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The importance of store hygiene for reducing post-harvest losses in smallholder farmers' stores: Evidence from a maize-based farming system in Kenya

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ABSTRACT

Knowledge of the role of hygiene in reducing food loss in farm stores is limited among extensionists, researchers, and farmers. Store hygiene practices during post-harvest handling and storage of maize were assessed using a cross-sectional survey of 342 farmers, with regular follow-up of 40 farmers' stores over seven months to measure losses caused by insects, and to score the hygiene levels using a standard checklist. Fractional Response Model was used to evaluate the associations between hygiene practices and the losses. Farmers stored their produce in sacks (98.2%) kept in outside granaries (60.1%), or rooms in dwelling houses (39.9%). Co-storage with other items — stover or animal feed (29%), old storage containers (41%), farm implements (30%), other crops (65%) and recycling of old storage bags (40%) were common practices. Nine out of ten farmers cleaned their stores before introducing the new harvest, but only half cleaned their stores during the course of storage. High hygiene scores correlated significantly with lower losses. Storing in the bedroom or living room correlated with lower losses by 2.8 and 4.6 percentage points, respectively, compared to storing it in granaries, while storage in the kitchen correlated with higher losses by 19 percentage points margin. Co-storage was associated with higher losses by 2.8 percentage points. Repairing or disinfesting the store before introducing a new harvest did not significantly reduce losses. Training in grain storage did not have a significant effect either, while maize farming experience and younger age were associated with lower losses by 2.8 and 5.9 percentage points, respectively. Stores where majority of the post-harvest handling decisions were made by women had lower losses by 2.8 percent points. These findings are pointers for the need to strengthen education and mechanisms that enable farmers to put knowledge into practice for effective integrated pest management in farm stores.

1. Introduction

The productivity of smallholder farmers must increase sustainably in order to address the challenge of food and nutrition insecurity. An essential component of sustainable food production is the prevention of loss of harvested produce, and the retention of its nutritional value and safety. Maize is a food and income-generating crop for millions of rural farmers in East and Southern Africa. In Kenya, the annual per capita consumption is 79 kg, accounting for 30.7% of the recommended daily calorie intake (FAOSTAT 2017). However, poor post-harvest management results in approximately 15–25% grain loss, which is equivalent to US$ 180–240 million in forfeited incomes or the grain required to feed close to 2 million households each year (C. Mutungi, personal communication). Preliminary operations including harvesting,

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drying, shelling, winnowing, bagging, and transportation already result in significant losses, even before storage, through incomplete collection, mechanical damage, spoilage, and spillage (Abass et al., 2014). Maize harvesting and drying losses, for instance, range between 6 and 10% in some African countries (Hodges et al., 2014). Further quantity losses that are economically significant occur during secondary processing and storage (Abass et al., 2014). In Kenya, across the different agro-ecological zones, pest infestations (insects, rodents) and mould contaminations result in 11–20% loss of the maize grain stored on-farm (Edoh Ognakossan et al., 2016), while insects, rodents, moulds, spillages, birds, and over-drying cause 11–21% loss of the stored grain weight in private- and public-owned off-farm stores (Mwangi et al., 2017).

The fact that high food losses continue in smallholder storage systems despite the existence of effective control measures calls for a better understanding of the strengths and weaknesses of the approaches that farmers apply to manage the stored produce. An alternative frontier proposed for the mitigation of storage losses is integrated pest management that makes the storage conditions unfavorable for pest habitation and proliferation (Kader 2005). Pest exclusion can be achieved by, among other means, the application of best practices such as storage hygiene. Specifically, storage hygiene targets two broad areas: purity or cleanliness of grain destined for storage and cleanliness of storage facility and the surrounding environment (Gwinner et al., 1990; Toews and Subramanyam 2002). Cleaning grain refers to the process of separating broken grains, straw, chaff, stones, soil, and weed seeds from whole kernels (Kumar and Kalita 2017). Unclean grain impedes airflow during aeration and leads to reduced permeation of fumigants or adhesion of contact pesticides (Toews and Subramanyam 2002). Thus, drying and pest control in poorly cleaned grain may fail, further encouraging food safety hazards and health risks. Indeed, higher mould infection and mycotoxin levels were associated with unclean, poorly dried, and damaged maize (Sétamou et al., 1997).

Proper sanitation and hygiene in food facilities are the foundation of effective integrated pest management (IPM) programs for stored products throughout the post-harvest supply chain (Morrison et al., 2019). Generally, good sanitation programs reduce the abundance and diversity of insects. According to Morrison et al. (2019), sanitation interacts with other pest control measures, and decreased sanitation could reduce the efficacy of chemical, physical, and cultural pest control methods. Sanitation should, therefore, be of utmost importance for food facility managers and farmers concerned about improving the efficacy of a wide range of pest management tactics (Morrison et al., 2019). Some small-scale farmers already recognize poor hygiene as a critical factor aggravating insect infestation in stores (Mendesil et al., 2007). However, to the best of our knowledge, empirical studies on the role of hygiene in smallholder farm stores are scant (Toews and Subramanyam 2002). In the context of modern pest control, where the use of chemical-free methods is encouraged, sanitation, and good post-harvest practices that reduce pest abundance should lend more meaning to technologies such as hermetic bags. In Australia, the combination of good hygiene practices and protectant applications prevented the development of detectable insect infestation in stored grain, while poor hygiene was associated with evolution of pest resistance by encouraging refugia that allow susceptible individuals to escape treatment (Herron et al., 1996). Consequently, hygiene practices involving the removal of dirt and grain remnants may enhance pest control. Storage hygiene measures are regarded simple and feasible with little cost and effort (Gwinner et al., 1990), but the socio-cultural dimensions around them need to be understood (Affognon et al., 2015). The aims of this study were, therefore, to evaluate the extent to which storage hygiene may contribute to improved grain care in rural smallholder farm stores. Such knowledge should provide vital insights into areas that need more support in implementing measures to reduce food loss in stores and ensure the nutrition security of farm families.

2. Materials and methods

2.1. Description of the study area and timing

The study was conducted in Nakuru County, Kenya, which lies within the highland tropical maize agro-ecological zone (Fig. 1). The area is a high maize production region (De Groote 2002), with a mix of smallholder agricultural enterprises (Ogeto et al., 2013). The farming system is a mixed crop-livestock system. Major crops include (maize, wheat, sorghum), root and tubers (Irish potato, sweet potato), legumes (common beans, garden peas, cowpeas, soybeans), vegetables (kale, spinach, carrot, cabbage, tomato, onion), fruits (avocado, orange, passion fruit, banana, pawpaw) and fodder (Napier grass, Lucerne, Sudan grass). Maize, Irish potato, common beans, cabbage, onions, bananas, and Napier grass are the dominant crops in the various categories. Cattle, poultry, sheep, and goats dominate the livestock production. Dairy farming and maize production are the leading livestock and crop enterprises, respectively. Two out of the eleven sub-counties in the County were selected: Njoro (0° 19′44.4″ N; 35° 56′40″ E) and Rongai (0° 10′23.99″ N; 35° 51′49.75″ E). Njoro sub-County is a higher altitude location with an elevation of 1650–2450 m above sea level (m.a.s.l) and receives an annual average rainfall of 600–1800 mm. Temperatures range between 11 and 24.5 °C. in contrast, Rongai sub-County is a lower altitude locality situated between 1650 and 1850 m.a.s.l. The annual rainfall averages between 600 and 1000 mm, and temperatures range between 17 and 29 °C (Ogeto et al., 2013). Both sub-counties experience a mono-modal rainfall pattern. Maize is planted in April and harvested in October/November. The study was accomplished from March–October 2017. Thus the study commenced three months after harvesting and continued for seven months, ending just before the harvest season.

2.2. Determination of sample size for the survey and data collection

The appropriate sample size was determined using Cochran's methodology (Cochran 1977). The estimated ratio of farm families to households in the study site was 0.69 (Foeken and Owuor 2001). At the 95% confidence level, a minimum sample of 329 farmers was adequate. Four out of six wards in Njoro sub-County and another four out of five wards in Rongai sub-County were randomly selected. In Njoro sub-County, 47 farmers in each of the four wards (Mauche, Lare, Njoro, and Nesuit) who had harvested maize in 2015 and 2016 were selected randomly and interviewed. Likewise, in Rongai sub-County, 38 or 39 farmers in each of the four wards (Soin, Visoi, Solai, and Mosop) who had harvested maize in 2015 and 2016 were selected randomly and interviewed. A total of 342 maize farmers participated in the survey.

In each of the households visited, the research team identified and interviewed the person responsible for post-harvest handling and storage activities. In households where several members were involved in post-harvest handling activities, the household member responsible for making majority of the decisions on post-harvest handling activities was interviewed. Trained enumerators conducted face to face interviews in the national language (Kiswahili). The team of enumerators were all fluent in the national language and had a good understanding of at least one of the native languages spoken in the survey area. Enumerators conversant with the farmers' native language, conducted the interview whenever

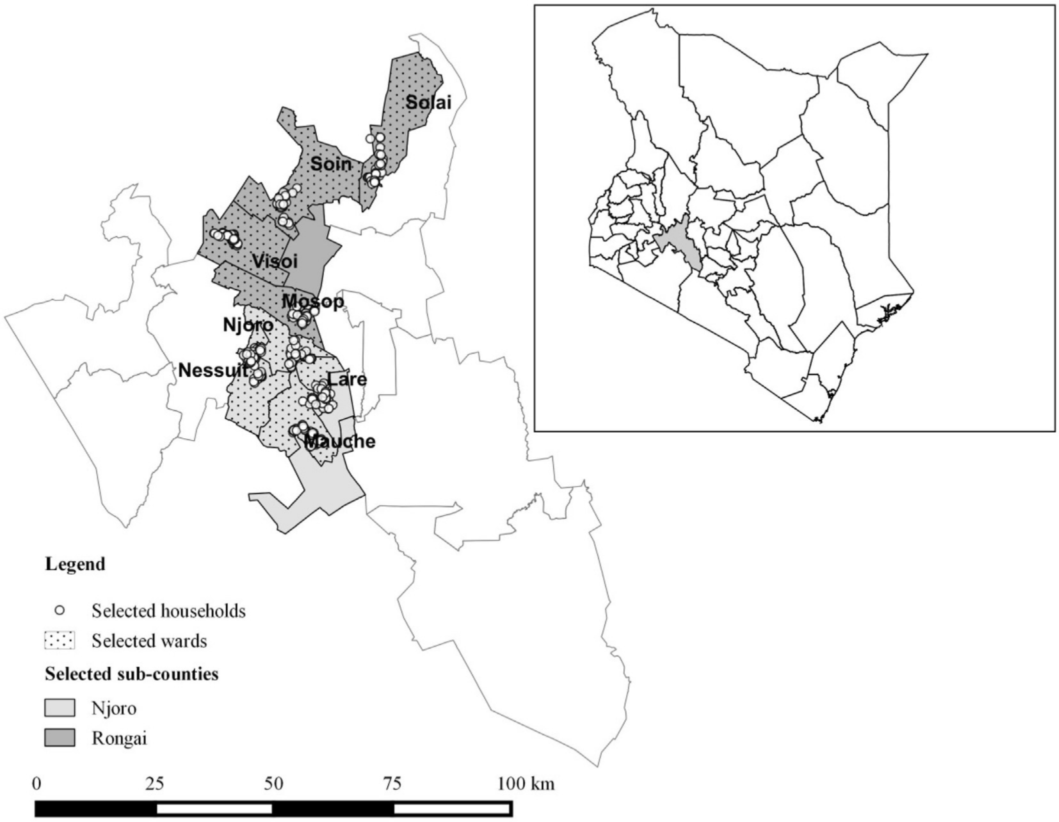

Fig. 1. Map of Nakuru County showing the sub-counties, wards, and the actual locations of households surveyed during the study.

farmers had limited proficiency in the national language. Data collected included socio-demographic characteristics of farmers, storage structures, post-harvest handling practices, storage problems encountered, strategies used to cope with the storage problems, and the proportion of grain lost during the previous crop year. To enable estimation of storage losses, the concept of post-harvest loss, as well as the various loss causing agents (insects, rodents, moulds, spillage), were explained to the respondents. The respondents then estimated the quantity of grain lost to each of the loss causing agents relative to the total harvest stored.

2.3. Estimation of hygiene score and actual losses by insect pests

Stores of 40 households (ten from each ward; half with women as persons responsible for making majority of the decisions on post-harvest handling activities) were monitored and sampled at two-month intervals over 7 months. The 40 farming households were among those interviewed during the survey and had at least 400 kg (>four 90 kg-bags of shelled maize grain in store, preserved to last a reasonable period of time. At each sampling occasion, maize samples (2 kg) were taken using a.sampling spear and purchased from the farmer for weight loss analysis using the count and weigh method (Boxall 1986). Additionaly, using a standard checklist, the store was inspected to acertain the general condition of the storage environment, the exterior and interior structural status, and cleanliness (Gwinner et al., 1990). The overall hygiene score was the outcome of the evaluation of a fixed set of attributes grouped into six criteria ($x_1 - x_6$) as follows:-

x_1: Physical condition of the grain — (1) damaged cobs not stored together with the produce; (2) maize free of foreign matter (pieces of cobs, sheaths, dust, filth); (3) produce has no signs of rewetting (e.g. water marks on bags); (4) produce has normal smell, colour and appearance (rotten/diseased/mouldy grain); (5) no live insects on produce);

x_2: Status of store surrounding — (1) surroundings free of discarded grains, old bags, and cobs; (2) surroundings free from domestic waste, refuse pits or trash dumping sites; (3) surroundings clear of weeds, tall grasses, and bushes; (4) surroundings free of evidence rodents (droppings, burrows, gnawed grains); (5) surroundings free of stagnant water);

x_3: Soundness of the exterior of the store — (1) roof of store intact; (2) store sufficiently raised; (3) walls free of holes or cracks; (4) ventilation openings have screens to prevent entry of insects, rodents, and birds; (5) store fitted with rat guards/rodent traps;

x_4: Soundness of the interior of the store — (1) walls, door, and roof undamaged; (2) holes and cracks on wall absent or filled to seal hiding places for pests; (3) ventilation openings function properly; (4) doors and windows of store/granary close well; (5) floor smooth without cracks or widely-spaced junctions;

x_5: Adherence to good storage practices in the store — (1) bagged produce placed on pallets or raised platform; (2) stacked bags do not have perforations/physical damage; (3) Bags stacked away from the wall; (4) bags stacked in a way that allows adequate ventilation; (5) bags stacked away from non-food commodities (empty insecticide containers, empty fertilizer sacks, empty rodent baits); (6) bags stacked away/separated from other food commodities; (7) domestic animals (poultry, calves, sheep, goat) do not reside in the store; (8) old stocks kept separately from the new harvest; (9) unused bags and pallets stored away/separately;

x_6: Cleanliness of the store — (1) walls and roof free of accumulated dust, dirt, cobwebs; (2) floor free of spilled grain, dirt, trash; (3) walls, floor, and ceiling free of crawling or flying insects;

(4) surfaces of bags free of crawling insects; (5) store is free of evidence of rodent presence (hairs, droppings, pungent smell); (6) store is free of evidence of birds (feathers, droppings); (7) grain handling equipment (buckets, samplers, tarpaulins, brooms, sieves) clean; (8) difficult-to-reach areas clean (corners, underneath pallets, behind the doors, floor cracks/junctions; (9) store free of musty smell or dampness on walls/ceilings.

The attributes examined under each criterion and details of the score derivations are explained in the Supplementary Material S1. For each criterion, the score was [1] if more than half of the attributes were satisfied, and [0] if not. Thus, each store received a maximum score of six and a minimum of zero at each sampling occasion. The scores were averaged for the number of sampling occasions (2–4 depending on when the stocks became depleted) to give the overall hygiene score of the store. Out of the 40 households, nine depleted their stocks within 3 months, 11 within 5 months and 20 within 7 months, counting from the time visits to the stores commenced. Hence, nine, 11 and 20 households were sampled twice, thrice and four times, respectively.

2.4. Statistical analyses

Data on demographic characteristics of respondents, pre-storage practices (grain drying, sorting, threshing, and winnowing), storage structures, storehouse cleaning and disinfestation, storage problems, and the coping strategies used were expressed as percentages and summarized as contingency tables or graphs. Differences among categories for different practices were determined using the Chi-Square test and pairwise comparisons performed using the 'chisq.multcomp.' function with Bonferroni *p*-values adjustment in the RVAideMemoire package of the R 3.4.3 software (R Core Team 2017). Data on the magnitude of perceived storage losses, reported by respondents in kilograms, was converted into proportions of the quantity of maize stored. Data were checked for normality using the Shapiro-Wilk test, and found to be not normally distributed (total losses: df = 341, statistic = 0.985, $p < 0.001$; insect losses: df = 341, statistic = 0.907, $p < 0.001$; mould losses: df = 341, statistic = 0.521, $p < 0.001$; rodent losses: df = 341, statistic = 0.924, $p < 0.001$; losses due to theft: df = 341, statistic = 0.280, $p < 0.001$). Means were therefore separated using the non-parametric Kruskal-Wallis test in R 3.4.3 software.

A regression analysis of the data from 40 farmers whose stores were followed and sampled over 7 months elucidated the relationships between loss levels (dependent variable) and storage practices, hygiene, and the socio-economic characteristics of the farmers. We grouped the explanatory variables in two categories: (i) the farmers' socio-economic characteristics (gender, age, education level, experience in maize farming), and (ii) the storage and hygiene practices (storage structures, place of storage, storage of maize with other products, store disinfestation before grains introduction, storage duration, training on grain storage protection, and hygiene score of the farmer's store). As the losses data were expressed as fractions (kg/kg) bounded between [0–1], an ordinary least squares regression would result in biased parameter estimates. Other models, such as Tobit, are also biased due to the non-normal distribution and heteroskedasticity of their error terms. The Fractional Response Model (FRM) proposed by Papke and Wooldridge (1996) was thus used to overcome this limitation. The model synthesizes and extends the generalized linear models and quasi-likelihood methods to a class of functional forms with satisfying properties that overcome most of the known limitations of the other conventional econometric models for bounded dependent variables (Ogoudedji et al., 2019; Chegere 2018). Other advantages of the model are the direct estimation of the conditional expectation of the dependent variable, allowing the bounded values [0 and 1] as well as intermediate values to appear. The model also gives consistent parameter estimates regardless of the distribution of the dependent variable and computes standard errors by default (Gallani et al., 2015; Baum 2008). STATA 14 (StataCorp L.P., TX, USA) was employed to perform the regression analysis using the logit Quasi-Maximum Likelihood estimation method. The marginal effects were computed from the fitted model to make interpretation o the model's results easier.

3. Results

3.1. Socio-demographic characteristics of respondents

The overall sampled farming population consisted of a significantly higher (χ^2 (1) = 6.19, $P = 0.013$) proportion (56.7%) of female respondents. In Rongai sub-County the proportion of female respondents (58.4%) was significantly higher than male (χ^2 (1) = 4.38, $P = 0.036$) but in Njoro sub-County the proportion of females (55.3%) and males (44.7%) was statistically similar (χ^2 (1) = 2.128, $P = 0.145$). Two thirds (68.2%) of the respondents were aged 25–55 years (Table 1). Overall, 35.4% of the respondents were aged 18–40 years. The male and female respondent numbers in this age bracket (18–40 years) were fairly equal in Rongai sub-County (14.3% females versus 13.6% males). Contrastingly, the proportion of female respondents in this age (18–40 years) outnumbered the male respondents (28.2% versus 13.3%) in Njoro sub-County. Three quarters (76.7%) of farmers in both sub-counties had completed at least eight years of formal education, although the percentage was lower (70.2%) in Njoro sub-County compared to Rongai sub-County (84.5%). In addition, the proportion of farmers with >12 years of formal education was higher in Rongai (more men than women) than Njoro, while the proportion of farmers with <8 years of formal education was higher in the latter (more women than men). Only 5.8% of respondents in the sub-counties had not acquired any formal education.

In both sub-counties, 70.2% of the respondents had more than ten years of experience in maize farming, but the proprtion was higher in Rongai (65%) than Njoro (77%). In particular, the proportion of farmers with less that 5 years of experience was higher in Njoro, while that of farmers with >20 years of experience was lower in Njoro than Rongai. There were significantly more women than men with <10 as well as > 10 years of maize farming experience in both sub-counties. The male farmers with <10 as were more in Njoro than Rongai. Likewise, the proportion of male farmers with >10 years experience was higher in Njoro than Rongai. The average farm-land size owned per household was 4.9 ± 0.3 acres, out of which 2.5 ± 0.3 acres were for maize cultivation. The maize grain harvested per household during the study year was 37.4 ± 0.3 bags (90 kg per bag). Farmers sold three quarters (75.1%) of the harvested grain and set aside a quarter (24.9%) for home consumption. The proportion of households storing maize for short duration (1–4 months) was significantly lower (χ^2 (2) = 33.54, $P < 0.001$ (Njoro)); (χ^2 (2) = 44.12, $P < 0.001$ (Rongai)) compared to the proportion that stored for longer durations (5–8 months and 9–12 months). Generally, there were no significant differences in the maize production and utilization patterns of households in the two sub-counties.

3.2. Storage facilities and locations used by farmers

Storage in bags was more popular than other storage containers or places (metal silos, on the floor in rooms or granaries) in both sub-counties; (χ^2 (3) = 517.06, $P < 0.001$(Njoro)) and (χ^2 (3) = 462, $P < 0.001$ (Rongai)). All the farmers (100%) in Rongai sub-County stored maize in bags. In Njoro sub-County, 96.8% stored maize

Table 1
Socio-demographic characteristics of respondents[a].

	Percentage of respondents		(N = 342)
	Njoro (N = 188)	Rongai (N = 154)	
Gender of the respondentrowhead			
Female	55.3^{a}A	58.4^{a}A	56.7^{a}
Male	44.7^{a}A	41.6^{b}A	43.3^{b}
χ2 (1)	2.13	4.39	6.19
p-value	0.14	0.036	0.013
Age (Years)rowhead			
< 18	0.0^{c}A	0.0^{b}A	0.0^{c}
18–24	4.8^{b}A	0.6^{b}B	2.9^{b}
25–40	36.7^{a}A	27.3^{a}B	32.5^{a}
41–55	35.1^{a}A	36.4^{a}A	35.7^{a}
> 55	23.4^{a}A	35.7^{a}A	28.9^{a}
χ2 (4)	108.12	103.34	200.49
p-value	<0.001	<0.001	<0.001
Age by genderrowhead			
Males 18–40 years	13.3^{b}A	13.6^{b}A	13.5^{b}
Females 18–40 years	28.2^{a}A	14.3^{b}B	21.9^{b}
Males > 40 years	31.4^{a}A	28.6^{ab}A	30.1^{ab}
Females > 40 years	27.1^{a}A	43.5^{a}A	34.5^{a}
χ2 (3)	14.47	36.91	35.47
p-value	0.002	<0.001	<0.001
Level of formal educationrowhead			
No formal education	8.0^{c}A	3.2^{c}B	5.8^{c}
< 8 years	21.8^{b}A	12.3^{b}B	17.5^{b}
Completed 8 years	38.3^{a}A	40.3^{a}A	39.2^{a}
Completed 12 years	24.5^{a}A	26.0^{ab}A	25.1^{b}
> 12 years	7.4^{c}B	18.2^{b}A	12.3^{c}
χ2 (4)	62.05	60.74	112.91
p-value	<0.001	<0.001	<0.001
Level of formal education by genderrowhead			
Males with no formal education	2.1^{b}A	1.3^{c}A	1.8^{c}
Females with no formal education	6.4^{b}A	1.9^{c}B	4.4^{c}
Males with <8 years	6.9^{b}A	5.2^{cb}A	6.1^{bc}
Females with <8 years	14.9^{ab}A	7.1^{cb}B	11.4^{b}
Males completed 8 years	15.4^{ab}A	11.0^{cb}A	13.5^{b}
Females completed 8 years	22.3^{a}A	29.9^{a}A	25.7^{a}
Males completed 12 years	14.9^{ab}A	12.3^{b}A	13.7^{b}
Females completed 12 years	9.6^{ab}A	13.0^{a}A	11.1^{bc}
Males with >12 years	5.3^{b}A	11.7^{b}A	8.2^{bc}
Females with >12 years	2.1^{b}A	6.5^{cb}A	4.1^{c}
χ2 (9)	74.87	91.97	146.77
p-value	<0.001	<0.001	<0.001
Experience in maize farming (years)rowhead			
1–5	18.1^{b}A	9.1^{b}B	14.0^{b}
6–10	18.1^{b}A	13.0^{b}A	15.8^{b}
11–15	13.8^{b}A	11.7^{b}A	12.9^{b}
16–20	16.0^{b}A	8.4^{b}B	12.6^{b}
>20	34.0^{a}B	57.8^{a}A	44.7^{a}
χ2 (4)	24.34	138.53	131.89
p-value	0.002	<0.001	<0.001
Experience in maize farming by genderrowhead			
Males < 10 years	17.0^{b}A	11.7^{b}B	14.6^{c}
Females < 10 years	26.6^{a}A	31.2^{a}A	28.7^{b}
Males > 10 years	19.7^{b}A	10.4^{b}B	15.5^{c}
Females > 10 years	36.7^{a}A	46.8^{a}A	41.2^{a}
χ2 (3)	17.40	55.56	64.95
p-value	<0.001	<0.001	<0.001
Storage duration (months)rowhead			
1–4	14.9^{b}A	11.0^{c}A	13.2^{b}
5–8	43.1^{a}A	57.1^{a}A	49.4^{a}
9–12	42.0^{a}A	31.8^{b}B	37.4^{a}
χ2 (2)	28.79	49.26	70.02
p-value	<0.001	<0.001	<0.001
Land ownership (acres)rowhead	4.9 ± 0.5A	4.9 ± 0.5A	4.9 ± 0.3
Land under maize cultivation (acres)rowhead	2.6 ± 0.2A	2.4 ± 0.2A	2.5 ± 0.3
Quantity harvested (90 kg bags)rowhead	39.2 ± 3.6A	35.3 ± 3.5A	37.4 ± 0.3
Quantity consumed (90 kg bags)rowhead	9.1 ± 0.5A	9.6 ± 0.6A	9.3 ± 0.4
Quantity sold (90 kg bags)rowhead	30.1 ± 3.5A	25.7 ± 3.3A	28.1 ± 2.4

[a] The respondent was the member in a household responsible for making majority of the decisions on post-harvest handling activities. Within each sub-County as well as the overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare the two sub-Counties; same letters indicate no significant difference ($P > 0.05$).

grain in bags while the rest stored directly on the floor in the rooms within the dwelling house (1.6%), granaries (1.1%), or in metal silos (0.5%). Compared to other bag types (hermetic, jute/sisal, polypropylene + jute/sisal), the use of woven polypropylene bags (87.5%) was significantly higher in both sub-counties (χ^2 (3) = 425.74, $P < 0.001$ (Njoro)); (χ^2 (3) = 282.62, $P < 0.001$ (Rongai)). However, comparing the popularity of specific types of bags between the two sub-counties, the use of woven polypropylene bags was significantly more popular (χ^2 (1) = 4.91, $P = 0.027$) in Njoro sub-County. In contrast, hermetic bags were significantly more widely used (χ^2 (1) = 5.14, p = 0.023) in Rongai sub-County. Storage of bags in granaries as opposed to rooms in the dwelling house was significantly widely practiced in both sub-counties (Njoro: χ^2 (1) = 8.51, $P = 0.004$; Rongai: χ^2 (1) = 5.09, $P = 0.024$).

Farmers stored maize in outside granaries or rooms in their dwelling houses. The granaries were raised, rectangular structures, assembled using wooden rafters or timber with iron sheet roofing (improved cribs; 98%) or grass thatch (traditional granaries; 2%). The storage rooms within the dwelling house were almost exclusively (94.2%) iron sheet-roofed, with either cemented (36.5%), wooden (15.3%) or earthen (48.2%) floors and walls made of bricks (27%), timber (21.9%) or mud (51.1%). Farmers stored maize in the living room, bedroom, or kitchen, and in some instances, a special room reserved for the purpose of storing grain. In Rongai sub-County, a significantly higher proportion (42.9%; (χ2 (3) = 18.71, $P = < 0.001$) of the farmers who stored maize in dwelling houses used a special room that served as a store. In Njoro sub-County a significantly lower (13.5%; (χ^2 (3) = 12.70, $P = 0.003$) proportion of farmers kept bagged produce in the kitchen (Table 2).

3.3. Pre-storage handling practices

Nine-tenths (90.4%) of farmers sorted out the damaged cobs after harvesting (Table 3). A significantly higher proportion of respondents (81.2%) separated the mouldy cobs, compared to those who sorted insect-damaged ones (47.6%). Furthermore, the proportion of farmers who sorted insect-damaged cobs was significantly higher (χ^2 (3) = 155.97, $P = <0.001$) than that of farmers who sorted other types of damaged produce including damage by rodents (28.8%) and birds (19.4%). Three-quarters of farmers (76%) dried their maize before storage, mainly as de-husked cobs before shelling. A significantly higher proportion of farmers (79%) dried the cobs on tarpaulins while others dried on bare ground (16.5%), concrete floors (4.2%), and rooftops (0.8%). The majority of farmers used mechanical threshers (82.2%; χ^2 (3) = 601.27, $P = < 0.001$) to shell the maize cobs, and cleaned the grain of foreign matter by hand winnowing (68.8%) or sieving (41.1%) before bagging. A significantly higher proportion of farmers (86.9%; χ^2 (3) = 190.89, $P = < 0.001$) removed the chaff; fewer farmers removed other foreign matter such as dust (32.6%), soil or sand (9.9%), broken cobs (7.4%), and weed seeds (6.7%). A few farmers picked the foreign matter by hand (12.8%) or relied on fans attached to the shelling machine (10.9%). There were no major differences in the way farmers conducted pre-storage handling practices on maize in the two localities (see Table 3).

3.4. Co-storage practices

Storage practices varied among farmers. Maize was often stored together with other types of grain, maize stovers, commercial animal feeds, hay, Irish potato, onions, used bags, old plastic containers or agrochemicals, and old farm implements (see Supplementary Material S2). Co-storage of maize with non-food items was significantly higher in the granaries (stovers: χ^2 (1) = 31.12, $P < 0.001$; animal feeds: χ^2 (1) = 29.81, $P < 0.001$; used bags: χ^2 (1) = 10.61, $P = 0.001$; plastic containers: χ^2 (1) = 19.29, $P < 0.001$; agrochemicals: χ^2 (1) = 15.07, $P < 0.001$ (Fig. 2a), while the co-storage with other grain types was significantly higher among farmers who stored inside their dwelling houses (χ^2 (1) = 4.45, $P = 0.035$). Other types of grain stored together with maize included beans, wheat, green peas, sorghum, and millet (Fig. 2b). In some instances, farmers stored these crops in the unthreshed form in the granaries. Overall, the storage of beans together with maize was more frequent (77.3%; χ^2 (6) = 571.01, $P = < 0.001$) compared to the other grain types.

Table 2
Storage structures, types of bags used and locations where bagged maize was stored.

	Percentage of respondents		
	Njoro (N = 188)	Rongai (N = 154)	Overall (N = 342)
Storage structuresrowhead			
Bags	96.8^{a}A	100^{a}A	98.2^{a}
Metal silo	0.5^{b}A	0.0^{b}A	0.3^{b}
Directly on the floor in the house	1.6^{b}A	0.0^{b}A	0.9^{b}
Directly on the floor in the granary	1.1^{b}A	0.0^{b}A	0.6^{b}
χ2 (3)	517.06	462	978.58
p-value	<0.001	<0.001	<0.001
Types of bags usedrowhead			
Woven polypropylene	91.2^{a}A	83.1^{a}B	87.5^{a}
Jute or sisal	2.2^{b}A	0.6^{c}A	1.5^{c}
Woven polypropylene + jute/sisal	2.2^{b}A	3.2^{c}A	2.7^{c}
Improved hermetic	4.4^{b}B	13.0^{b}A	8.3^{b}
χ2 (3)	425.74	282.62	703.6
p-value	<0.001	<0.001	<0.001
Storage locations for bagged maizerowhead			
Granary	61.0^{a}A	59.1^{a}A	60.1^{a}
Living room	6.6^{bc}A	9.7^{b}A	8^{bc}
Bedroom	14.8^{b}A	11.7^{b}A	13.4^{b}
Kitchen	4.4^{c}A	1.9^{c}A	3.3^{c}
Special store room	13.2^{b}A	17.5^{b}A	15.2^{b}
χ2 (4)	198.05	156.65	352.69
p - value	<0.001	<0.001	<0.001

Within each sub-County as well as the overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare the two sub-counties; same letters indicate no significant difference ($P > 0.05$).

Table 3
Grain pre-storage handling practices of farmers.

	% of respondents by storage place		% of respondents by locality		Overall (N = 342)
	Granary (N = 205)	Room in living house (N = 137)	Njoro (N = 188)	Rongai (N = 154)	
Sort damaged cobsrowhead	89.3B	92A	88.8A	92.4A	90.4
Insect damage	47.0^{b}B	48.4^{b}A	43.5^{b}A	52.5^{b}A	47.6^{b}
Mould damage	80.3^{a}B	82.5^{a}A	81.5^{a}A	80.9^{a}A	81.2^{a}
Rodent damage	31.1^{bc}A	25.4^{c}B	25.6^{c}A	32.6^{b}A	28.8^{c}
Bird damage	18.0^{c}A	21.4^{c}A	22.6^{c}A	15.6^{c}B	19.4^{c}
$\chi2$ (3)	89.92	66.89	85.51	73.25	155.97
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Dry maize before storagerowhead	70.2A	84.7A	75.5A	76.6A	76
Dry on bare earth	16.0^{b}A	17.2^{b}A	13.0^{b}A	17.8^{b}A	16.5^{b}
Dry on tarpaulins	77.8^{a}A	79.3^{a}A	81.9^{a}A	77.1^{a}A	78.5^{a}
Dry on concrete floor	4.9^{c}A	3.4^{c}A	3.6^{c}A	5.1^{c}A	4.2^{c}
Dry on roof top	1.4^{c}A	0.0^{c}A	1.4^{c}A	0.0^{c}A	0.8^{c}
$\chi2$ (3)	220.61	190.21	242.35	178.88	410.62
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Thresh grainsrowhead	100A	100A	100A	100A	100
Hand threshing	2.9^{c}A	1.5^{c}A	4.3^{bc}A	0.0^{c}A	2.3^{c}
Beat exposed de-husked cobs with a stick	3.4^{c}A	6.6^{bc}A	2.7^{c}A	6.6^{bc}B	4.7^{c}
Beats cobs in a sack with a stick	10.7^{b}A	10.9^{b}A	10.1^{b}A	11.7^{b}A	10.8^{b}
Use threshing machines	82.9^{a}A	81.0^{a}B	83.0^{a}A	81.2^{a}A	82.2^{a}
$\chi2$ (3)	370	231.79	339.36	263.4	601.27
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Removes foreign matterrowhead	79.5B	86.9A	77.7A	88.3A	82.5
Weed seeds	6.7^{c}A	6.7^{c}A	6.8^{c}A	6.6^{c}A	6.7^{c}
Chaff	84.7^{a}B	89.9^{a}A	82.2^{a}A	91.9^{a}A	86.9^{a}
Sand	9.2^{c}A	10.9^{c}A	12.3^{c}A	7.4^{c}A	9.9^{c}
Dust	33.7^{b}A	31.1^{b}A	33.6^{b}A	31.6^{b}A	32.6^{b}
Broken cobs	9.2^{c}A	5.0^{c}B	6.2^{c}A	8.8^{c}A	7.4^{c}
$\chi2$ (4)	249.76	211.66	214.05	248.21	460.12
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Remove foreign matter by:rowhead					
Sieving	47.2^{a}A	32.8^{b}B	32.9^{b}A	50.0^{a}A	41.1^{b}
Winnowing	64.4^{a}A	74.8^{a}A	63.0^{a}A	75.0^{a}A	68.8^{a}
Hand picking	11.6^{b}A	14.5^{c}A	16.3^{c}A	9.0^{b}B	12.8^{c}
Sheller fan	11.9^{b}A	9.4^{c}A	9.7^{c}A	12.2^{b}A	10.9^{c}
$\chi2$ (3)	101.38	96.62	81.33	113.68	190.89
p - value	<0.001	<0.001	<0.001	<0.001	<0.001

Down the columns: granary (storage place), room in house (storage place), Njoro (locality), Rongai (locality) and overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare practices in granary storage versus room in house storage (across rows) and storage in Njoro versus Rongai; values across the rows followed by the same uppercase letter under the caterogories (storage place or locality) are not significantly different ($P > 0.05$).

3.5. Storage bag recycling practices

Farmers stored maize mainly in bags. About 40% of the farmers used recycled bags, particularly those who stored in granaries (see Table 4). Among the farmers who recycled storage bags, close to half (46%) disinfested by treating with chemicals (53.2%), exposing in the sun (17.7%), and dipping in hot (19.4%) or cold (9.7%) water. The proportion of farmers who did not treat the bags before reusing them was higher in Njoro than Rongai. Among farmers who stored in granaries, treating recycled bags with chemicals was significantly more popular (χ^2 (3) = 22.51, $P = < 0.001$) than use of hot or cold water or sun exposure. However, the use of various methods of disinfesting bags did not differ significantly in popularity (χ^2 (3) = 6.24, $P = 0.101$) among farmers storing maize in the dwelling houses. Among the different chemicals used for the treatment of recycled bags, Actellic® super dust (Pirimiphos-methyl 1.6% w/w + Permethrin 0.3% w/w) was predominantly (65.2%) used among farmers who stored grain in granaries. In contrast, Skana® super (Malathion 2% w/w + permethrin 0.3% w/w) was the pesticide of choice (50%) among farmers who stored maize in rooms. Overall, among the pesticides used for the disinfestation of bags Actellic® super dust was used by a higher proportion of farmers compared to Skana® super and K-Obiol® DP2 dust (deltamethrin 5% w/w). Bag usage, and recycled bags' treatment methods did not differ between the two localities.

3.6. Store cleaning practices

Nine in every ten farmers (89.8%) cleaned their stores before introducing newly harvested grain (see Table 5). However, only half (49.7%) of farmers cleaned their stores after loading the produce, and the frequency of cleaning varied with storage duration. Farmers who stored grain in rooms within the dwelling house cleaned their stores more frequently compared to those who stored in granaries. The proportion of farmers cleaning their stores on a daily or weekly basis was significantly higher in rooms within the dwelling house (χ^2 (1) = 14.22, $P < 0.001$ (daily) and χ^2 (1) = 7.41, $P = 0.006$ (weekly)) whereas the proportion of farmers who cleaned their stores twice a year (after every 6 months) was significantly higher among farmers who stored their grain in granaries (χ^2 (1) = 9.80, $P = 0.002$) (Fig. 2c). Sweeping was the preferred method of cleaning the stores among farmers who stored in granaries (χ^2 (2) = 127.92, $P = < 0.001$) as well as those who stored in the dwelling house (χ^2 (2) = 71.73, $P = < 0.001$). Almost 20% of farmers, in addition to sweeping, mopped, or dusted the stores (see Table 5). Slightly less than half of the farmers (44.4%) disinfested their stores before introducing new grain. Among these farmers, slightly more than two-thirds used Actellic® super dust in the granaries compared to half of the farmers who stored in the houses. Another 13.2% of the farmers who disinfested their stores could not recall the particular product used (Table 5). There were no differences in store cleaning practices between the localities.

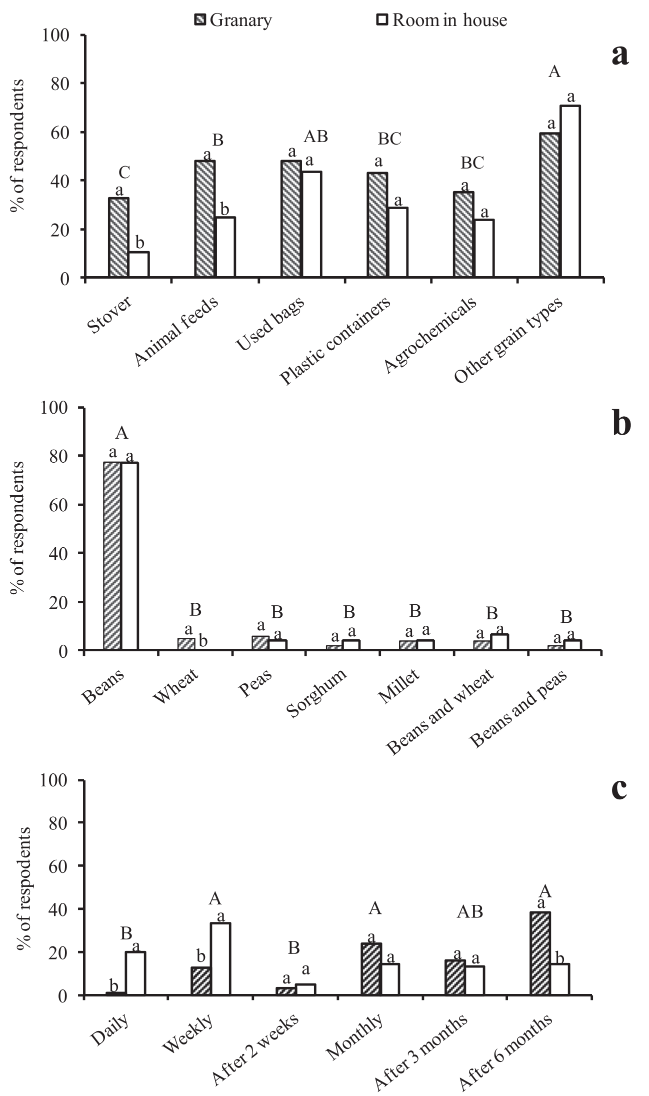

Fig. 2. Other items stored together with maize (a), other types of grain stored together with maize (b), and cleaning frequency of storehouses after loading with maize (c). The same uppercase letters indicate no significant difference ($P > 0.05$) among categories in the overall sample. Lowercase letters compare storage in granaries versus rooms in the dwelling house; same letters indicate no significant difference ($P > 0.05$).

3.7. Storage challenges, perceived losses and control measures

More than two-fifths of farmers identified insects (44%) and rodents (42.1%) as causes of storage problems while a fifth identified moulds (18%) and theft (20%) (Fig. 3a). Farmers ranked the importance of these problems equally, irrespective of whether they stored in granaries or the living house (Fig. 3b). The perceived losses from insect infestation were the highest (3.92 ± 0.37), followed by those resulting from rodent attacks (3.31 ± 0.29), although these were not significantly different (Table 6). Further, the loss levels were similar irrespective of whether farmers stored in granaries or the living house, and also did not differ by locality. Insecticides were significantly (χ^2 (4) = 422.71, $P < 0.001$) more widely used by 56.4% of farmers across the two storage systems compared to other pest control methods such as the application of wood ash (3.8%), plant leaves (2.9%), exposure to the sun (12.6%), or sieving (7%). Actellic® super dust was used by a significantly higher (χ^2 (3) = 270.42, $P < 0.001$) proportion (70.5%) of farmers. Other insecticides applied with lower frequencies included Skana® super (10.4%), K-Obiol® DP2 dust (4.1%), and Sevin® Dudu dust (Carbaryl 7.5% w/w) (4.1%).

3.8. Effect of demographic characteristics and storage hygiene practices on actual loss levels

The fractional response model (Table 7) estimated the correlations between the actual quantity loss caused by insect pests and the demographic characteristics of farmers and their practices. The measured losses were 5.9 ± 3.8% (range: 1–14.5%) over an average period of 5.6 ± 1.6 months (range 3–7 months). The marginal effects measure the impact of a level change in an explanatory variable; all others held constant. Women-managed stores were associated with significantly lower losses by 2.8 percentage points than men managed stores. Likewise, farmers older than 24 years experienced significantly higher losses than their younger counterparts (<24 years) by a similar margin. However, the farmers with maize farming experience exceeding twenty years incurred significantly lower losses by a margin of 4.3 percentage points compared to farmers who had experience of less than twenty years, while training in storage did not have a significant effect on the level of losses. Farmers who bagged and stored the produce in the bedroom or living room experienced lower losses by 2.8 and 4.6 percentage points, respectively, compared to those who stored in granaries. Farmers storing in the kitchen risked higher losses by a margin of 19% compared to those who stored in granaries. Storing in woven bags or hermetic containers (bags or silo) resulted in similar loss levels. Moreover, the actual length of storage, which varied between 3 and 7 months, was not significant. Storing maize together with other food or non-food items resulted in higher losses by 2.7 percentage points compared to storing separately. On the contrary, inspecting and repairing the store before storage or disinfesting the store before storage were not significant. Those farmers' stores recieving a higher hygiene score, however, had significantly lower losses ($P = 0.043$).

4. Discussion

Clean produce and clean storage environment are the first lines of defense for adequate protection of produce against damage by pests and microflora during storage. Grain cleaning includes winnowing, screening/sifting, and sorting to eliminate the impurities. The majority of farmers (90%) sorted cobs that were damaged by mould, rot, and pests. The proportion of the farmers who sorted was equal to that of farmers who dried the maize before storage, thus the sorting of cobs occurred during the drying stage. Sun-drying was the preferred method of drying maize, although it is slow, labor-intensive, and dependent on weather. The use of tarpaulins enabled farmers to gather the grain without difficulty and prevented contact with the soil hence also minimized insect and fungal infestations. Drying on the bare ground can increase insect infestation 3–4 -fold (Mutungi et al., 2019). The fact that a high proportion of farmers sorted out mouldy cobs may suggest that challenges of harvest quality from delayed harvesting, poor maturing characteristics of cultivated varieties, or even erratic weather patterns at harvest time were not uncommon. Sorting is part of quality improvement. However, because of the potential losses, some farmers skip the operation while unscrupulous traders blend the grade-outs (part of the grain that is sorted out) with the wholesome grain (Mwangi et al., 2017) since such defects are easily masked by milling into flour. Studies in Tanzania reported quantity losses of 5–15% from pre-storage sorting depending on agro-location, time of harvesting, and drying approach (Mutungi et al., 2019). Nonetheless, earlier studies showed that sorting out the

Table 4
Bag usage and treatment approaches for recycled bags.

	% of respondents by storage place		% of respondents by locality		Overall (N = 336)
	Granary (N = 202)	Room in house (N = 134)	Njoro (N = 182)	Rongai (N = 154)	
Bag usagerowhead					
Uses new bags	60.9^{a}A	58.2^{a}B	57.7^{a}A	62.3^{a}A	59.8^{a}
Recycles bags	10.9^{c}A	14.2^{c}A	13.2^{c}A	11.0^{c}A	12.2^{c}
Uses both new and recycled	28.2^{b}A	27.6^{b}B	29.1^{b}A	26.6^{b}A	28.0^{b}
χ2 (2)	78.13	40.94	55.53	63.91	118.62
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Treatment of recycled bagsrowhead					
Treat recycled bags	51.9^{a}A	37.5^{a}B	40.3^{a}A	53.4^{a}A	45.9^{a}
Do not treat recycled bags	48.1^{a}A	62.5^{a}A	59.7^{a}A	46.6^{a}B	54.1^{a}
χ2 (1)	0.11	3.5	2.92	0.28	0.9
p-value	0.936	0.061	0.087	0.599	0.344
Methods used to treat bagsrowhead					
Chemicals	56.1^{a}A	47.6^{a}B	58.1^{a}A	48.4^{a}A	53.2^{a}
Hot water	17.1^{b}A	23.8^{a}A	25.8^{a}A	12.9^{a}A	19.4^{b}
Cold water	7.3^{b}A	14.3^{a}A	6.5^{b}A	12.9^{a}A	9.7^{b}
Exposing in the sun	19.5^{b}A	14.3^{a}A	9.7^{b}A	25.8^{a}A	17.7^{b}
χ2 (3)	22.51	6.24	20.74	10.42	27.68
p-value	<0.001	0.101	<0.001	0.01	<0.001
Chemicals used to treat recycled bagsrowhead					
Cannot recall	21.7A	30A	33.3A	13.3A	24.2
Actellic® super dust	65.2^{a}A	20.0^{a}B	50.0^{a}A	53.3^{a}A	51.5^{a}
Skana® super dust	8.7^{b}A	50.0^{a}A	11.1^{ab}A	33.3^{ab}A	21.2^{ab}
K-obiol® DP 2 dust	4.3^{b}A	0.0^{a}A	5.6^{b}A	0.0^{b}A	3.0^{b}
χ2 (2)	20.33	5.43	9.5	7.538	15.68
p - value	<0.001	0.066	<0.097	0.023	<0.001

Down the columns: granary (storage place), room in house (storage place), Njoro (locality), Rongai (locality) and overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare practices in granary storage versus room in house storage (across rows) and storage in Njoro versus Rongai; values across the rows followed by the same uppercase letter under the caterogories (storage place or locality) are not significantly different ($P > 0.05$).

Table 5
Store cleaning practices applied by maize farmers.

	% of respondents by place of storage		% of respondents by locality		Overall (N = 342)
	Granary (N = 205)	Room in house (N = 137)	Njoro (N = 188)	Rongai (N = 154)	
Cleans store before introducing harvestrowhead	88.8B	91.2A	86.7A	100A	89.8
Mode of cleaningrowhead					
Swept only	72.5^{a}A	68.8^{a}B	70.7^{a}A	71.3^{a}A	71.0^{a}
Mopped only	9.3^{b}A	12.0^{b}A	13.4^{b}A	7.0^{c}B	10.4^{c}
Swept and mopped	18.1^{b}A	19.2^{b}A	15.9^{b}A	21.7^{b}A	18.6^{b}
χ2 (2)	127.92	71.73	103.37	97.524	199.16
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Cleans store after introducing harvestrowhead	42.4A	60.6A	47.9A	51.9A	49.7
Mode of cleaningrowhead					
Swept only	65.5^{a}A	63.9^{a}A	68.9^{a}A	60.0^{a}A	64.7^{a}
Mopped only	2.3^{cd}A	4.8^{b}A	3.3^{b}A	3.8^{c}A	3.5^{c}
Dusted	13.8^{bc}A	6.0^{b}A	11.1^{b}A	8.8^{bc}A	10.0^{b}
Swept and mopped	1.1^{d}B	15.7^{b}A	7.8^{b}A	8.8^{bc}A	8.2^{b}
Swept and dusted	17.2^{b}A	9.6^{b}A	8.9^{b}A	18.8^{b}A	13.5^{b}
χ2 (4)	121.22	102.72	135.89	84.75	216.76
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Disinfests the storerowhead	46.8A	40.9B	34.0A	57.1B	44.4
Disinfectant usedrowhead					
Cannot recall	9.4A	19.6A	20.0A	8.0A	13.2
Actellic® super dust	70.8^{a}A	48.2^{a}B	50.8^{a}B	71.3^{a}A	62.5^{a}
Skana® super dust	8.3^{b}A	17.9^{ab}A	10.8^{bc}A	12.6^{b}A	11.8^{b}
Sevin® dudu dust	3.1^{b}A	5.4^{bc}A	4.6^{bc}A	3.4^{bc}A	3.9^{bc}
K-obiol® DP2 dust	3.1^{b}A	0.0^{c}A	4.6^{bc}A	0.0^{c}A	2.0^{c}
Rodenticide	3.1^{b}A	3.6^{bc}A	7.7^{bc}A	0.0^{c}B	3.3^{bc}
Cow dung	2.1^{b}A	5.4^{bc}A	1.5^{c}A	4.6^{bc}A	3.3^{bc}
χ2 (5)	238.45	68.47	84.38	237.98.47	301.34
P-value	<0.001	<0.001	<0.001	<0.001	<0.001

Down the columns: granary (storage place), room in house (storage place), Njoro (locality), Rongai (locality) and overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare practices in granary storage versus room in house storage (across rows) and storage in Njoro versus Rongai; values across the rows followed by the same uppercase letter under the caterogories (storage place or locality) are not significantly different ($P > 0.05$).

mouldy, diseased, and discolored kernels reduced aflatoxin (Fandohan et al., 2005) and fumonisin (Pearson et al., 2010) levels. Thus, sorting would enhance safety besides improving storability.

Farmers predominantly shelled the maize using mechanized shellers. While the use of machines reduces breakage of grain compared to the traditional method of beating with sticks,

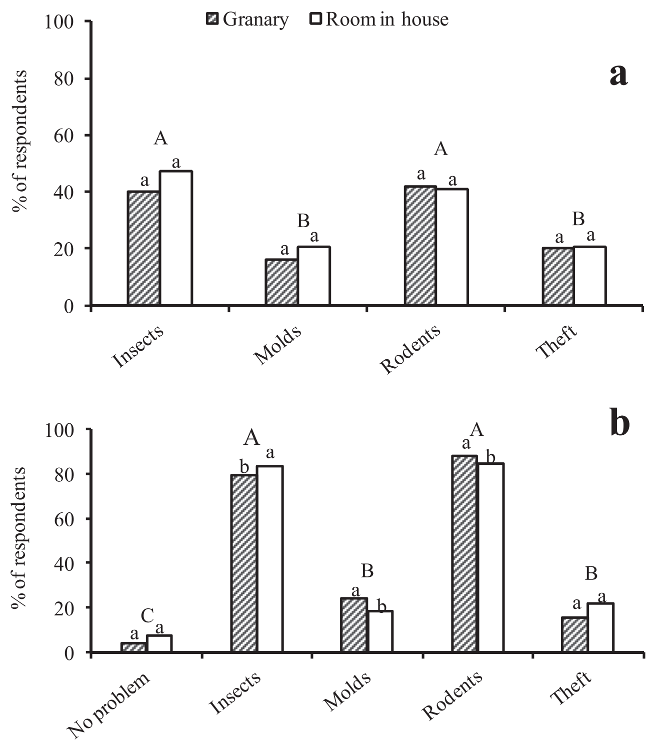

Fig. 3. Causes of storage problems (a), and the frequency of farmers who ranked a particular problem as 'most important' during storage (b). The same uppercase letters indicate no significant difference ($P > 0.05$) among categories in the overall sample. Lowercase letters compare storage in granaries versus rooms in the living house; same letters indicate no significant difference ($P > 0.05$).

incorrect setting of the machines and shelling of moist or over-dried cobs may lead to high levels of mechanical damage (Srison et al., 2016). Other factors, such as physical and morphological characteristics of the cobs and sheller design, also determine the amount of broken grain and cob cores that end up mixed with the shelled grain. Large amounts of the broken grain encourage insects and micro-organisms (Fandohan et al., 2006) and are therefore undesirable on grain lots intended for storage. Inadequately dried maize cores may elevate grain moisture while chaff, dust, and the minute parts of broken cores obstruct airflow around individual grains, thereby encouraging the growth of moulds and insects. The majority of farmers winnowed the shelled grain manually or mechanically to separate the chaff, while a few also hand-picked the large debris. According to Mwangi et al. (2017), cleaning and drying shelled grain before storage can lower storage losses by margins of 4.5 and 7.9 percentage points, respectively.

Clean storage environments deter pests from invading stored products. The present study revealed that most farmers swept their stores before introducing the new harvest. This action potentially decreased the population of resident insect pests as the adult insects, larvae, and eggs were swept away together with dirt, dust, and grain residues. Other authors (Reed et al., 2003) investigated the possibility of grain residues of wheat on floors of storage bins acting as reservoirs of grain beetles. They found lower insect densities in samples collected from bins cleaned before refilling, pointing to the significance of proper cleaning even of the grain handling equipment. Two-fifths of farmers used recycled bags, and only less than half of these farmers disinfested them. Used bags harbor insects and moulds from the previous harvest. The re-use of old bags was estimated to result in higher losses by 13.5 percentage points in off-farm stores (Mwangi et al., 2017).

Over 98% of respondents used bags to store their maize grain in. This is due to flexibility, ease of handling, e.g., loading and unloading during transportation, ease of inspection, and ease of sale because the 90 kg bag is a standard unit of grain commerce in Kenya. The use of woven polypropylene bags was more popular than other types of bags (jute, sisal bags, air-tight bags) because of the lower cost and easy accessibility. The use of air-tight storage bags was low, although more farmers were using them (8.3%) than metal silos (0.3%). Unlike metal silos, the air-tight bags are vulnerable to rodents damage, which many farmers identified as a storage problem. This vulnerability was probably a reason for the low adoption; we encountered many rodent-damaged hermetic bags during the survey. Good hygiene practices, such as clearing the surrounding area as well as frequent store inspection, could lower rodent populations, and thereby increase the usefulness of hermetic bags. The majority of the farmers kept bagged grain in granaries, but the practice of storing the bagged grain in the dwelling house was also widespread (40% of farmers stored in their houses) due to a fear of theft (Bunei and Rono 2014). It is, however, worth noting that the farmers' estimation of their maize storage losses whether kept in granaries or in the dwelling houses, did not differ. Also, whether the farmers stored their main in granaries or their dwelling houses, they rated losses caused by rodents and insects as being of equal importance. Unlike granaries, rooms in the dwelling house are more commonly frequented and cleaned, hence making the detection of infestations in them easier. However, poor aeration may promote moulds and pests if the grain is inadequately dried or protected (Hell et al., 2000). The perceived total losses (8%) were lower than those previously reported (17%) in the same agro-ecological zone (Edoh Ognakossan et al., 2016). We attribute this difference to seasonal variation, timing of the study, or sampling factors.

Contrary to expectations, disinfestation of the store prior to introducing the new harvest did not lead to lower losses. Mwangi et al. (2017) reported a similar observation in off-farm stores. A plausible reason is that the majority of the farmers used dust-based insecticides to disinfest their granaries or store rooms, which do not penetrate into the cracks and crevices. Hence, adult insects, larvae, or eggs hidden in these places escape insecticide exposure (Toews

Table 6
Magnitudes of storage losses (% w/w) cause by the various loss agents as perceived by farmers.

	Storage place		Locality		Average
	Granary	Room in house	Njoro	Rongai	
Insectsrowhead	3.6 ± 0.43^{a}A	4.4 ± 0.67^{a}A	3.77 ± 0.45^{a}A	4.09 ± 0.62^{a}A	3.92 ± 0.37^{a}
Mouldsrowhead	1.09 ± 0.25^{b}A	1.03 ± 0.4^{b}A	1.74 ± 0.38^{b}A	0.24 ± 0.09^{b}A	1.06 ± 0.22^{b}
Rodentsrowhead	3.45 ± 0.39^{a}A	3.12 ± 0.45^{a}A	3.49 ± 0.43^{a}A	3.10 ± 0.38^{a}A	3.31 ± 0.29^{a}
Theftrowhead	0.23 ± 0.10^{c}A	0.33 ± 0.08^{c}A	0.25 ± 0.11^{c}A	0.32 ± 0.11^{b}A	0.27 ± 0.07^{c}
Totalrowhead	8.12 ± 0.57	8.58 ± 0.99	8.12 ± 0.57	8.58 ± 0.99	8.3 ± 0.52

Mean (±S.E.) values within a column followed by the same lowercase superscript letter are not significantly different ($P > 0.05$); values across the rows followed by the same uppercase letter under the caterogories of storage place or locality are not significantly different ($P > 0.05$).

Table 7
Effect of farmers socio-economic characteristics, storage and hygiene practices on the magnitude of actual losses (n = 40) in shelled maize storage.

Variables	Estimated coefficient (SE)	Marginal effect (SE)
Socio-economic characteristicsrowhead		
Gender (*dummy = 0 if male; dummy =1 if female*)rowhead	−0.516 (0.258)[b]	−0.028 (0.015)[a]
Age (*dummy =0 if age is 18 to 24 years; dummy =1 if age > 24 years*)rowhead	0.560 (0.198)[c]	0.028 (0.100)[c]
Education level (*dummy = 0 if no formal education or not gone primary education; dummy =1 if attended secondary school or tertiary education*)rowhead	−0.104 (0.186)	−0.005 (0.010)
Experience in maize farming (*dummy = 0 if ≤ 20 years; dummy =1 if > 20 years*)rowhead	−0.961 (0.241)[c]	−0.059 (0.017)[c]
Received training in grain storage protection (*dummy =0 if no; dummy =1 if yes*)rowhead	0.001 (0.203)	.000 (0.011)
Storage practicesrowhead		
Location of storage device (*Granary = base category*)rowhead		
Bedroom	−0.637 (0.244)[c]	−0.028 (0.009)[b]
Special room	−0.061 (0.260)	-.003 (0.014)
Kitchen	1.676 (0.271)[c]	0.190 (0.050)[c]
Living room	−1.379 (0.699)[b]	−0.046 (0.014)[c]
Storage devices (*dummy = 0 if ordinary polypropylene bag; dummy = 1 if hermetic bag or metal silo*)rowhead	0.286 (0.331)	0.016 (0.021)
Storage duration (months)rowhead	0.078 (0.053)	0.004 (.002)
Farmer examined and repaired store before storage (*dummy = 0 if no; dummy =1 if yes*)rowhead	−0.379 (0.237)	−0.020 (0.013)
Store treated with protectants before grains introduced (*dummy = 0 if no; dummy =1 if yes*)rowhead	−0.252 (0.211)	−0.013 (0.011)
Co-storage with other products (*dummy = 0 if no; dummy =1 if yes*)rowhead	0.637 (0.305)[b]	0.028 (0.011)[b]
Hygiene scorerowhead	−0.129 (0.067)[b]	−0.007 (0.003)[b]
Constantrowhead	−2.617 (0.553)	
Wald $\chi 2$ (25)rowhead	302.36	
*P- value*rowhead	<0.0001	

SE: Robust standard errors.
[a] $P < 0.1$.
[b] $P < 0.05$.
[c] $P < 0.01$.

and Subramanyam 2002). A further explanation may be related to the nature of the surfaces. According to Gwinner et al. (1990), the activity of insecticides on dirty surfaces tends to be short-lived irrespective of the formulations or the active ingredient. The potency of residual insecticides applied to wood, brick, or concrete attenuates within a short time due to the absorptive capacity of these surfaces (Jankov et al., 2013). Morrison et al. (2019) reviewed the effects of sanitation on chemical control of insect pests and found a 1.3−fold reduction of efficacy of grain protectants in low sanitation conditions. The efficacy reduction was 11−fold for residual insecticides and 1.6−fold for passive methods such as hermetic storage. Hence, while store disinfestation is a good practice, cleaning the store before, would enhance the efficacy by removing dust and debris that bind or dilute the disinfectant, besides directly reducing carry-over of pests from the previous season. Findings elsewhere showed significantly lower losses by 3.1 percentage points for farmers who disinfested their store prior grain storage in Tanzania (Chegere 2018). The nature, formulation, or ingredients of the chemicals used for disinfestation were, however, not expounded on.

Storing bagged maize in the bedroom or living room was associated with lower actual (measured) losses by margins of 2.8 and 4.6%, respectively, compared to storage in granaries. However, the storage of the bagged grain in the kitchen was associated with significantly higher losses by a margin of 19 percentage points. The warmer temperature and higher relative humidity in the kitchen environment, which would favor insect proliferation (Throne 1994), are possible reasons for this observation. Co-storing maize with other farm produce and equipment resulted in significantly higher losses by a margin of 2.8%. Whereas the majority of storage insects prefer to attack particular grain types, most insects can feed on multiple grains. However, the co-storage of produce with other farm implements and products such as hay, onions, potatoes, old bags, and clothes would also encourage pest harbourage and make store cleaning operations difficult and ineffective. The practice may contaminate the new harvest or create favorable conditions for pests and pathogens to thrive, e.g., commodities such as onions and potatoes can increase the humidity in storage spaces. Some authors (Hell et al., 2000), for instance, reported higher aflatoxin levels in maize stored together with sorghum or cowpea.

The use of either ordinary polypropylene bags or improved airtight containers (bags or metal silos) did not result in different loss levels. Chegere (2018) reported similar findings. Although the hermetic technologies are effective in protecting stored maize against insect pests in East Africa (Tefera et al., 2011; Ng'ang'a et al., 2016), their usefulness depends on the farmers' ability to seal them in a manner that ensures sustained hermeticity. During this survey, hermetic devices in the majority of farmers' stores were either left open, improperly sealed, or were damaged. Many of the farmers who used ordinary polypropylene bags applied pest control measures, including insecticides, wood ash, plant leaves, sieving or exposing the grain to sun. The appropriate application of insecticides in particular, is equally as effective against storage insect pests as hermetic containers (Abass et al., 2018). A higher hygiene score was associated with lower losses by a margin of 1%. Thus, storing clean produce in externally and internally, well-maintained clean stores contributed to lower pest infestations by limiting the shelter, food, and chances of development. These practices, together with improved post-harvest storage technologies, should be encouraged as part of better pest management in farmers' stores. Future research should investigate the conditions of the stores during the period between harvest depletion and loading of new harvests. Such knowledge could provide insightful information on the life-cycle and behaviour of storage pests in the absence of their primary food sources.

Finally, this study revealed that socio-economic factors influenced the implementation of proper post-harvest practices in farm stores. The stores of households in which women were responsible for making majority of the decisions on post-harvest handling activities were associated with lower actual losses. From a sanitation and hygiene point of view, women play a greater role in the household and may, therefore, attend better to storage hygiene practices. Moreover, lower losses were associated with more experience of maize farming (>20 years), suggesting that farmers mastered better techniques over time to manage storage pests. These findings agree with the observations of an earlier study (Edoh Ognakossan et al., 2016). By contrast, the younger farmers in the present study incurred significantly lower losses. One possible reason is that the stores owned by the younger farmers are quite pristine and devoid of years of pest accumulation. Other authors (Midega et al., 2016) also reported a trend where young farmers seem to be abandoning traditional storage methods in favor of modern ones partly due to a lack of knowledge and ability to construct and manage traditional structures. These findings hgihlight the need for integrating greater understanding of the socio-economic perspectives into interventions targeting the protection of stored produce in farm stores.

Credit author statement

Kobia Makinya: Investigation; Data curation, Formal analysis, Writing – Original draft; **John Wagacha:** Supervision; **Judith Odhiambo:** Supervision; **Paddy Likhayo:** Supervision; **Kukom Edoh-Ognakossan:** Investigation, Formal analysis; **Tadele Tefera:** Project administration; Writing – Review & editing; **Adebayo Abass:** Funding Acquisition, Writing – Review & Editing; Project Administration; **Christopher Mutungi:** Conceptualization, Funding Acquisition, Methodology, Visualization, Writing – Review & editing, Project Administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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