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The influence of extension approaches on uptake of postharvest technologies among maize farmers in Uganda

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ABSTRACT
High postharvest losses exist among farmers in sub-Saharan Africa despite the introduction of several improved postharvest handling technologies. This is indicative of low adoption associated with dissemination approaches used. This study assessed postharvest technology uptake and maize postharvest losses among smallholder farmers in Kamuli and Apac districts of Uganda. Random sampling was used to select 108 farmers from 12 farmer groups in the two districts receiving extension services using the participatory and farmer to farmer extension approaches. Farmers under both approaches were trained in good postharvest handling technologies and practices. Under farmer to farmer extension approach, farmers were trained by trained farmers while under the participatory approach, farmers were trained by researchers and engaged in on-farm trials. The assessment for losses was done at harvest, drying and storage. The promoted technologies were tarpaulins, raised racks, hermetic bags and metallic silos. Uptake of the promoted technologies was higher among the farmers under the participatory approach. Total quantitative losses reduced significantly ($p \leq 0.05$) at post-intervention by 64.6% and 32% under the participatory approach and farmer to farmer approach, respectively. Similarly, mold infection in maize reduced by 17.3% and 4% under the participatory approach and farmer to farmer approach, respectively from 90.47±5.11% pre-intervention. The aflatoxin level in maize reduced significantly from 46.63±4.84ppb pre-intervention to 8.07±1.51ppb and 21.47±2.73ppb under the participatory approach and farmer to farmer approach group post-intervention, respectively. Participatory extension approach resulted into higher technology uptake and subsequent lower quantitative losses, mold infection and aflatoxin contamination of maize.

Keywords: Extension approaches, postharvest technology uptake, postharvest losses, aflatoxins, maize

RESUME
Les agriculteurs d'Afrique subsaharienne enregistrent de fortes pertes après récolte, malgré l'introduction de plusieurs technologies de manutention post-récolte améliorées. Cela indique une faible adoption associée aux approches de diffusion utilisées. Cette étude a évalué l'adoption de la technologie post-récolte et les pertes post-récolte de maïs chez les petits agriculteurs des districts de Kamuli et d'Apac en Ouganda. L'échantillonnage aléatoire a été utilisé pour sélectionner 108 agriculteurs de 12 groupes d'agriculteurs dans les deux districts recevant des services de vulgarisation en utilisant les approches participatives et de vulgarisation entre agriculteurs. Dans les deux cas, les agriculteurs ont reçu une formation sur les bonnes techniques et pratiques de manutention après la récolte. Dans le cadre de l'approche de vulgarisation agricole, les agriculteurs étaient formés

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par des agriculteurs formés, tandis que dans le cadre de l'approche participative, les agriculteurs étaient formés par des chercheurs et engagés dans des essais à la ferme. L'évaluation des pertes a été effectuée à la récolte, au séchage et à l'entreposage. Les technologies promues étaient des bâches, des supports surélevés, des sacs hermétiques et des silos métalliques. L'adoption des technologies promues était plus élevée chez les agriculteurs dans le cadre de l'approche participative. Les pertes quantitatives totales ont considérablement diminué ($p \leq 0,05$) après l'intervention de 64,6 % et 32 % selon l'approche participative et l'approche agriculteur-agriculteur, respectivement. De même, l'infection à moisissure du maïs a diminué de 17,3 % et de 4 % dans le cadre de l'approche participative et de l'approche agriculteur à agriculteur, passant respectivement de 90,47±5,11 % avant l'intervention. Le niveau d'aflatoxine dans le maïs a considérablement diminué, passant de 46,63± 4,84ppb avant l'intervention à 8,07±1,51ppb et 21,47±2,73ppb dans le cadre de l'approche participative et du groupe d'approche agriculteur-agriculteur après l'intervention, respectivement. L'approche participative de vulgarisation a permis d'accroître l'adoption de la technologie et, par la suite, de réduire les pertes quantitatives, l'infection par la moisissure et la contamination par l'aflatoxine du maïs.

Mots clés : Approches de vulgarisation, adoption de technologie post-récolte, pertes post-récolte, aflatoxines, maïs

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important agricultural commodities worldwide in terms of amounts produced, consumed, and traded (Wu, 2014). Maize contribute 147 kcal and 388 kcal, respectively to per capita dietary energy intake globally and in Africa (FAO, 2018). The crop accounts for nearly 20% of plant-based food supply (Abebe *et al.,* 2009). Over 70% of maize production in developing countries is by smallholder farmers. Maize production in developing countries is also characterized by high postharvest losses (APHLIS, 2017; FAO, 2018). Postharvest losses include direct physical losses and quality losses that reduce the economic value of the crop and may make it unsuitable for human consumption (Kumar and Kalita, 2017). Postharvest grain losses are largely attributed to inappropriateness of postharvest handling technologies and practices, inefficient processing facilities, biodegradation due to microorganisms and insects, among others (World Bank, 2011; Kumar and Kalita, 2017). These problems are mostly recorded among smallholder farmers. Quantitative maize postharvest losses are estimated to be highest at drying and storage (World Bank, 2011; APHLIS, 2017; Tibagonzeka *et al.,* 2018).

Insects and pests are reported to cause the highest losses in maize during storage (Kaminski and Christiaensen, 2014; Ng'ang'a *et al.,* 2016). One of the most important global concerns in terms of grain quality losses is aflatoxins contamination. Aflatoxins are toxic secondary metabolites, naturally occurring hepatocarcinogens produced by aflatoxigenic molds of the genus Aspergillus (Klich, 2007). Aflatoxins are most prevalent in crops in tropical and subtropical regions of the world and may occur in the field and at postharvest (Kaaya *et al.,* 2006; Kaaya and Kyamuhangire, 2006; Wu, 2014; Kamala *et al.,* 2016). The Food and Agriculture Organization (FAO) estimates that 25% of the world's agricultural commodities are contaminated with mycotoxins, leading to significant economic losses (Wu, 2007). The International Agency for Research on Cancer categorizes aflatoxins as confirmed carcinogens especially aflatoxin B1. It has been estimated that over 5 billion people worldwide are exposed to uncontrolled aflatoxins in their diet (Strosnider *et al.,* 2006). Global risk assessment studies associate between 25,200 and 155,000 human liver cancer cases per year with aflatoxin exposure (Williams *et al.,* 2004). In order to enhance trade and consumer protection, over 100 nations have established maximum tolerable levels for aflatoxin in food and standards especially for the most toxic and carcinogenic aflatoxins, aflatoxin B1 (Wu and Khlangwiset, 2010). Due to this, aflatoxins in food products in both the local and global market impose large burdens on trade in terms of rejection and failure of penetration into lucrative markets. Production of aflatoxins in food products is governed by the crop (genotype, nutrients), physical (temperature, soil type, water stress, excess rainfall, humidity, damage to crop, moisture), biotic (insects, interference competition) and cultural (poor timing of harvest, poor postharvest handling, inadequate drying, aeration during drying and storage, pre-harvest mold growth) factors (Smith and Moss, 1985; Miller, 1995; Kaaya and Warren, 2005).

High postharvest losses in maize are persistent among small holder farmers despite the fact that several improved postharvest technologies such as hermetic storage, raised platforms, tarpaulins, which are associated with lower losses have been introduced to farming communities. Raised drying platforms and tarpaulins utilize open sun drying which prevent direct contact of produce with dirt. It has been suggested that avoidance of direct contact between grain and soil through drying the grain on a mat or on a raised drying platform reduces contamination by toxigenic fungi (Magan and Aldred, 2007) and accelerates the drying process (Kamala *et al.,* 2016). Hermetic storage has been reported to reduce maize storage losses to as low as 1-2% (Kumar and Kalita, 2017) and reduce insect infestation and damage to below 1% during storage (Ng'ang'a *et al.*, 2016). Metallic silos, a hermetic technology which has been introduced to the farmers in Africa since 2008 have been associated with reduced grain damage and losses from insect pests (Tefera *et al.,* 2011; De Groote *et al.,* 2013). Hermetic bags, on the Ugandan market exist in two major brands that include Purdue Improved Crop Storage (PICS bagsTM) and SuperGrainBagTM. These consist of an outer polypropylene bag and inner linings of High-Density Polyethylene (HDPE). Hermetic bags are associated with reduced insect infestation, damage and mold infection (Ng'ang'a *et al.,* 2016).

The mismatch between farmer practice and existing technologies is linked to low technology uptake and adoption (Tibagonzeka *et al.,* 2018). Technology adoption is associated with the approach used for dissemination (World Bank, 2011). Akinnagbe and Ajayi (2010) asserted that for research to be effective, there must be an efficient mechanism whereby its results can be used by the end users. Several agricultural extension approaches have been used in technology dissemination and these include participatory approach, farmer to farmer approach, farming systems approach, training and visit approach, national campaigns approach, among others (Davis, 2008). Of recent, extension is shifting from supply-led to demand-driven approaches (LRD, 2015; Singh *et al.,* 2015) due to limitations of the former such as the assumption of relevance of technology to farmers (LRD, 2015). Supply-led approaches are the traditional view of technology transfer which is a one-way process where innovations from research are passed on to extension then to farmers (Akinnagbe and Ajayi, 2010). Demand-driven approaches on the other hand involve a negotiated system through which farmers and rural community members determine their needs and have some control over extension services which are delivered by public, private, NGO or farmer organizations (Akinnagbe and Ajayi, 2010). Some of the demand-driven extension approaches include the participatory rural appraisal, farmer field schools, participatory research and the farmer to farmer approach. The farmer to farmer approach is one of the commonest demand-driven approaches and it involves practicing farmers acting as extension agents (Ssemakula and Mutimba, 2011). It is reported that approaches with active participation have showed potential for increasing adoption rates (Job *et al.,* 2015). One of such approaches is the participatory extension approach (Singh *et al.,* 2015).

Participatory approach involves researcher-farmer interaction and active participation of the farmers in research. It was therefore important to understand the interaction between extension approach, technology uptake and reduction in postharvest losses. This study therefore sought to evaluate the effectiveness of the participatory and farmer to farmer approaches in enhancing postharvest technology uptake, grain quality and reducing postharvest losses among small holders.

MATERIALS AND METHODS

Study area. The study was carried out in two (2) districts located in two different agro-ecological zones of Uganda namely; the Kioga plains (Kamuli district) and the North-Western Savannah grasslands (Apac district). The districts were selected purposively by virtue of their high maize production (UBOS, 2017a) and evidence that farmers experienced substantial grain losses along the postharvest value chain (Tibagonzeka *et al.,* 2018).

Study design and sampling strategy. The study employed a pretest-posttest quasi-experimental design. Four maize producing sub counties in Kamuli and Apac districts were selected and these included Butansi and Bugulumbya in Kamuli and Chegeere and Apac sub counties in Apac. From these sub counties, a list of active farmer groups with at least fifteen (15) members was generated from which, six farmer groups were selected per district purposively taking into consideration the level of maize production within the group and distance between the groups to prevent spillover effects. The farmer groups were randomly assigned to participatory and farmer to farmer extension approaches in the ratio of 1:1. The sample size was calculated at 95% confidence level using a formula by Yamane (1967) (see Eq. (1). The population of maize producing households was derived from government statistics (UBOS, 2017b; UBOS, 2017c). A total of 108 farmers were selected from the six farmer groups per district (9 farmers randomly selected per group). To be included in the study sample, only farmers that grew maize every season, stored part of the harvest (at least 25kg) for a period of at least six months and had at least 10m by 10m of ready to harvest maize were included.

$$n = N/1 + N(e)^2 \qquad \text{Eq. (1)}$$

Where; n- sample size; N- population size (total number of maize growing households in Kamuli (8,699) and Apac (7,568) districts); e- level of precision at 10%

n = 99.4 ~ 100 farmers; The used sample size was 108 farmers.

Baseline and post-intervention assessment. A baseline or pretest study was conducted to establish the current practices used by farmers at drying and storage, the technologies and practices used, postharvest losses and quality of maize. Quantitative losses, mold infection and aflatoxin contamination were determined at harvest, drying and storage (1 month, 3 months and 6 months). Following the baseline, the farmers under each extension approach were trained. The training involved modules on good postharvest handling practices and technologies, their likely effects and benefits. The participatory extension approach involved researcher-farmer interaction in training, farmer engagement in on-farm trials, farmer engagement in data collection and sharing of results with the farmers. A two-day training workshop was conducted for each farmer group to cover the modules. This was followed by demonstrations and experiments, data collection and results sharing over a six-month period illustrating the operation of the technologies. Under the farmer to farmer extension approach, two farmers per farmer group were undertaken through a Training of Trainers session by researchers in the different modules of postharvest handling practices and technologies in a two-day workshop. The trained farmers were exposed to the technologies, their operation, benefits and likely risks, however, no elaborate demonstrations and experiments were done. After the training, the trained farmers trained other farmers in their respective farmer groups covering the same modules.

Six months post training, a post-intervention assessment was done to establish the postharvest handling practices of the farmers in each of the treatment groups. This was followed by an assessment of quantitative losses, mold infection and aflatoxin contamination of maize at harvest, drying and storage (1 month, 3 months and 6 months). Socio-demographic characteristics of the selected farmers were also collected using a rapid appraisal structured questionnaire. Information gathered included age, gender, education level, average land area allocated to maize (acres), primary economic activity, major crops grown, purpose of production, technologies used pre-intervention and reasons for using them, technologies used post-intervention and reasons for uptake for the technologies and reasons for not using other promoted technologies.

At least 25kg of harvested untreated shelled maize grain from the harvest season was reserved from each participating farmer. From each farmer, 1 kg sample of maize grain was collected at harvest, drying and storage (1 month, 3 months and 6 months) stages of the postharvest chain. The samples were packed in clear plastic sample bags, labeled with identification information about the farmer, extension approach and technology or practice used. The samples were then transported to the School of Food Technology, Nutrition and Bio-Engineering laboratory at Makerere University for analysis. The variables assessed included moisture content, mold infection and aflatoxin contamination.

Moisture content determination. Moisture content of the samples was determined using the standard oven method (AOAC, 1999).

Quantitative loss determination. The actual percentage weight loss at each postharvest stage was determined using the weigh-in and weigh-out method. This method determined the weight of the produce before a stage, Wb and the weight of the produce after the stage, Wa and corrects for differences in moisture content, Dm. Percentage weight loss was calculated using Eq. (2) below;

$$\%\ Weight\ loss = {}^{(Wb - Wa - Dm) * 100}/_{Wb}$$
Eq. (2)

Enumeration and identification of internal molds. Mold infection was determined by direct plating technique for internal mold infection (Pitt and Hocking, 1997). About thirty (30) kernels of grains from each sample were surface disinfected for 1 minute with sodium hypochlorite (10% commercial bleach, Jik, Rickitt Benckiser, East Africa Ltd), rinsed three times with sterile distilled water and aseptically placed directly on the surface of acidified potato dextrose agar prepared by mixing 39 g of powdered potato dextrose agar in 1 liter of distilled water. Ten kernels were placed directly on each agar plate. The plates were incubated upright at 25°C for five days and then the emerging mold colonies were enumerated and identified. The mold species were identified using morphological characteristics (Watanabe, 1994).

Aflatoxin analysis. The Vicam fluorometer procedure for maize was used to test for total aflatoxins using AflaTest® Series-4 EX Fluorometer® following the manufacturer's instructions (VICAM, A Waters business 34 Maple Street, Milford, MA 01757, USA). The maize kernels were ground using a laboratory blender (Waring commercial blender model HGBTWTS3, Torrington, USA). From each sample, 50g of the flour were weighed, mixed with 5g sodium chloride and placed in the blender jar. About 100 ml of methanol: water solution (80:20, v/v) were added to the sample and blended at high speed for one minute. The blended mixture was filtered using fluted filter paper. Ten (10) ml of filtrate were pipetted into a clean vessel, diluted with 40 ml of distilled water, mixed thoroughly and filtered through a glass microfiber filter into a clean glass syringe. From the syringe, 10 ml of the filtered extract (10 ml = 1.0 g sample equivalent) was passed through the Aflatest®-P affinity column at a rate of 1 drop/second. The column was rinsed with 10 ml of distilled water twice at a rate of 1-2 drops of water. The affinity column was eluted by passing 1 ml HPLC grade methanol at a rate of 1 drop/second. The eluate was collected into a glass cuvette. One milliliter of Aflatest® developer solution was added to the eluate, mixed thoroughly and the cuvette placed in the fluorometer earlier calibrated to read total aflatoxin. Aflatoxin concentration (ppb) in the samples was detected and recorded after 60 seconds.

Statistical analysis. Data for mold incidence, aflatoxin contamination, weight loss and moisture content were subjected to analysis of variance (ANOVA) using Stata SE version 12 (StataCorp LP, Texas, USA). Means were separated using Tukey's HSD test at 95 % confidence level. Data from interviews were sorted, coded and entered into Statistical Package for Social Sciences (SPSS) version 19.0. Correlational analysis using Pearson's coefficient was then conducted to determine relationships between socio-demographic factors such as age, gender and education level and technology uptake level.

RESULTS

Demographic characteristics of the study sample. The demographic characteristics of the study sample are summarized in Table 1. Majority of the farmers (62.1%) that engaged in this study were aged 31 to 50 years with more females (66.7%) engaged than males. The majority (65.7%) of the farmers had primary level education and only 21.3% reached secondary level . The primary economic activity done by majority of the farmers (99%) was crop farming. Most of the farmers (93%) produced maize alongside other staples such as cassava, sweet potatoes, millet, and sorghum among others. Production by majority of the farmers (53%) was done on less than one acre (0.4 ha) of land and up to 90% were largely smallholder producers. The purpose for production was largely for food. The surplus was sold for cash.

Influence of the extension approaches on postharvest handling technology uptake. Maize postharvest practices and technologies pre-intervention and post-intervention varied, with more farmers using improved postharvest technologies and practicing post-intervention than in the pre-intervention stage (Fig. 1). The commonly used drying practices pre-intervention were drying on bare ground (100%) and tarpaulins (6%). At storage, all the maize farmers used polypropylene bags. Post-intervention, uptake and usage of improved technologies at drying and storage increased among the farmers in the study. The uptake and usage of all the promoted improved postharvest handling technologies was higher among the farmers that received extension advise through the participatory approach than the farmer to farmer extension approach. In both approaches, tarpaulins were adopted by the highest proportion (100% for participatory approach and 97.4% for farmer to farmer approach) of farmers. Technologies reported by farmers to be relatively expensive had lower level of use (drying racks and metallic silos) than relatively cheaper technologies (tarpaulins and hermetic bags).

The results indicate that in both groups, technology uptake had a significant negative correlation with total losses and aflatoxin contamination (Table 2). Uptake of the promoted technologies among the participatory approach group was not significantly correlated to education level and age. However, in the farmer to farmer approach, uptake of the

Table 1. Demographic characteristics of the study sample

Characteristics Age (years)	Category	Percentage (%)
	20-30	7.4
	31-40	35.2
	41-50	26.9
	51-60	18.5
	above 60	12.0
Gender	Female	66.7
	Male	33.3
Education level	None	9.3
	Primary	65.7
	Secondary	21.3
	Tertiary	3.7
Average land area allocated to maize (acres)	<1	53
	1.0-4.0	38.0
	>4	9.0
Primary economic activity	Crop farming	99
	Livestock production	0.5
	Others (charcoal burning, retail, etc.)	0.5
Major crops grown	Maize only	7
	Maize + other staples	93
Purpose of production	Food only	13
	Cash only	0
	Food and Cash	87

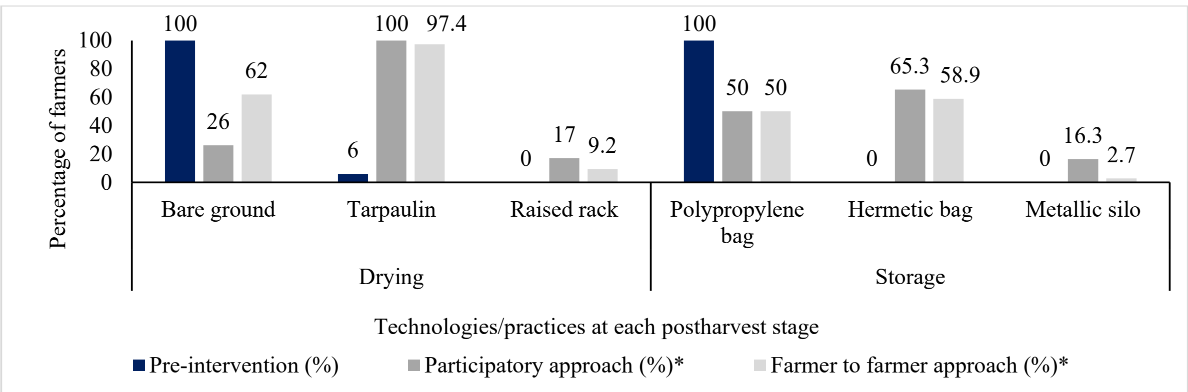

Figure 1. Postharvest handling practices and technologies used by maize farmers pre- and post-intervention

*Percentage exceeds 100 per stage because some farmers were using more than one technology per stage promoted technologies had a significant positive correlation with education level. Within the same group, age was positively correlated with total losses.

Moisture content of maize from farmers pre- and post-intervention. The mean moisture content of maize grain from farmers under the farmer to farmer and participatory approaches did not significantly vary along the postharvest chain except at harvest (Table 3). The results indicate that the mean moisture content of maize grain at harvest from the farmers under participatory approach (25.67±3.60%) was significantly higher (p≤0.05) than that from farmers' pre-intervention (22.59±3.45%) and under farmer to farmer approach (21.17±3.81%). Generally, the mean moisture content of maize dried using similar technologies was not significantly different between the groups. However, the moisture content of maize from farmers pre-intervention was higher than that for post-intervention. The results further indicate that in both pre-intervention and post-intervention, maize was dried to moisture content below 15%. At storage under similar technologies, no significant difference (p>0.05) in the mean moisture content among the treatment groups was observed, however, the moisture content of maize pre-intervention (13.73±0.98%) was significantly higher than that of maize post-intervention.

Table 2. Relationship between socio-demographic factors, technology uptake and losses for farmers post-intervention

Variable	Age	Technology uptake	Education	Total Losses	Aflatoxin contamination
		Participatory approach			
Age	1	0.293	0.064	-0.151	-0.252
Technology uptake	0.293	1	0.044	-.599*	-0.574*
Education	0.064	-0.044	1	-0.086	-0.219
		Farmer to farmer approach			
Age	1	0.162	-0.078	0.348*	0.077
Technology uptake	0.162	1	.300*	-.641*	-0.551*
Education	-0.078	.300*	1	0.104	-0.036

* Correlation is significant at the 0.05 level (2-tailed)

Table 3. Final mean moisture content (%) of maize at the end of each postharvest stage

Stage	Technology	Pre-intervention	Farmer to farmer	Participatory
Harvest		22.59±3.45[a]	21.17±3.81[a]	25.67±3.6[b]
Drying	Bare ground	14.2±0.9[a]	14.09±0.52[a]	13.93±0.61[a]
	Tarpaulin	14.37±0.95[b]	13.87±0.59[a]	13.85±0.62[a]
	Raised racks	N/A	13.69±0.46a	13.63±0.64[a]
Storage	Polypropylene bag	13.73±0.98[b]	13.51±2.39[a]	13.18±0.49[a]
	Hermetic bag	N/A	13.61±0.97[a]	13.59±0.21[a]
	Metallic silo	N/A	13.87±0.51[a]	13.67±0.97[a]

Means with different superscripts within the same row are significantly different at p≤0.05 level; N/A- not applicable since farmers were not using these technologies

Quantitative postharvest losses of maize among farmers pre- and post-intervention. Generally, quantitative postharvest maize losses significantly reduced from pre- to post-intervention (Fig. 2). At the end of the analysis period (6 months of storage), the total quantitative losses pre-intervention was 40.4±5.66%, and this reduced significantly post-intervention by 64.6% and 32%, respectively, for farmers under the participatory approach and farmer to farmer approach. The highest reduction in losses was observed at storage. Post-intervention, farmers under the farmer to farmer approach had higher losses than farmers under participatory approach at each stage. Quantitative loss registered at harvest under the participatory approach group (5.19±3.79%) was significantly ($p<0.05$) lower than that of the farmer to farmer approach group (13.51±5.04%) and the pre-intervention losses (9.94±3.35%). The mean quantitative losses at drying were not significantly different among the farmer to farmer (1.77±1.31%) and participatory (1.43±1.19%) groups but these were significantly lower than the losses attained pre-intervention (2.46±1.56%). In cases where farmers under both extension approaches used similar technologies at drying, no significant differences in the mean postharvest losses were observed among the groups (Fig. 3). Higher losses were obtained when farmers from either group dried maize on bare ground than when drying was on tarpaulins and raised racks.

The total storage losses made by the farmers under the participatory group (7.61±0.74%) were significantly lower than those made by the farmers under the farmer to farmer group (14.08±0.76%) and those made pre-intervention (28±3.3%). Post-intervention, the losses however, varied with technologies used. The highest storage losses were made in polypropylene bag storage and these losses were significantly higher in the farmer to farmer group (25.51±7.22%) than the participatory group (20.73±1.98%). The results further indicate that farmers that used hermetic bags under participatory approach had significantly lower mean storage losses that those that used the same technology under farmer to farmer approach. However, in the case where metallic silos were used by both groups, no significant difference was observed. Considering similar technology combinations, the farmers under participatory extension approach got significantly lower quantitative losses than the farmers under the farmer to farmer extension approach. The highest cumulative losses from harvest to storage in both groups were made by

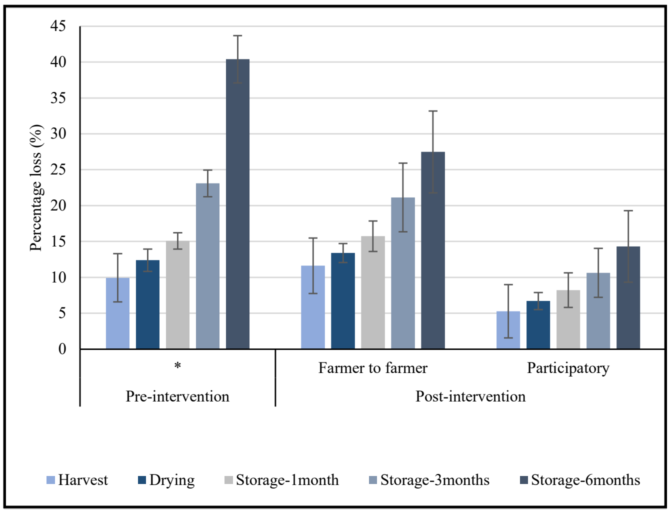

Figure 2. Cumulative quantitative postharvest maize losses pre- and post-intervention

farmers who used a combination of drying on bare ground and storage in polypropylene bags (farmer to farmer-40.11%; participatory-30.6%). Since none of the farmers that were drying on raised racks stored their maize in metallic silos in both groups, the lowest cumulative losses from harvest to storage were made by farmers who used a combination of drying on tarpaulins and stored in metallic silo.

Mold infection of maize from farmers pre- and post-intervention. High mold infection was observed along the postharvest chain both pre- and post-intervention (Fig. 4). By the end of the analysis period (sixth month of storage), the mold infection in maize post-intervention reduced by 17.3% and 4% among the farmers under the participatory approach and farmer to farmer approach respectively from 90.47±5.11% pre-intervention. The mold infection of maize at harvest was significantly lower among the farmers under the participatory approach (64.56±9.68%) than the farmer to farmer approach (70.99±10.87%). The mean mold infection among the groups was not significantly different at drying and storage where similar technologies were used. Considering different drying and storage technology combinations, the highest mold infection across the postharvest chain was observed when drying was done on bare ground and storage was in polypropylene bags and at the sixth month of storage, it was 98% for both groups (Fig. 5). The technology used in drying affected mold infection of the maize over the storage period. Throughout the storage period, the maize grain stored using any of the storage options but dried on raised racks had lower mold infection than that dried on bare ground and tarpaulin. The maize stored in any of the storage technologies but dried on tarpaulins had lower mold infection than that dried on bare ground. The results further indicate that irrespective of the drying technology used, the highest mold infection of maize over the storage period of six months was observed when storage was done in polypropylene bags and the lowest when storage was done in metallic silos.

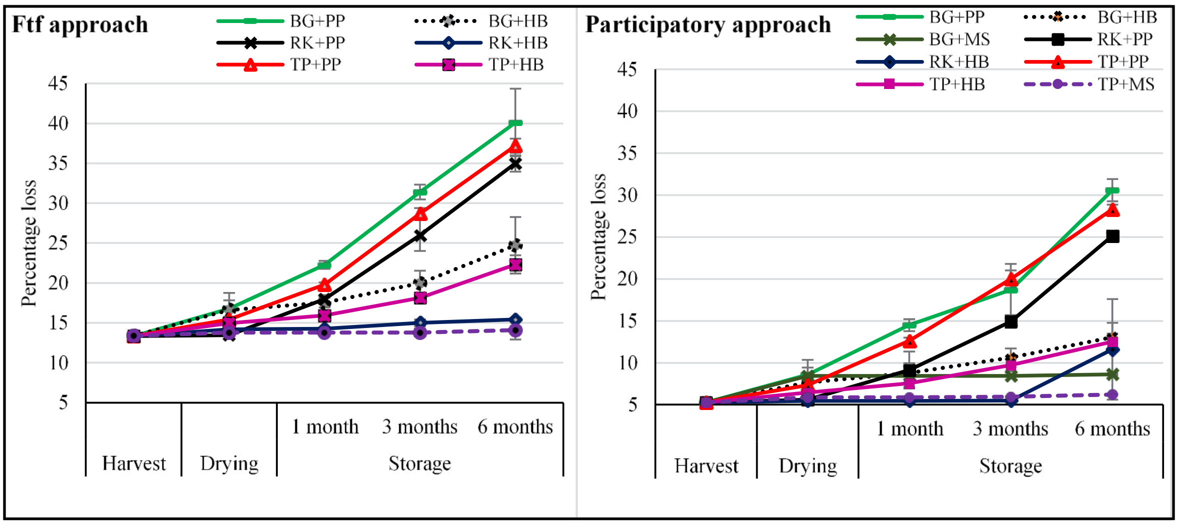

Figure 3. Cumulative quantitative postharvest maize losses post-intervention along the postharvest chain

Ftf: Farmer to farmer approach; BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB- Hermetic bag, MS- Metallic silo

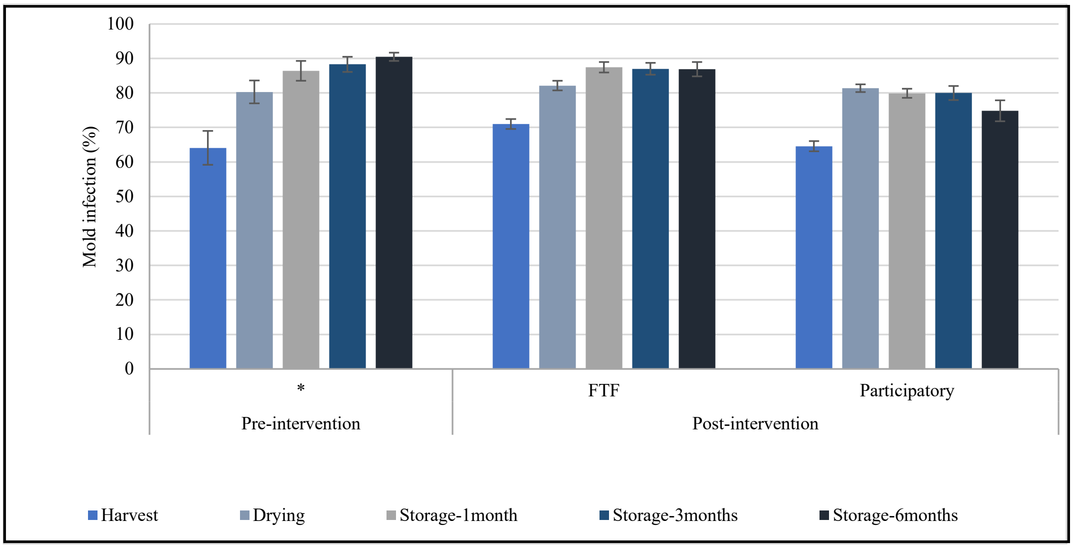

Figure 4. Mold infection of maize from farmers pre- and post-intervention
FTF- Farmer to farmer

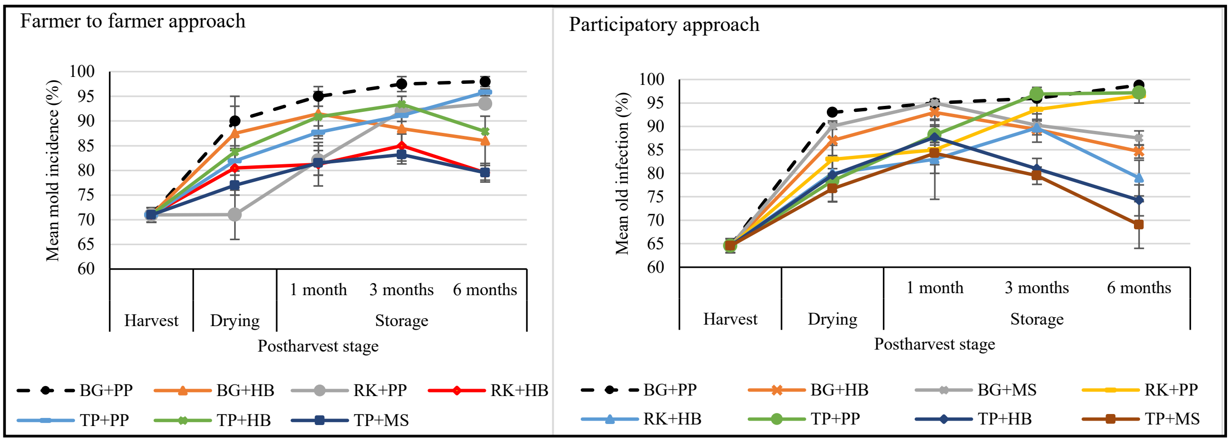

Figure 5. Mold infection of maize from farmers post-intervention
BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB- Hermetic bag, MS- Metallic silo

Aflatoxin levels in maize from farmers pre- and post-intervention. Across the postharvest chain, the aflatoxin levels in maize pre-intervention were significantly higher than the levels in maize post-intervention, irrespective of the extension approach used. Post-intervention, the aflatoxin levels in maize from farmers under farmer to farmer approach had higher contamination than that from farmers under participatory approach along the postharvest chain. Majority (82% to 91%) of the samples from farmers pre- and post-intervention were contaminated with aflatoxins at the point of harvesting. The mean aflatoxin level (0.58±0.77ppb) in maize from the participatory group was lower than that of the farmer to farmer group (1.41±0.8ppb) (Fig. 6). After drying, 92.7% and 91% of the samples from farmers under farmer to farmer and participatory groups, respectively, were contaminated with aflatoxins. However, none of the samples had aflatoxin levels above the permissible limit of 10ppb. The mean aflatoxin level of maize at drying was lower for the participatory group (1.16±0.88ppb) than the farmer to farmer (1.82±1.12ppb) group. Both groups registered lower aflatoxin levels than that recorded (1.94±0.93ppb) pre-intervention. Under all the drying technologies and practices, the maize from farmers under the farmer to farmer group had significantly higher aflatoxin contamination than maize from farmers under the participatory group. Highest aflatoxin contamination at drying was observed in maize dried on bare ground. Samples from farmers that used raised racks under the farmer to farmer group (1.68±1.14ppb) and the participatory group (0.89±0.71ppb) had the lowest aflatoxin levels at drying.

At the end of the sixth month of storage, the aflatoxin level of maize reduced significantly from 46.63±4.84ppb pre-intervention to 8.07±1.51ppb and 21.47±2.73ppb, respectively for farmers in the participatory and farmer to farmer groups. No significant difference was observed in the aflatoxin levels of maize stored in polypropylene bags in both groups (Fig. 7). However, the aflatoxin levels of maize stored in metallic silos and hermetic bags were significantly higher ($p \leq 0.05$) in the farmer to farmer group samples than the participatory group. None of the samples from farmers in both groups that used metallic silos had aflatoxin levels above 10ppb which asserts the effectiveness of this technology in enhancing quality and safety of grain at storage. Considering a combination of a drying and storage technology, the highest aflatoxin contamination by the end of the storage period (6 months) in both groups was observed where drying was done on bare ground and storage was in polypropylene bags (46±25.1ppb for the farmer to farmer group and 34±15.7ppb for the participatory group). Throughout the storage period, the maize grain stored in either of the storage technologies but dried on raised racks had lower aflatoxin levels than that dried on bare ground and tarpaulin. Maize grain stored in either of the storage technologies but dried on tarpaulins had lower aflatoxin levels than that dried on bare ground.

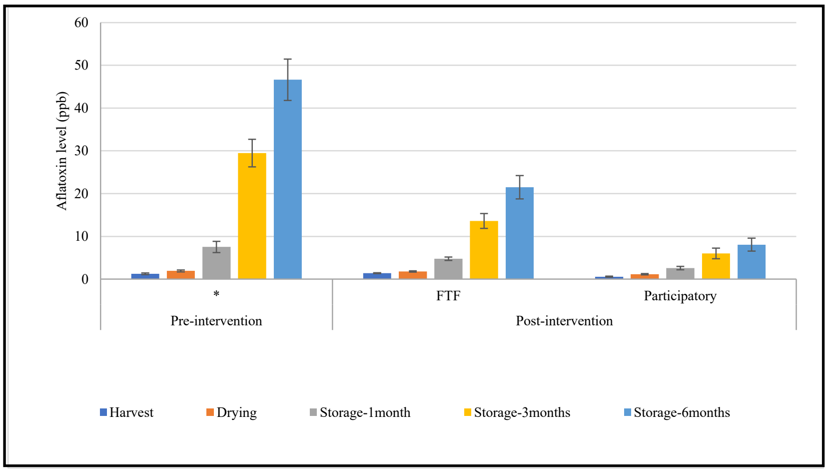

Figure 6. Aflatoxin level in maize from farmers pre- and post-intervention
FTF- Farmer to farmer

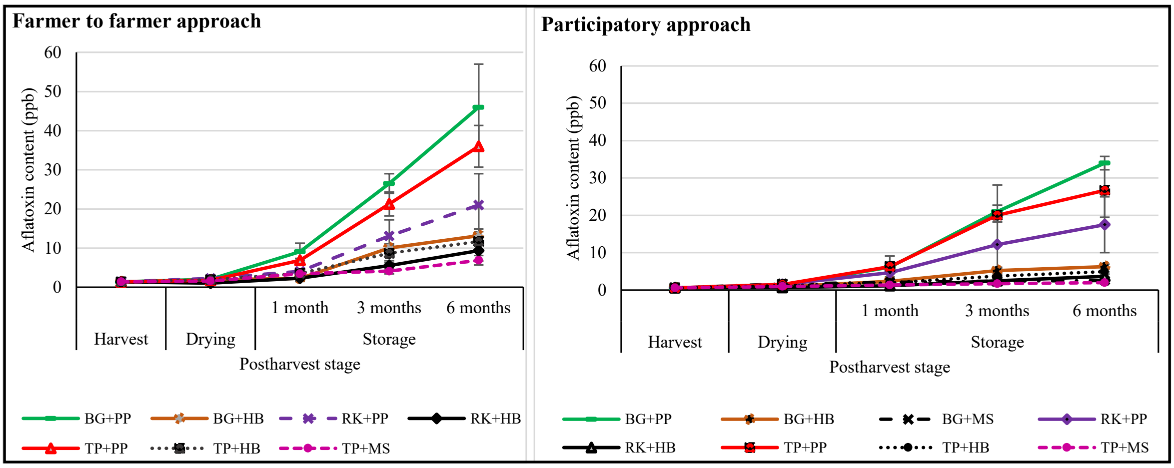

Figure 7. Aflatoxin levels in maize from farmers post-intervention
BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB- Hermetic bag, MS- Metallic silo

DISCUSSION

Maize post-harvest losses, mold infection and aflatoxin levels were found to reduce at post-intervention, the extent varying with extension method and technology applied by farmers. Technology uptake was higher among the farmers under the participatory approach than the farmer to farmer approach. This could be attributed to farmer exposure to the technologies and engagement in trials for the technologies in the participatory approach, factors associated with increased technology uptake (Matata *et al.,* 2010; Job *et al.,* 2015). Activities based on active farmer participation in research and extension have also showed potential for increasing adoption rates (Singh *et al.,* 2015). Some of the key drivers for uptake of the technologies as reported by farmers included the observed benefits accrued from using the improved technologies such as reduction in losses and improved quality of grain, the simplicity and ease of use, cost of the technology and the extensive training conducted. In agreement with these findings, Rogers (1995) identified six factors that influence the diffusion and adoption of research innovations. These include complexity of the innovation, perceived relative advantage of the innovation, compatibility of the innovation to existing values, experience and need, ease of operation, degree to which the results of using an innovation are visible, and degree to which the research is applicable to practice. Failure to uptake and use the improved technologies by some farmers was due to cost constraints since these technologies were more expensive than their current technologies. Oladele and Kareem (2003) reported that farmers are sometimes unable to adopt an innovation even though they have mentally accepted it because of economic and situational constraints such as uneven market price, inadequate finance and inadequate supply of innovation. Within the farmer to farmer extension approach group, more educated farmers were more likely to uptake the technologies promoted than the less educated farmers (Table 2), which could be attributed to their higher ability to appreciate the importance of technology in improving product quality and reducing postharvest losses.

Farmers pre-intervention and post-intervention under both extension approaches made losses at harvest due to leaving the crop in the field while harvesting, intentionally discarding diseased and infested grain or grain scattering. Losses due to grain or maize cobs left in the garden during harvesting were attributed to the laborious nature of harvesting since it is a manual and slow process. Maize harvesting was either done by hand or using hand tools such as knives and sticks. Kumar and Kalita (2017) attributed quantitative losses at harvest mainly to poor timing of harvest, crop maturity and moisture content. The recommended moisture content at which harvesting of maize should be done is 23-28% which is indicative of physiological maturity (Kumar and Kalita, 2017). Harvesting at lower moisture content than that of physiological maturity indicates an extended field drying which has been reported to increase quantitative and qualitative losses mainly due to pest attack, mold infection and aflatoxin contamination of the grain (Kaaya *et al.,* 2005; Wagacha and Muthomi, 2008; Kumar and Kalita, 2017). Extensive field drying was observed among the farmer to farmer group and farmers pre-intervention which could justify the differences in the losses, moisture content, mold infection and aflatoxin levels in comparison to the participatory approach.

The difference in the quantitative and qualitative postharvest losses among the participatory and farmer to farmer groups is attributed to the higher uptake of improved technologies at drying and storage by the former. At drying, tarpaulins and raised racks are associated with lower quantitative losses, mold infection and aflatoxin contamination than drying on bare ground (Filazi and Tansel, 2013; Kumar and Kalita, 2017). Hermetic storage (improved technology) is associated with lower losses (Ng'ang'a, 2016; Kumar and Kalita, 2017), lower mold infection and aflatoxin contamination (Baoua *et al.,* 2014; Williams *et al.,* 2014; Ng'ang'a, 2016).

The difference in losses, mold infection and aflatoxin level in maize from farmers who used similar technologies post-intervention under the farmer to farmer and participatory approach can be attributed to the effectiveness of use of the technologies and practices, for instance where farmers under both approaches stored their maize in polypropylene bags, rodent control was a key practice embraced more among the farmers under participatory approach than the farmer to farmer approach yet rodents were responsible for a proportion of quantitative and quality losses; thus the difference.

CONCLUSION

Postharvest technology uptake and use is influenced by the extension approach used in promotion. Extension, irrespective of the approach used, led to a reduction in postharvest loss and improvement of quality of maize. The participatory extension approach resulted into higher levels of technology uptake than the farmer to farmer approach. Consequently, farmers that received extension through the participatory approach had lower postharvest losses and better quality of maize than the farmers that received extension through the farmer to farmer approach. In as much as the improved postharvest technologies can reduce postharvest loss and improve quality of maize among smallholder farmers, their effectiveness is affected by the extension approach. Thus, the right technologies need to be paired with the most effective extension approach to optimize impact. Therefore, to reduce maize postharvest losses among small holder farmers, the right technologies such as tarpaulins, raised racks and hermetic storage systems should be promoted and disseminated through the participatory approach. Further research is needed to establish the long-term effects of the two extension approaches and the sustainability of these effects. In addition, given the wider reach by farmer to farmer approach, more research is needed to establish how this approach can be made more effective.

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STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper

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