0.005
	(0.143)
Constant	2.021^{***}
	(0.317)
Observations	331
R^2	0.070
Adjusted R^2	0.056
Residual Std. Error	1.201 (df = 317)
F Statistic	4.791^{***} (df = 5; 317)

*Notes: *** p<0.01, ** p<0.05, * p<0.1*
Figures in parenthesis are standard errors
PHNL knowledge – Postharvest nutrient loss knowledge
Education: Low (no formal education), Medium (standard, primary education and Zimbabwe Junior Certificate i.e. less than 8 years of education) and High (secondary education and above i.e. 8 and above years of education).

3.4 Determinants of smallholder farmers' maize grain storage protectant practices

A multinomial logit model was applied to estimate the factors associated with the use of different grain storage practices. The results of the multinomial logistic regression model marginal effects are shown in Table 4. The reference category of the dependent variable was farmers using no treatment to protect their maize grain.

The model had four significant variables in accounting for the probability to use the different storage practices. These variables were age, total grain produced, education and PHNL knowledge. District (location), sex and farm size had no significant association with the use of the storage practices (Table 4).

A one-year increase in a farmer's age was found to be associated with a 0.2% decreased likelihood of their use of non-recommended chemicals as grain protectants (Table 4). The use of commercial synthetic grain protectant pesticides was positively correlated with farmer's total maize production (Table 4). A one-unit increase in the quantity of maize produced by a farmer was more likely to increase the use of synthetic grain protectant pesticides.

The likelihood of using synthetic grain protectant pesticides or traditional storage protection practices was found to increase by 20.8% and 8.5%, respectively, as farmers' education increased from a low to a high level. In terms of PHNL knowledge, one-unit increase in PHNL knowledge was associated with a 2.3% increased likelihood of using traditional storage practices (Table 4).

Table 4 Factors associated with the use of different maize grain storage protectant practices based on marginal effects of multinomial logit regression (basal group is those using no treatment)

	Dependent variable (Storage practice)					
	Synthetic pesticides		Traditional		Non-recommended chemicals	
	dy/dx (se)	z	*dy/dx* (se)	z	*dy/dx* (se)	z
District_Mbire	-0.087 (-0.06)	-1.394	0.048 (-0.04)	1.307	-0.04 (-0.05)	-0.811
Sex_Female	0.03 (-0.05)	0.552	0.005 (-0.03)	0.155	-0.012 (-0.04)	-0.281
Age	0.002 (0.000)	1.403	0.000 (0.000)	0.317	-0.002* (0.000)	-1.817
Farm size	0.005 (-0.01)	0.513	0.002 (0.000)	0.32	-0.006 (-0.01)	-0.775
Total maize produced	0.000*** (0.000)	2.73	0.000 (0.000)	-1.412	0.000 (0.000)	1.286
Education_High	0.208*** (-0.08)	2.605	-0.085** (-0.04)	-1.958	-0.034 (-0.06)	-0.534
Education_Medium	0.160** (-0.07)	2.335	-0.071** (-0.03)	-2.103	-0.071 (-0.06)	-1.205
PHNL knowledge	-0.005 (-0.02)	-0.231	0.023* (-0.01)	1.762	-0.007 (-0.02)	-0.409

Notes: *** p<0.01, ** p<0.05, * p<0.1

Figures in parenthesis are standard errors (se)

PHNL knowledge – Postharvest nutrient loss knowledge Education: Low (no formal education), Medium (standard, primary education and Zimbabwe Junior Certificate i.e., less than 8 years of education) and High (secondary education and above i.e., 8 and above years of education).

4. Discussion

4.1 Stored maize grain protection practices

Synthetic chemical grain storage protectant pesticides were the most commonly used storage pest management method in both Guruve and Mbire districts of Zimbabwe. This concurs with a previous study in Hwedza district of Zimbabwe, reported by Nyabako et al. (2020). A study in the Eastern province of Kenya, also reported the use of synthetic grain protectant chemicals as smallholder farmers' main stored grain pest management strategy (Abtew et al., 2016).

Hermetic storage technologies are not being widely used within Zimbabwe. The current study found that just 1% of respondents in Guruve and Mbire districts were using them, despite their high efficacy in protecting stored grain (Obeng-Ofori, 2011; De Groote et al., 2013; Chigoverah and Mvumi, 2016; Mlambo et al., 2017; Murashiki et al., 2018; Singano et al., 2019; Mubayiwa et al., 2021). Similar findings were reported by Moussa et al. (2014), Bokusheva et al. (2012) and Gitonga et al. (2015); highlighting the slow adoption of modern hermetic technologies by farmers in many parts of Africa. Where promotion has occurred, such as in Nigeria, Niger and Burkina Faso, about two thirds of women farmers were reported to use some type of modern hermetic technology e.g., hermetic grain storage bags or metal silos. Such farmers cited training by extension staff and the radio as the most important sources of information on use of hermetic storage technologies (Ibro et al., 2014). In the current study, during the FGDs and KIIs, farmers and agricultural extension staff explained the major constraints for use of hermetic technologies were their unavailability locally, combined with a lack of knowledge about them. Training and awareness-raising regarding use of modern hermetic technologies are critical in creating demand and ensuring that maximum benefits can be obtained from the use of them.

The farmer's stored maize grain may be infested by a wide range of insect species and/or rodents and fungi. These result in loss of grain quantity and nutrition due to feeding and biological activities in the grain (Stathers et al., 2020). Fungi may consume the carbohydrate and fat for energy, which contributes to nutritional changes (Reed et al., 2007). The fungi may also produce toxic secondary metabolites and contaminate the grain with mycotoxins. However, mycotoxin contamination is typically invisible. In situations where food safety standards are implemented, such contamination, if above the agreed maximum tolerable level, will result in a 100% loss of all the grain and the nutrients it contained. In a typical SSA domestic food system, where food safety standards are rarely monitored or enforced and the bulk of the population consume their own produce, grain infected by fungi may not be removed resulting in the consumption of grain with reduced nutritional content and the harmful effects of mycotoxin contamination (Shephard, 2008, Ayalew et al., 2016, Omotayo et al., 2019). The current study, however focused on farmers postharvest nutrient loss knowledge. Further studies incorporating fungi infestation and subsequent mycotoxin contamination is recommended.

In the current study, farmers reported using chemicals such as Cabaryl 85 WP, a cotton field pesticide, to protect their grain during storage. This is not recommended as the chemical is highly toxic with a rat oral LD_{50} of 225 mg/kg (compared with > 2000 mg/kg for registered synthetic grain pesticides) and may cause food poisoning when ingested. However, during the FGDs, the farmers explained that these non-recommended pesticides were highly effective and cost-effective in preventing insect pests attacking their stored grain. This situation is not specific to Zimbabwe, for example, a survey in Volta Region of Ghana found 25-45% of farmers used chemical pesticides on their stored grain, with 10% of farmers using unregistered and environmentally harmful products such as Dichlorodiphenyltrichloroethane (DDT) (Addo et al., 2002). Although Cabaryl 85 WP, was banned in some countries such as in California, it is not yet banned in Zimbabwe and other SSA countries. Fumigants are also being used by smallholder farmers in Guruve and Mbire districts, despite the risk they can pose to human health and the environment if used by non-certified actors. Farmers reported preferring fumigants to other methods due to their ease of use, rapid action and affordability, among other reasons. Key informant interviews and FGDs revealed poor understanding of the use of fumigants by farmers in both districts and absence of the necessary equipment (i.e. gas respirators, gloves, phosphine meters), facilities (i.e. air-tight and a physical distance of at least 100m from human habitation), and training on safe application and monitoring of fumigants.

The use of traditional and locally-available grain storage protectants, such as maize cob ash or Eucalyptus leaves was found to be low in Guruve and Mbire districts in the current study. These traditional protectants, have been reported to have low efficacy, as they are effective for a short period and smallholder farmers are uncertain about the optimal application rates (Mlambo et al., 2017). However, as farmers in the FGDs explained, they are low-cost and locally available. Overall, 8.5% of the farmers in Guruve and Mbire districts used ‘no protectant treatment’ on their stored grain. This may be due to a lack of funds to procure storage protectants. However, leaving grain untreated during storage can result in weight losses, of up to 50% (Mlambo et al., 2017). More farmers in Mbire district (14.4%) than Guruve district (2.9%) used no protectant treatment on their stored grain. This is likely linked to the farmers in Guruve district being more knowledgeable about postharvest systems than those in Mbire and perhaps due to better access to road networks, markets and information. In addition, the farmers may be afraid of adding chemicals directly to their food.

4.2 Factors associated with the use of different maize grain storage protectant practices

Use of improved grain storage protectant practices is crucial for the reduction of both quantitative and qualitative PHLs and for improving farmers income generation from grain sales (Garbaba et al., 2017). The current study found that a farmer's age has a significant association with the use of non-recommended chemicals as grain protectants, older farmers were less likely to use non-recommended chemicals than younger farmers. This may suggest older farmers are more knowledgeable regarding the health dangers of using non-recommended chemicals on their stored food grain. Furthermore, it suggests that the younger farmers were more likely to grow cotton and other commercial crops where insecticides such as Carbaryl 85 WP are supplied as input packages by contract buyers. Possibly, it was because of ignorance of the health hazards or because they were not intending to consume the grain themselves, that the young farmers applied those non-recommended chemicals to protect stored grain.

Our study revealed that higher PHNL knowledge was positively associated with use of traditional storage protectant practices as opposed to leaving grain untreated during storage. Traditional storage protectant practices may be preferable due to their local-availability, lower cost than commercially-available synthetic pesticides, and long-term integration in the local culture.

There was no significant relationship between having higher PHNL knowledge and use of synthetic chemical grain protectants. Despite the importance of the safety aspects of adding chemicals to one's stored food, people do not want to eat food that has been laced with chemicals (whether approved or not), as they perceive chemicals to affect the taste and wholesomeness of the food.

Use of commercially-available synthetic chemical grain protectants, was positively associated with higher levels of maize production. This may be due to a number of factors, including farmers who produce more grain being more conscious about protecting it from PHLs and thus being more interested in and having more resources to invest in improved storage practices, such as, use of synthetic chemical grain protectant pesticides. Farmers' production volume has been reported to be positively related to income and access to credit (Kumar et al., 2020; Moahid and Maharjan, 2020), higher income may therefore allow farmers to invest in commercially-available synthetic grain protectant pesticides. Currently, the Zimbabwe Government is rolling out a new policy on subsidising grain protectant inputs which may promote use of improved grain protectants by smallholder farmers.

Farmers' education level was positively correlated with the use of commercial synthetic grain protectant pesticides, and negatively associated with use of traditional storage protectant practices. Higher education may prompt farmers to mitigate PHLs through use of commercial synthetic grain protectant pesticides, which may be more effective in protecting grain than traditional storage grain protectant practices (Mlambo et al., 2018). Farmers' education level has also been shown to be positively correlated with pest management technology awareness and adoption (Abang et al., 2014), knowledge about the negative health effects of pesticides and contamination routes (Abtew et al., 2016), and their openness to innovative ideas and new technologies that promote change (Madisa et al., 2010; Mwebaze and Mugisha, 2011; Atibioke et al., 2012). Additionally, in Uganda, Mwebaze and Mugisha. (2011) found that even if the household head was illiterate, the existence of a literate spouse in the family confers a "positive externality which questions traditional thinking", increasing the chances of using new postharvest technologies. Training and extension services have also been reported to be positively associated with the adoption and use of new postharvest technologies in Swaziland (Mwebaze and Mugisha, 2011). However, the cost of the technology may also influence technology adoption despite the level of education; the higher the cost the more prohibitive to smallholder farmers. Although in contrast to this, Gbénou-Sissinto et al. (2018) reported that the high cost of technology was viewed as an indicator of good quality by large-scale farmers, and therefore promoted adoption and use of improved storage technologies in Benin.

Our study found the district (location) the farmer resided was not correlated with the farmers' maize storage protectant practice, suggesting that factors other than location may be associated with adoption. In a study on the adoption of hermetic technologies for cowpeas, the factors positively correlated with adoption were; living in a village with hermetic bag activities, participating in the activities and exposure to village technicians (Moussa et al., 2014). This highlights the influence of access to information on postharvest management for postharvest technology adoption or use.

The sex of the household head had no association with the type of grain storage protectant practice used in the current study. However, in Nigeria, male-headed households were more receptive to postharvest technology adoption than female-headed (Atibioke et al., 2012) while in Swaziland, women were found to be more likely to have adopted postharvest technologies than men (Villane et al., 2012). These examples highlight how culture, gender and geographical location, among other factors, interact and influence the use of grain storage technologies.

Farm size had no correlation with the farmers' maize grain storage protectant practices choice. It had been expected that ownership of larger pieces of land would translate to higher production and thus farmer income which could be used for investing in commercially-available synthetic chemical grain protectant pesticides. A study in the Northern Ecological Zone of Edo State, Nigeria found that farmers with large farm sizes were four times more likely to adopt new storage technologies than those with smaller farms (Okoedo-Okojie and Onemolease, 2009). Land ownership is, however, an important determinant as land property rights increase the eagerness to invest, and generally land owners have larger capital investment making it easier for them to acquire the improved postharvest technologies such as synthetic grain protectant pesticides (Ersado et al., 2004; Bokusheva et al., 2012).

5. Conclusion

Most farmers (>60%) in the focal districts, admix their maize grain with the commercially-available synthetic chemical grain protectant pesticides to protect it from insect attack during storage. Non-recommended chemicals were found to be being used as grain protectants by 14.6% of farmers. Few farmers (7%) in either of the focal districts use traditional storage protection practices, such as admixture with ash or plant materials, although in other field trials these methods have been reported to be ineffective. Very few farmers (1%) were storing their maize grain in hermetic bags or metal silos. PHNL knowledge was found to be positively correlated to education level, and negatively correlated to farmers' age. PHNL knowledge differed between the two districts. Farmers' maize storage grain protectant practices were associated with farmers' age, total grain quantity produced, education and PHNL knowledge. The higher a farmer's education and maize production levels the more likely the adoption/use of commercial synthetic grain protectant pesticides. While use of traditional storage protectant practices as opposed to synthetic chemical grain protectant use or use of non-recommended chemicals or leaving of grain untreated during storage, was positively associated with higher

PHNL knowledge levels. Training and timely support services, e.g., smallholder farmer-focused extension on awareness of and management of postharvest losses in the quality as well as quantity of grain during storage, and the food and nutrition security and safety risks posed by quality losses in storage, together with the dangers of using non-recommended chemicals on stored food grain, are strongly recommended. To drive increased awareness and adoption/use of interventions that reduce both quantitative and qualitative PHLs, investment may be needed to support supply chain development for new storage technologies alongside capacity building of service providers and farmers on postharvest management.

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