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ON-FARM EVALUATION OF EFFECTIVENESS OF IMPROVED POSTHARVEST HANDLING OF MAIZE IN REDUCING GRAIN LOSSES, MOLD INFECTION AND AFLATOXIN CONTAMINATION IN RURAL UGANDA

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ABSTRACT

Postharvest losses remain a challenge among smallholder farmers in sub-Saharan Africa. The uses of hermetic storage containers (hermetic bags and metallic silos), tarpaulin sheet (plastic sheet) and raised racks reduce postharvest deterioration of grain. This study evaluated the effectiveness of selected improved drying and storage postharvest technologies and practices in reducing maize grain postharvest losses among smallholder farmers in Kamuli and Apac districts, Uganda. The assessed improved storage technologies were hermetic bags and metallic silos against woven polypropylene bags (common farmer practice). For drying, use of tarpaulins and raised racks were assessed against drying on bare ground (common farmer practice). Grain quality and quantity were determined at harvest as well as during drying and six months of storage using Longe 10H variety. Mean quantitative losses, mold infection and aflatoxin level of maize at harvest were 13.72 ± 5.44%, 59.01 ± 17.97% and 1.21 ± 0.7 ppb, respectively for traditional practice. Improved drying and storage technologies resulted in significantly lower ($p \leq 0.05$) losses, mold infection and aflatoxin level than the common farmer practices. Drying on bare ground (3.04 ± 1.50%) resulted in 1.94 times and 7.07 times higher quantitative losses than drying on tarpaulins (1.56 ± 1.09%) and raised racks (0.43 ± 0.58%). By the sixth month of storage, polypropylene bag storage resulted in 3.7 times and 84 times higher quantitative losses (23.7 ± 5.11%) than hermetic bags (6.33 ± 5.41%) and metallic silos (0.28 ± 0.22%), respectively. Polypropylene bag storage also resulted in 4.4 times and 6 times higher aflatoxin levels (45.82 ± 20.88 ppb) than hermetic bags and metallic silos, respectively. The interaction effects of type of drying technology and storage technology used on aflatoxin levels at the end of the storage period was significant. The highest mold infection and aflatoxin levels were observed when drying was done on bare ground and storage was in polypropylene bags and by the sixth month of storage, mold infection was 90.54 ± 5.48% and average aflatoxin content was 53.47 ± 22.79 ppb. Storage in metallic silos was the most effective in controlling mold infection and aflatoxin contamination, regardless of drying practice, while storage in polypropylene bags was the least effective. From the results, improved drying and storage technologies and practices were found to reduce postharvest maize losses, mold infection and aflatoxin level by over 50%. Use of raised drying racks and storage in metallic silos was found to be the most effective combination in maintaining maize quality and reducing postharvest losses.

Key words: Aflatoxins, maize quality, mold infection, grain storage, postharvest losses

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INTRODUCTION

Maize (*Zea mays L.*) is one of the most important agricultural commodities worldwide in terms of amounts produced, consumed, and traded [1], contributing 161 kcal and 408 kcal per capita daily globally and in Africa, respectively [2]. Despite its relative importance, high postharvest losses in maize are experienced especially in developing countries [2, 3]. Postharvest losses include quantitative and qualitative losses, and are largely attributed to inappropriateness of postharvest handling, biodegradation due to microorganisms and insects, among others [4]. Quantitative maize postharvest losses are estimated to be highest during drying and storage [3, 5]. Insects and pests are reported to cause the highest losses in maize during storage [6]. One of the most important global concerns in terms of grain quality losses is aflatoxins, which are toxic secondary metabolites, naturally occurring hepatocarcinogens produced by aflatoxigenic molds of the genus *Aspergillus* [7]. Aflatoxins are most prevalent in crops in tropical and subtropical regions of the world and may occur in the field and in the postharvest phase [1, 8, 9, 10]. About 25% of the world's agricultural commodities are contaminated with mycotoxins above the lower CODEX limits, leading to significant economic losses [11]. The International Agency for Research on Cancer categorizes aflatoxins as confirmed carcinogens especially aflatoxin B1 [12]. Uganda loses US$ 577 million dollars annually as a result of 3,700 aflatoxin-induced liver cancer cases [13]. In order to enhance trade and consumer protection, over 100 nations have established maximum tolerable levels for aflatoxin in food, especially for the most toxic and carcinogenic type, aflatoxin B1 [14]. Due to this, aflatoxins in food in both the local and global market impose large burdens on trade due to rejection and failure to penetrate lucrative markets. Production of aflatoxins in food is influenced by crop (genotype, nutrients), physical (temperature, soil type, water stress, 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 [15, 16].

Improved postharvest technologies such as hermetic storage, raised drying platforms, and tarpaulins have been introduced to farming communities to contribute to reduction in postharvest losses [5]. Raised drying platforms and tarpaulins utilize open sun drying, while preventing direct contact of produce with dirt. Avoidance of direct contact between grain and soil reduces contamination by toxigenic fungi [17] and accelerates the drying process [8]. About 50 to 60% of grains can be lost during the storage stage. However, the use of improved storage technologies such as hermetic storage can reduce these losses to as low as 1 to 2% [4]. Hermetic storage is reported to reduce insect infestation and damage in maize, during storage, to below 1% [6]. Metallic silos are a hermetic technology, which has been introduced to the farmers in Africa since 2008 and have been associated with reduced grain damage and losses from insects [18]. Household metallic silos are made out of galvanized sheeting of 100x200 cm and 0.5 mm thick (No. 26) with a capacity of 0.1-3 metric tons (MT). Hermetic bags, on the Ugandan market exist in two major brands that include Purdue Improved Crop Storage (PICS bags^{TM}) and SuperGrainBag^{TM}. These bags consist of an outer polypropylene bag and inner linings of high-density polyethylene. Hermetic bags are associated with reduced insect infestation, damage and mold infection [6]. While several studies have evaluated the effectiveness of hermetic storage and improved drying technologies on reducing mold infection and aflatoxin contamination [4, 6, 8, 17], these previous works have assessed the stages of the postharvest chain in isolation yet maize goes through the entire postharvest chain. This study sought to assess the effectiveness of selected improved drying and storage technologies to reduce quantitative losses, aflatoxin contamination and mold infection in combination, along the entire postharvest chain, under farm conditions among smallholder farmers in rural Uganda.

MATERIALS AND METHODS

The study was conducted in four maize producing sub counties in Kamuli (Butansi and Bugulumbya) and Apac (Chegeere and Apac) districts in Uganda. These have high maize production [19] and high occurrence of postharvest losses [5]. The study areas have an annual average rainfall of 1,330-1,350 mm and temperature range of 17-29°C [20]. From each of the sub counties, three farmer groups were selected and randomly assigned to treatment (hermetic storage technologies and tarpaulins or racks) and control arms (used common farmer practices – drying on bare ground and storage in polypropylene bags) with each assigned one drying and storage technology or practice. Hermetic storage technologies included hermetic bags (SuperGrainbag^{TM} – consisting of an outer polypropylene bag and inner linings of high-density polyethylene) and metallic silos (1 MT hermetic storage made of galvanized sheeting). Participatory on-farm trials were conducted with a total of 108 farmers randomly selected (9 farmers per group). The farmers had at least 10 m by 10 m of ready to harvest maize and were willing to store at least 25 kg over a six-month period. The sample size was calculated at 95% confidence level, 10% precision level and the maize producing households as the population [21, 22].

$$n = N/1 + N(e)^2 \tag{1}$$

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

n = 99.4 ~ 100 farmers; for evenness in the allocation of technology combinations, the used sample size was 108 farmers.

At least 25 kg of harvested untreated shelled maize grain 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 airtight sample bags and labelled. 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 AOAC method 7.045 standard oven drying method [23].

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Quantitative loss determination

The percentage weight loss at each postharvest stage was determined using the weigh-in and weigh-out method. This method was used to determine the weight of the produce before a stage, W_b and the weight of the produce after the stage, W_a and corrected for differences in moisture content, D_m. Percentage weight loss was calculated using formula (2).

$$\%Weight\ loss = \frac{(Wb-Wa-Dm)}{Wb} * 100 \qquad (2)$$

Enumeration and identification of internal molds

Mold infection was determined by direct plating technique for internal mold infection [24]. About thirty (30) kernels 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. Ten kernels were placed directly on each agar plate [10]. The plates were incubated upright at 25°C for 5 days and then emerging mold colonies were enumerated and identified using microscopic observation and colonial morphological characteristics such as color and arrangement of spores [25].

Aflatoxin analysis

The Vicam fluorometer procedure for corn 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, 50 g of the flour were weighed, mixed with 5 g 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.

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RESULTS AND DISCUSSION

Moisture content of maize handled using different postharvest technologies and practices

The mean moisture content of the harvested maize was 21.92 ± 3.74%. After drying for three days, the mean moisture content was 13.78 ± 0.47%, 14.09 ± 0.70% and 14.16 ± 0.57%, respectively for maize dried on raised racks, bare ground and tarpaulins (Figure 1). Moisture content of maize dried on different drying surfaces was not significantly different ($p>0.05$). The mean moisture content of maize at first day of storage (just at the start of storage) was above 13%, the recommended level for safe storage [26]. The moisture content of maize stored in hermetic bags and metallic silos did not significantly change ($p>0.05$) over the storage period. However, the mean moisture content of maize stored in polypropylene bags significantly reduced over the storage period, from a mean moisture content of 14 ± 0.54% at the start of storage to 13.37 ± 0.51% after six months. By the end of the sixth month of storage, maize in polypropylene bags had the lowest moisture content (13.37 ± 0.51%) in comparison to those in hermetic bags (13.87 ± 0.68%) and metallic silos (13.77 ± 0.49%). Polypropylene bags, contrary to hermetic technologies have low barrier properties against moisture exchange, which allows equilibration with the surrounding ambient conditions resulting into moisture content fluctuation over the storage period [6, 27].

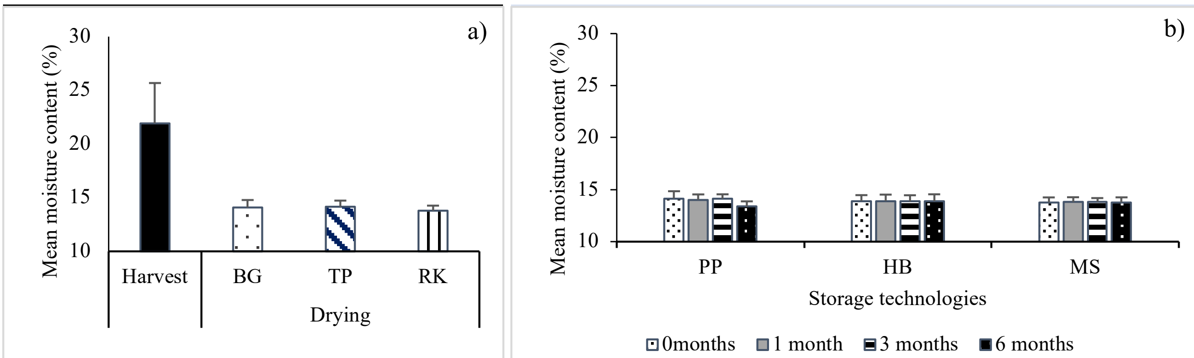

Figure 1: Mean moisture content of maize grain along the postharvest chain a) drying and harvesting; b) storage

BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB- Hermetic bag, MS- Metallic silo

Quantitative postharvest losses for maize handled using different postharvest technologies and practices

Generally, quantitative losses increased along the postharvest chain, irrespective of the technologies and practices used (Figure 2). The losses at harvest were 13.72 ± 5.44%, of which 9.80 ± 1.52% were due to leaving the crop in the field while 3.92 ± 2.34% were due to diseased, discarded and scattered grains. Losses at harvest are influenced mainly by timing of harvest, harvesting method, crop maturity and moisture content [4]. Delayed harvesting or extensive field drying lead to higher losses due to birds, rodent attacks and shattering.

The losses continued at drying and the extent significantly differed ($p<0.05$) with the practices used in drying. The highest losses were observed when drying was done on bare ground (3.04 ± 1.50%) and this was significantly higher ($p<0.05$) than the mean loss obtained when grain was dried on tarpaulins (1.56 ± 1.09%) and raised racks (0.43 ± 0.58%). Losses at drying could be attributed to shattering, and birds and animals that fed on the grain, a common problem with open sun drying [4]. The most common practice while using tarpaulins is having the tarpaulin on the ground, which makes the grain liable to losses due to animals, including domestic fowls and other livestock. Raised rack, on the other hand, are normally about 1 meter above the ground, which keeps the grain less exposed to losses due to animals.

At storage, losses were generally higher for grain stored in polypropylene bags than in metallic silos and hermetic bags. By the sixth month of storage, significantly higher losses ($p<0.05$) were realized in polypropylene bags (23.7 ± 5.11%) than in hermetic bags (6.33 ± 5.41%) and metallic silos (0.28 ± 0.22%). With hermetic bags being susceptible to rodent damage, higher losses (16.10 ± 7.86%) over the storage period were observed in cases where rodents damaged them. The mean losses of maize stored in hermetic bags and metallic silos did not significantly increase ($p>0.05$) over the storage period. The highest cumulative losses from harvest to storage were incurred by farmers who used a combination of drying on bare ground and storage in polypropylene bags (40.46 ± 2.75%), drying on racks and storage in polypropylene bags (37.85 ± 2.79%) and drying on tarpaulin and storage in polypropylene bags (38.98 ± 3.21%). The lowest cumulative losses from harvest to storage were incurred by farmers who used a combination of drying on racks and storage in metallic silo (14.43 ± 0.01%), drying on tarpaulins and storage in metallic silo (15.56 ± 0.01%) and drying on bare ground and storage in a metallic silo (17.04 ± 0.01%). Generally, higher losses were obtained at storage than drying when inappropriate technologies were used in both scenarios. Losses were almost restricted to the harvest stage where improved drying and storage technologies were used. In comparison to the common farmer practices, use of improved drying practices reduced losses by 8.8%-15% while use of the hermetic bags and metallic silos reduced losses by 79% and 98.8%, respectively. Losses under polypropylene bag storage were largely attributed to rodent and insect damage since these storage containers offer less resistance to rodent attack and have low barrier properties to gaseous exchange that permit profuse build-up of insect populations and damage [6]. Hermetic storage (metallic silo and hermetic bag) limits gaseous exchange and subsequently, reduces insect infestation, seed damage and ultimately storage losses [4].

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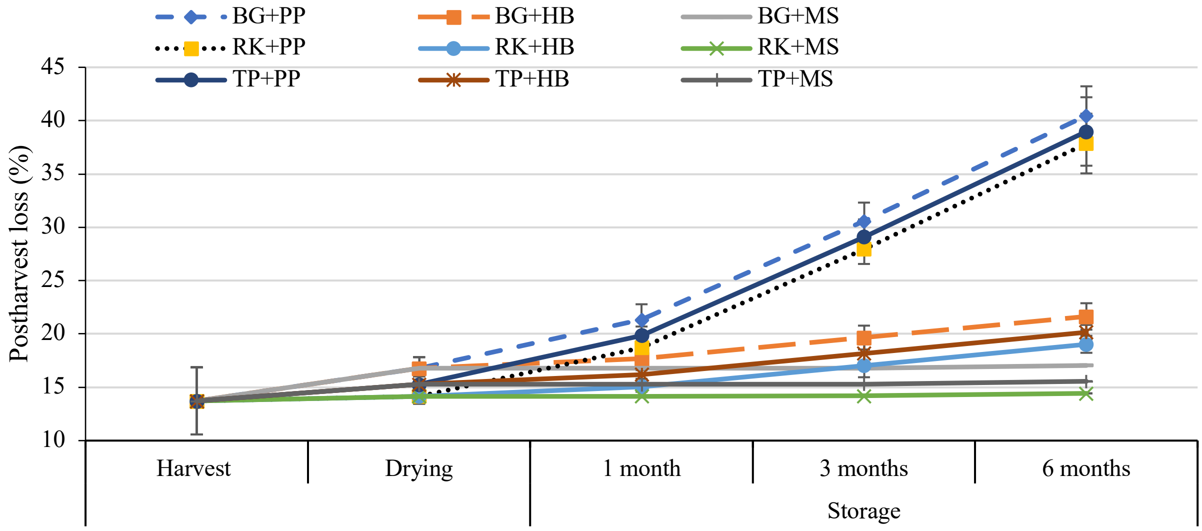

Figure 2: Cumulative quantitative postharvest losses of maize along the postharvest chain

BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB- Hermetic bag, MS- Metallic silo

Mold infection for maize handled using different postharvest technologies and practices

Mold infection of maize grain generally increased along the postharvest chain and varied at different stages, technologies and practices (Figure 3). Mold infection at harvest was 59.01 ± 17.97%, indicative of high prevalence of pre-harvest infection. Several studies indicate that mold growth can take place in the field under appropriate conditions of temperature and relative humidity [9, 10, 28]. The recommended moisture content of maize at harvest, indicative of physiological maturity, is 23%-28% [4]. Lower harvest moisture content as observed in this study is an indication of delayed harvesting and field drying, associated with higher mold infection due to exposure to fluctuations in temperature and humidity, bird and insect damage [4, 29, 30].

Maize kernels dried on bare ground had significantly higher mold infection (80.89 ± 5.76%) ($p<0.05$) than those dried on tarpaulins (68.79±5.80%) and raised racks (64.19±5.33%). Sun drying on bare ground allows direct contact of the grain with soil which is a host for aflatoxigenic molds and other molds and thus facilitates mold infection [29, 31], unlike the use of raised racks and tarpaulins [8, 17]. In addition to restricting direct contact with soil, drying on a tarpaulin and raised rack results in faster drying, which limits growth of toxigenic fungi [8, 17]. Since it is a common practice to position the tarpaulin on the ground and drying is open, the likelihood of deposition of dirt particles from the ground onto the grains by the moving drying air increases, which could explain the difference in mold infection between drying on tarpaulins and raised racks.

At the end of the storage period, the mean mold infection of maize stored in polypropylene bags (89.00 ± 2.54%) was significantly higher ($p<0.05$) than that in the hermetic bag (70.49 ± 9.69%) and metallic silo (61.48 ± 1.84%) storage. Mold infection of maize grain stored in polypropylene bags generally increased over the storage period. The mold infection of maize stored in metallic silos peaked in the first month (72.00 ±

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6.56%) and decreased thereafter. In hermetic bag storage, the peak mold infection of maize was observed in the first month (76.00 ± 8.60%), which was followed by a decrease in the third month and a slight increase in sixth month. While interaction effects of drying and storage technologies and practices on mold infection at the sixth month of storage was not significant ($p>0.05$), regardless of the storage containers used, maize grain earlier dried on raised racks had the lowest mold infection. Irrespective of the drying practice used, the highest mold infection of maize over the sixth month storage period was observed in polypropylene bags and the lowest in metallic silos. The low barrier properties of polypropylene bags facilitated aerobic conditions and moisture pick up (under high relative humidity conditions in the third month), which are conducive conditions for mold proliferation. In this study, the experiments were set up two months prior to start of the main rains, a period associated with low relative humidity and by the third month, the onset of rains increased the relative humidity to 94% [20]. Hermetic storage such as hermetic bags and metallic silos operate on the principle of modified environments with high barrier properties against gaseous and moisture exchange [32], limiting mold growth [33, 34]. Hermetic storage systems have been reported to increase carbon dioxide and reduce oxygen levels in storage to levels inhibitory to mold growth and aflatoxin contamination [6, 35, 36]. The increases in mold infection observed in hermetic bag storage in the sixth month could be attributed to the fact that the modified gas conditions (increased carbon dioxide and lowered oxygen levels) are not maintained over time [6]. This case has been reported by Baoua *et al.* [37] where oxygen levels dropped to a range 2 – 3% within 12 days of storage before gradually rising to 12 – 15%, while carbon dioxide levels rose to 5% before gradually decreasing. This is because during prolonged storage, oxidative metabolism is severely attenuated, and as oxygen consumption drops, the concentration of oxygen around individual grains tends to increase as air proceeds to leak slowly through the partially impermeable HDPE liners following concentration gradient [38]. Some mold species such as *A. chevalieli* have also been reported to invade maize stored in hermetic systems although to a limited extent [32], which can contribute to the overall mold infection.

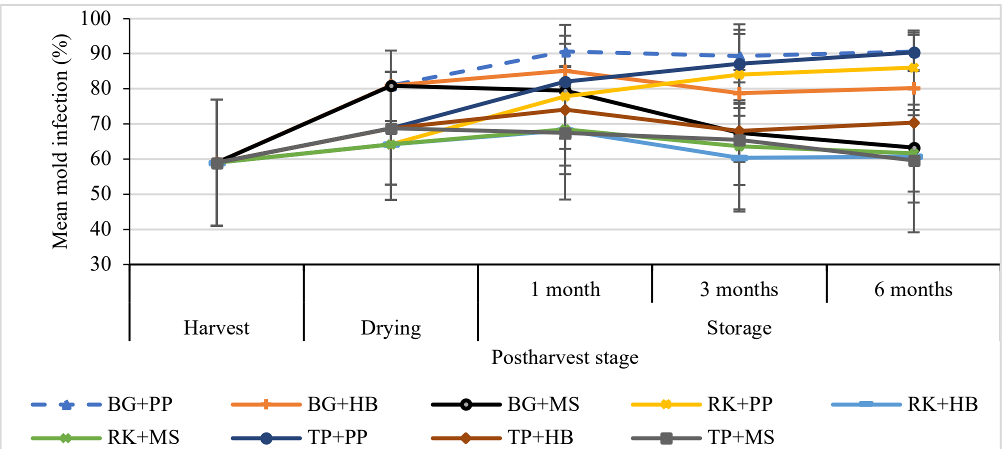

Figure 3: Incidence of molds on maize grain along the postharvest chain
BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB- Hermetic bag, MS- Metallic silo

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Across the postharvest chain, *Fusarium spp, Aspergillus spp, Rhizopus spp* and *Penicillium* spp were the predominant mold species (Table 1). Most of the grains were infected by more than one genus with incidence of the different genera on the grain varying at different stages and technologies. At harvest, the predominant genera were *Rhizopus spp* (15.19 ± 4.18%) and *Fusarium spp (*10.06 ± 1.81%). These two genera were also predominant at drying irrespective of the practice used. Maize dried on bare ground had significantly higher *Fusarium spp*, *Penicillium spp*, *Aspergillus spp* and *Rhizopus spp* incidence than that dried on tarpaulins and raised racks. The incidence of *Aspergillus spp* increased along the postharvest chain. The increase was higher in the polypropylene bag storage as opposed to hermetic bag and metallic silo storage. The highest incidence of *Aspergillus spp* was observed at the sixth month of storage and this was significantly higher in maize stored in polypropylene bags (36.23 ± 7.34%) than in hermetic bags (22.23 ± 5.51%) and metallic silos (18.73 ± 5.02%). The incidence of *Fusarium spp* increased from harvest to drying irrespective of the drying practice used. In polypropylene bag storage, the incidence of *Fusarium spp* increased till the third month, after which a decrease was observed. In cases where maize was stored in hermetic bags and metallic silos, *Fusarium spp* incidence was highest in the first month of storage after which the incidence reduced. The study findings agree with results from several studies that identified the genera in maize in the subtropics [5, 6, 10]. Co-existence of several genera was reported to be common among the toxigenic fungi on commodities during storage [16].

Effect of improved postharvest technologies and practices on aflatoxin contamination of maize grains

Aflatoxin levels in maize grain generally increased along the postharvest chain but varied with the stage, postharvest handling technologies and practices (Figure 4). Aflatoxin level in maize at harvest was 1.21 ± 0.70 ppb (range: 0-3.33 ppb). Aflatoxin accumulation has been reported to take place in the field [10, 28]. Delayed harvesting and extensive field drying, a practice by majority of the farmers in the study area have been reported to increase the risk of field contamination with aflatoxins [10, 29].

The aflatoxin contamination (2.30 ± 1.35 ppb, 0.53-4.92 ppb) of maize grains dried on bare ground was significantly higher ($p < 0.05$) than those dried on tarpaulins (1.48 ± 0.89 ppb, 0-3.20 ppb) and raised racks (1.15 ± 1.13 ppb, 0-3.16 ppb). Percentage incidence of aflatoxins varied with drying practice; the highest level being recorded in drying on bare ground (Table 2). Incidence of aflatoxins was 100%, 93.5% and 72.7%, respectively for samples dried on bare ground, tarpaulins and raised racks. Although the aflatoxin incidence in maize grains was high, none of the samples had contamination above 10 ppb. During drying on bare ground, there is direct contact of the grain with soil, which is a host for aflatoxigenic molds and other molds but is also a slow and inefficient drying method that leads to delays in reduction in moisture content, facilitating infection and proliferation of molds [31] as well as subsequent aflatoxin production. Drying grain on tarpaulins or raised racks prevents direct contact with soil and accelerates the drying process [8], factors that result in lower aflatoxin contamination.

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The aflatoxin levels in maize grain further increased during storage. There was significant interaction between the effects of drying and storage technologies and practices on aflatoxin contamination ($p<0.05$). The highest aflatoxin contamination was observed in grain that was dried on bare ground and stored in polypropylene bags and by the sixth month of storage, grains following this treatment had average aflatoxin concentration of 53.47 ± 22.79 ppb. Throughout the storage period, the grains dried on raised racks had lower aflatoxin contamination than those dried on bare ground and tarpaulins, regardless of the storage container used. Irrespective of the drying practice used, the highest aflatoxin level in maize grains over the storage period of six months was observed in those stored in polypropylene bags and the lowest in metallic silo storage. All the maize samples at storage were positive for aflatoxins irrespective of the technologies used. However, the aflatoxin levels varied. In the first month of storage, 16.12% and 1.67% of the samples of grain stored in polypropylene bags and hermetic bags, respectively had aflatoxin levels above 10 ppb. At three months of storage, 74.19% and 5% of the samples of grain stored in polypropylene and hermetic bags, respectively had above 10 ppb aflatoxin content (East African Community Standard). None of the samples of grain stored in metallic silos had aflatoxin content above 10 ppb in the first and third month of storage. At six months of storage, 93.54%, 21.67% and 16.12% of the samples of grain stored in the polypropylene bags, hermetic bags and metallic silos, respectively had above 10 ppb aflatoxin contamination. These findings concur with data from studies conducted in Kenya [6] and West Africa [35] that reported significant increase in mold infection and aflatoxin levels in produce stored in woven polypropylene bags. Lower aflatoxin levels in hermetic storage can be attributed to the high barrier properties, gaseous composition and modification that is considered in their development and use [6]. Polypropylene bags have low barrier properties, which support proliferation of aerobic molds and permit moisture pick up when the humidity of the surrounding air is high, creating conditions conducive for aflatoxin contamination. Given that the average moisture content attained across the different drying technologies was above 13%, the recommended safe storage moisture content [26, 39] implies that maize was not adequately dried for safe storage and was quite susceptible to aflatoxin contamination. This may explain the substantial proportion of grains with unacceptably high levels of aflatoxin contamination, even under hermetic storage. Gaseous composition influences mold growth and with low oxygen concentrations (51%) and augmentation of carbon dioxide concentration reported to be efficient in preventing mold development [34, 36] while at least 25% carbon dioxide concentration reduced aflatoxin synthesis [33, 40]. Modification of the environment during hermetic storage is attributed to aerobic metabolism that is influenced by elements such as grain moisture content, insect population, fungal inocula, quality of the grain and gas-tightness [32]. Hermetic storage systems have been reported to increase carbon dioxide and reduce oxygen levels in storage to levels inhibitory to mold growth and aflatoxin contamination [6, 35].

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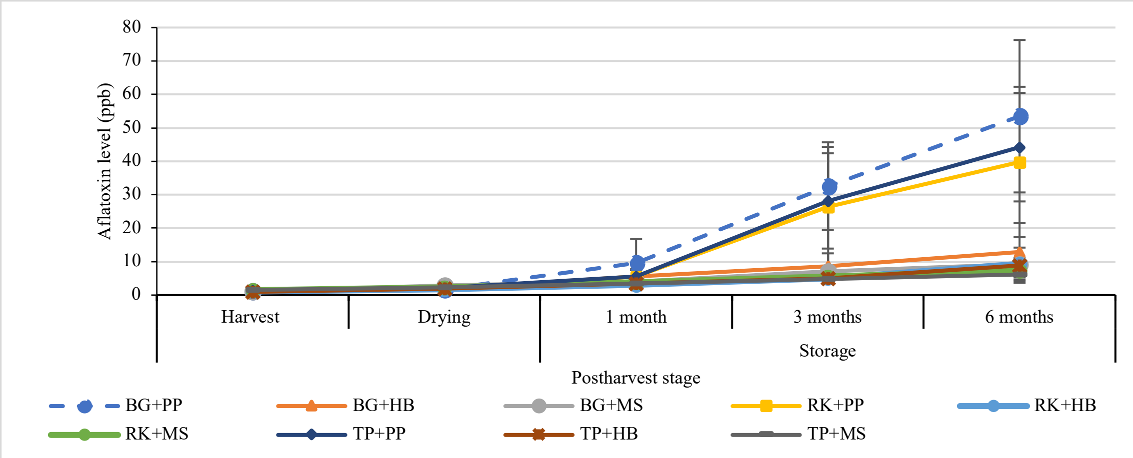

Figure 4: Aflatoxin levels of maize grain along the postharvest chain
BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB-Hermetic bag, MS- Metallic silo

CONCLUSION

Grain losses and safety along the postharvest chain remain a serious problem, especially among rural farmers that depend on agriculture for food and income security, with limited resources and knowledge to access and properly use chemical pest control options like contact pesticides and fumigants. Findings of this study established that a combination of hermetic storage and raised racks (non-chemical pest control options) at drying and storage leads to reduction in quantitative postharvest losses by over 50% and 85% reduction in aflatoxin levels in grain over a six months storage period. Use of inappropriate drying technologies such as drying of grain on bare ground exacerbated the aflatoxin and mold infection levels at storage. There is, therefore, need to promote the right combination of drying and storage technologies. Use of raised racks and storage in hermetic metallic silos were found to be the most effective in maintaining quality and reducing maize postharvest losses and can be recommended for promotion among smallholder farmers. Future research is needed to establish mechanisms that would enhance adoption of these improved technologies.

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Table 1: Incidence of mold genera in maize along the postharvest chain (%Mean ± SD)

Postharvest stage	Technology	*Aspergillus spp*	*Fusarium spp*	*Penicillium spp*	*Rhizopus spp*
Harvest		3.08±2.9	10.06±1.81	2.34±3.67	15.19±4.18
Drying	BG	9.77^{a}±2.58	23.37^{a}±6.12	8.53^{a}±5.8	22.97^{a}±8.76
	TP	8.70^{a}±0.53	11.50^{b}±0.98	5.60^{b}±0.72	19.27^{a}±1.89
	RK	3.97^{b}±1.25	10.43^{b}±0.42	2.83^{ab}±2.57	19.53^{a}±4.86
Storage (1month)	PP	13.37^{a}±2.22	25.73^{a}±12.6	16.43^{a}±5	42.17^{a}±6.43
	HB	8.67^{b}±3.33	23.53^{a}±12.3	8.00^{b}±2.78	32.60^{b}±2.25
	MS	8.37^{b}±1.82	17.90^{b}±7.1	5.90^{b}±1.56	19.83^{ab}±1.6
Storage (3 months)	PP	24.70^{c}±4.2	35.93^{c}±8.49	12.83^{c}±6.09	46.37^{c}±7.46
	HB	15.03^{d}±1.95	16.03^{d}±9.92	8.07^{d}±1.99	20.67^{d}±1.42
	MS	13.03^{d}±2.68	16.10^{d}±1.9	8.90^{d}±2.04	13.03^{e}±5.53
Storage (6 months)	PP	36.23^{e}±7.34	22.47^{e}±4.83	16.47^{e}±6.5	30.23^{f}±0.25
	HB	22.23^{f}±5.51	10.23^{f}±1.8	12.60^{f}±2.62	23.67^{g}±2.31
	MS	18.73^{f}±5.02	15.63^{g}±3.59	11.40^{f}±2.49	14.00^{h}±3.61

Means with different superscripts within the stage are significantly different at $p \leq 0.05$ level

BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB- Hermetic bag, MS- Metallic silo

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Table 2: Aflatoxin incidence in maize grain along the postharvest chain

Postharvest stage	Technology	Percentage aflatoxin positive samples	
		Total positive	Aflatoxin level >10 ppb
Harvest		84	0
Drying	BG	100	0
	TP	93.5	0
	RK	72.7	0
Storage (1 month)	PP*	100	16.12
	HB*	100	1.67
	MS*	100	0
Storage (3 months)	PP*	100	74.19
	HB*	100	5
	MS*	100	0
Storage (6 months)	PP*	100	93.54
	HB*	100	21.67
	MS*	100	16.12

**- An average for each of the technologies considered irrespective of drying technology*

BG- Bare ground, RK- Raised drying rack, TP- Tarpaulin, PP- Polypropylene bag, HB-Hermetic bag, MS- Metallic silo

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