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Drying Maize Using Biomass-Heated Natural Convection Dryer Improves Grain Quality During Storage

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Abstract: The objective of this study was establish the effect of the biomass-heated natural convection dryer on insect damage, mould infection, aflatoxin contamination and the germination potential of maize grain during storage. Maize grains were dried using two methods; on bare ground simulating farmer practices and using the biomass dryer. The maize dried on bare ground took five days to dry to safe storage moisture content of 14% while that of the biomass dryer took only 6 h. Drying maize grain using the biomass dryer delayed insect infestation by three months and significantly ($p \leq 0.05$) reduced mould and aflatoxin contamination during storage for 6 months. Maize dried using the biomass dryer was only infested with *Angoumois* grain moth (*Sitotroga cerealella*) while that dried on bare ground was infested by both the moth and the maize weevil (*Sitophilus zeamais*) implying that the biomass dryer controlled the most important storage insect pest of maize in Uganda. Drying maize using the biomass dryer had no effect on the germination potential of the grain. Thus, drying maize grain with the biomass dryer reduces drying time and greatly improves the quality of the grain during storage. However, the subsequent storage quality of the grain highly depends on the storage form (shelled or unshelled), time and environment.

Key words: Drying method, quality, storage form, time

INTRODUCTION

Maize (*Zea mays* L.) is the most important cereal crop grown in Uganda. In the year 2007, Uganda produced over 1,262,000 Metric Tonnes of maize (FAO, 2009). However, one of the major constraints facing maize producers in the country is drying the crop. Maize cobs are normally dried dehusked or in sheaths and a common traditional method involves spreading the crop on bare ground taking up to a week to dry late harvested cobs, but over two weeks to dry timely harvested crop under the open sun method (Odogola and Henriksson, 1991). Under these conditions, mould and mycotoxin contamination of maize is inevitable.

In Uganda, maize has been reported to be heavily contaminated with moulds and mycotoxins during storage. The most commonly reported moulds have been species of *Aspergillus*, *Fusarium*, *Penicillium* and *Rhizopus* (Kaaya *et al.*, 2005, 2006) while aflatoxins and fumonisins have been the mycotoxins reported by Sebunya and Yourtee (1990), Kaaya *et al.* (2005) and Atukwase *et al.* (2009). The most important factors positively associated with mould and aflatoxin contamination of maize have been reported to be delayed harvest, drying on bare ground, storage period as well as

agroecological zone effects (Kaaya *et al.*, 2005; Kaaya and Kyamuhangire, 2006; Atukwase *et al.*, 2009).

Various techniques have been recommended to control and prevent mould and aflatoxin contamination of maize. Although preharvest prevention techniques should be considered as strategies to control moulds and mycotoxins (Bhat, 1991; Munkvold and Desjardins, 1997; FAO, 1999), postharvest techniques involving drying, storage, processing, post-processing, transportation and marketing are also recommended (Vincelli *et al.*, 1995; Richard, 2000; Bankole and Adebajo, 2003).

As one of the solutions to the drying problems faced by farmers in the country, the National Agricultural Research Laboratories (NARL)-Kawanda, Uganda, designed the biomass-heated natural convection dryer. This dryer is simple and easy to construct (Mutya, 2000) using bricks, sand, earth and cement. The drying platform is built of wire mesh tray while the firing unit is composed of a radiator made of cut tin drums. A roof is built over to prevent rains from wetting the drying produce. It is a natural convection dryer i.e., biomass keeps on burning by natural free flow of air. It uses charcoal or wood shaving as source of heat energy and can dry cereals, legumes and root and tuber crops. It is effective for drying crops like maize, coffee, beans,

cassava and potato chips and sorghum among others (Mutuyaba, 2000). The drying is done cheaply in terms of time and labour and without having to worry about the weather. The dryer ensures crop safety and quality during drying by preventing contamination of produce by soil, dust and domestic animals. However, this method of drying has not been investigated in terms of management of insect pests, moulds and aflatoxins as well as its effect on seed viability, in the dried produce. These are important considerations as far as quality of dried maize grain is concerned for both consumption and home-saved seed. Currently, apart from synthetic fungicides, there are no technologies in Uganda that have been tested and approved for use in controlling moulds in produce.

The objective of this study was to establish the effect of the biomass-heated natural convection dryer on insect damage, mould infection, aflatoxin contamination and the germination potential of maize grain so that this method can be recommended to farmers as a postharvest management option in the control of grain loss agents.

MATERIALS AND METHODS

Preparation of maize samples for drying: Maize ears (variety Longe 5) partially dried in the field for three weeks after physiological maturity, were hand harvested during July 2004 from the National Crops Resources Research Institute (NaCRRI) Namulonge, Uganda. Majority of farmers leave maize to dry in the field for up to three weeks after physiological maturity (Kaaya *et al.*, 2005). The maize was divided into two lots. One lot was dried using the biomass dryer located at the National Agricultural Research Laboratories (NARL)-Kawanda, Uganda, while the other lot was open sun-dried on bare ground, at Makerere University Agricultural Research Institute Kabanyolo (MUARIK), simulating farmers' traditional drying method (Odogola and Henriksson, 1991). Prior to drying using both methods, maize ears were dehusked and their middle diameter measured using a Vanier caliper (P59618, Soviet Union) to obtain ears of almost same size in order to cater for the effects of crop size on the drying efficiency. In addition, five ears were randomly selected from the lot and were used to determine the initial moisture content of the kernels.

Maize drying using a biomass dryer: The ears (4.5-5.0 cm diameter) were distributed evenly in one layer on the dryer wire mesh (single layer drying) recommended by Mutuyaba (2000) to dryer capacity. The average initial temperature of the dryer (28°C) was determined using five thermometers (TEL-TRU Thermometer, Rochester, NY, USA, Temperature range 0-240°C) placed in the four corners and

centre of the dryer. These thermometers were also used to record average temperature changes during the biomass drying period. A charcoal stove (locally known as sigiri) was lit following the methods recommended by Mutuyaba (2000) and placed in the middle of the firing radiator made of a scrap metal drum, to start the drying process. The drying process started at 12.15 pm and ended at 6.15 pm, a period of six hours. Temperatures were recorded every hour and samples were taken off at this interval to determine changes in moisture content during drying. The ambient temperatures were also recorded during drying.

Bare ground drying of maize ears: The maize ears (also 4.5-5.0 cm diameter) were spread evenly on bare ground and open sun-dried till moisture content of the grain was about 14%, almost similar to the final moisture content of the biomass dried maize. The moisture content of the kernels was determined each day to establish the drying rate. In addition, the ambient temperatures were also recorded during drying. This experiment was regarded as the control since drying maize on bare ground is the most common practice used by farmers all over Uganda (Kaaya *et al.*, 2006; Atukwase *et al.*, 2009).

Storage of dried samples: The biomass and bare ground dried maize samples were stored in two forms; the shelled and unshelled, for a period of six months. This is the maximum period maize is usually stored by farmers in Uganda (Kaaya and Kyamuhangire, 2006). Shelling of maize samples was by hand. Each of the shelled and unshelled samples was divided into three sub-sample lots and each lot was properly sealed in a new interlaced polypropylene bag commonly used by farmers to store maize in Uganda. These bags replaced the sisal gunny bags. The samples in bags were stored at ambient temperature in a well protected room located in the Department of Crop Science, Makerere University, Kampala, Uganda. The total duration of the project was six months.

Determination of moisture content: During drying experiments, moisture content of the grains was determined using a moisture meter (Fermex Moisture Master) that reads directly for corn (maize) while during storage experiments, moisture content was determined using the standard air oven method (AOAC, 1999). The samples were dried at 100°C to constant weight and the mean moisture content calculated on a wet basis.

Determination of insect damage: Insect damage of the grain in each sample was assessed visually using a qualitative scale of 0-4, where 0 = no damage, 1 = low

(from 1 to 10 seeds), 2 = medium (11 to 20 seeds), 3 = high (21 to 30 seeds) and 4 = very high (>30 seeds). The samples were also observed for presence of live insect pests that developed during storage.

Determination of mould incidence: Thirty kernels of maize were randomly sampled from each sub-sample lot and were assayed by direct plating technique for internal mould infection (Munimbazi and Bulleman, 1996; Pitt and Hocking, 1997). The kernels were surface sterilised for 1 min with sodium hypochlorite (10% commercial bleach, Jik, Rickitt Benckiser, East Africa Ltd), washed three times with sterile distilled water and placed directly on the surface of malt salt agar prepared by mixing 68 g of sodium chloride, 10 g of malt extract, 20 g of agar and 1 L of distilled water (Hanlin and Uiloa, 1979). This media is used for growing mould species requiring a high osmotic concentration. The non-osmophillic moulds were identified on malt extract agar (Becton Dickinson Microbiological Systems, Becton Dickinson and Company, Sparks, MD 21152, USA) prepared by mixing 33.6 g in 1 L of distilled water as recommended by the manufacturers. Ten kernels were placed directly on each agar plate. The plates were incubated upright at 30°C for 42-72 h. After sufficient growth, some of the cultures that could not be identified were transferred onto acidified Potato Dextrose Agar (PDA) for purification and were identified using the keys recommended by Tuite (1982).

Determination of aflatoxin contamination: Aflatoxins were extracted from maize samples using methanol-water solution (80:20 vol.) and quantified in parts per billion (ppb) using Aflatest® Fluorometer following the manufacturer's instructions (VICAM L.P., 313 Pleasant Street, Watertown, MA 02472, USA). The mean aflatoxin content (ppb) of the samples were computed.

Determination of germination percentage: Germination percentage is a very important quality attribute of seeds because it indicates their viability potential. In this study, germination percentage tests were conducted on the biomass-dried maize samples according to Agona and Nadhy (1998). Two replicate samples, each three cobs, were randomly selected from the dryer before drying (control) and at an hour's interval to the end of the drying period. Fifty seeds per replicate were transferred to germination plates containing moistened sand and the seeds were allowed 10 days to germinate. The number of seeds that germinated was counted and expressed as percentage and the mean percentage was computed.

Data analysis: Data on moisture content, insect damage, aflatoxin contamination and germination percentage were

subjected to ANOVA using Genstat 5, Release 3.2, PC/Windows NT, Lawes Agricultural Trust, Rothamsted Experimental Station (1995) and the means were separated using LSD ($p = 0.05$).

RESULTS

Changes in maize moisture content and biomass temperature during drying: Mean drying temperature increased during the first four hours, from 28.1°C reaching a maximum of 52.4°C after 4 h and reduced to 39.2°C at the end of the drying period. Changes in temperature within the dryer were related to the burning efficiency of the charcoal stove (sigiri) used to heat the dryer. Grain mean moisture content decreased steadily during the drying period, from 24.8 to 13.2% indicating that the grain was consistently drying (Fig. 1).

Changes in maize moisture content and temperature during bare ground drying: As the drying temperatures increased, the moisture content of the grain reduced. Mean moisture content values reduced from 24.8% on day one to 14.2% on day five of drying (Fig. 2). The mean ambient temperatures remained high, generally above 28°C and this could have facilitated faster drying of the grain to the observed moisture content.

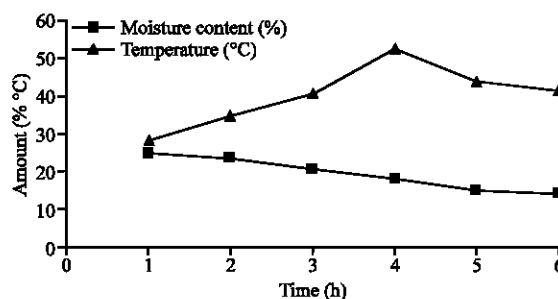


Fig. 1: Changes in grain moisture content and biomass temperature during drying of maize

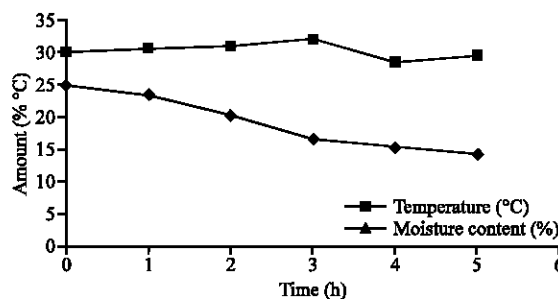


Fig. 2: Changes in grain moisture content and ambient temperature during drying maize on bare ground

Changes in quality parameters of maize dried on bare ground during storage:

The data were collected at the end of every month during the six months' storage period. All quality parameters of shelled and unshelled maize grain were adversely affected as storage time increased up to six months. By the end of three months' storage period, insect damage, aflatoxin content and *Aspergillus* infection had increased more than three times while at the end of the storage period all parameters had increased even more (Table 1). Although, moisture content increased significantly during storage, the trend was not as observed with insect damage, aflatoxin contamination and mould infection of the maize grain. Insect damage in the shelled grain was observed at the end of the second month while in case of grain stored unshelled, insect damage was observed at the end of the first month of storage.

Changes in quality parameters of biomass-dried maize during storage:

The data were collected at the end of every month during the six months' storage period. The quality parameters of both shelled and unshelled maize grain were significantly affected as storage time increased to six months (Table 2). By the end of the sixth month of storage, moisture content of the shelled grain had increased by about one percent while that of the unshelled had increased by about 2%. Insect damage in

both shelled and unshelled grain was observed for the first time after three months of storage and, by the end of the sixth month of storage this parameter had increased more than four times in all the grain. Aflatoxin levels in both shelled and unshelled grain consistently increased with storage time and, by the end of the sixth month the levels had increased more than 20 times. Mould incidence of both shelled and unshelled maize grain significantly increased during storage but the increase was highest in *Aspergillus* sp. followed by other mould species while that of *Fusarium* sp. was the least. In addition, the incidence of *Aspergillus* sp. remained consistently above that of the other mould species during the storage period (Table 2).

Comparison between maize grain quality dried using biomass and bare ground methods:

The values presented in each quality parameter for both shelled and unshelled maize grains are means computed for all the six months of storage. Drying method significantly ($p < 0.05$) affected moisture content, insect damage and aflatoxin levels but not mould contamination of maize (Table 3). During storage, maize kernels dried using bare ground method had higher moisture content and were generally found to be more than three times contaminated by insects and by aflatoxins compared to grain dried using the biomass dryer (Table 4).

Table 1: Changes in quality parameters of bare ground-dried maize during storage for six months in different forms (shelled and unshelled)

Storage time (months)	Quality parameters													
	MC (%)		ID ^a		Aflatoxin (ppb)		<i>Aspergillus</i> sp. (%)		<i>Fusarium</i> sp. (%)		<i>Penicillium</i> sp. (%)		Other moulds (%)	
	S	U	S	U	S	U	S	U	S	U	S	U	S	U
0	14.20	14.20	0.00	0.00	1.67	1.30	6.31	6.56	4.03	4.21	3.31	3.74	4.43	4.72
1	14.30	14.33	0.00	0.67	2.27	4.20	10.03	15.31	5.01	7.24	3.34	4.22	6.21	7.35
2	14.50	14.50	0.33	1.35	5.00	14.20	16.28	22.47	6.36	8.26	4.07	5.16	9.63	11.33
3	14.63	14.77	1.33	2.33	9.00	19.70	19.61	27.35	6.34	9.33	5.04	6.31	10.89	12.38
4	14.77	15.23	1.67	2.69	17.47	29.50	25.27	33.14	13.19	14.28	5.07	6.57	11.51	15.05
5	14.90	15.33	2.33	2.90	25.67	33.60	31.85	35.96	11.50	17.89	7.19	8.35	15.87	17.50
6	14.93	15.60	2.67	3.00	32.50	55.30	36.82	43.09	19.14	20.30	7.32	9.49	21.65	24.05
LSD ($p \leq 0.05$)	0.14	0.15	0.24	0.25	6.63	10.61	9.98	10.12	1.28	1.88	1.74	1.58	4.04	4.85

^aInsect damage ranked from 0-4 (0 = No damage, 1 = Low, 2 = Moderate, 3 = High, 4 = Very high); S: Shelled; U: Unshelled

Table 2: Changes in quality parameters of biomass-dried maize during storage for six months in different forms (shelled and unshelled)

Storage time (months)	Quality parameters													
	MC (%)		ID ^a		Aflatoxin (ppb)		<i>Aspergillus</i> sp. (%)		<i>Fusarium</i> sp. (%)		<i>Penicillium</i> sp. (%)		Other moulds (%)	
	S	U	S	U	S	U	S	U	S	U	S	U	S	U
0	13.20	13.20	0.00	0.00	0.50	0.93	3.20	4.25	2.54	3.11	1.22	1.72	2.24	2.73
1	13.30	13.43	0.00	0.00	0.83	1.00	5.01	6.14	2.51	3.65	1.75	2.14	3.16	3.95
2	13.40	13.73	0.00	0.00	0.87	1.97	8.35	9.76	3.03	4.53	2.03	2.52	4.85	5.88
3	13.60	13.93	0.00	0.00	1.33	2.33	9.86	12.17	3.28	4.97	2.56	3.65	5.59	7.56
4	13.73	14.40	0.33	0.66	2.23	4.67	12.64	15.19	6.65	7.16	2.88	3.98	5.84	6.61
5	13.90	14.57	1.00	1.68	7.67	11.50	15.98	16.58	6.73	8.98	3.50	4.20	7.91	9.84
6	14.00	14.73	1.38	2.67	11.83	22.67	18.45	25.04	6.54	10.05	3.75	4.75	9.85	11.88
LSD ($p \leq 0.05$)	0.15	0.19	0.24	0.67	2.47	4.38	4.87	4.43	1.41	1.25	1.22	1.30	3.02	3.61 ^a

Insect damage ranked from 0-4 (0 = No damage, 1 = Low, 2 = Moderate, 3 = High, 4 = Very high); M.C = Moisture content; S: Shelled; U: Unshelled

Table 3: Effect of drying method on quality parameters of maize stored for six months in different forms (shelled and unshelled)

Drying method	Quality parameters													
	MC (%)		ID ^a		Aflatoxin (ppb)		<i>Aspergillus</i> sp. (%)		<i>Fusarium</i> sp. (%)		<i>Penicillium</i> sp. (%)		Other moulds (%)	
	S	U	S	U	S	U	S	U	S	U	S	U	S	U
Bare ground	14.61	14.85	1.19	1.85	13.37	22.54	20.88	28.27	9.37	11.64	5.05	6.26	11.46	13.20
Biomass	13.59	14.00	0.39	0.72	3.61	6.44	10.50	12.73	4.52	6.06	2.53	3.28	5.63	6.92
LSD ($p \leq 0.05$)	0.97	0.12	0.07	1.26	9.08	12.54	10.39	15.58	4.86	6.58	2.62	3.01	5.98	6.35

^aInsect damage ranked from 0-4 (0 = No damage, 1 = Low, 2 = Moderate, 3 = High, 4 = Very high); MC = Moisture content; S: Shelled; U: Unshelled

Table 4: Effect of storage form on quality parameters of biomass and bare ground-dried maize samples stored for six months

Storage form	Quality parameters													
	MC (%)		ID ^a		Aflatoxin (ppb)		<i>Aspergillus</i> sp. (%)		<i>Fusarium</i> sp. (%)		<i>Penicillium</i> sp. (%)		Other moulds (%)	
	BG	BM	BG	BM	BG	BM	BG	BM	BG	BM	BG	BM	BG	BM
Unshelled	14.85	14.00	1.85	0.72	22.54	6.44	28.27	12.73	11.64	6.06	6.26	3.28	13.20	6.92
Shelled	14.61	13.59	1.19	0.39	13.37	3.61	20.88	10.50	9.37	4.52	5.05	2.53	11.46	5.63
LSD ($p \leq 0.05$)	0.21	0.38	0.52	0.15	8.11	1.83	7.40	2.10	2.85	1.45	1.18	0.64	1.08	0.98

^aInsect damage ranked from 0-4 (0 = No damage, 1 = Low, 2 = Moderate, 3 = High, 4 = Very high); MC = Moisture content; BG: Bare ground; BM: Biomass

Table 5: Effect of biomass drying on germination percentage of maize grain

Drying time (h)	Germination potential (%)
0	91.4
1	90.8
2	88.2
3	85.6
4	85.1
5	83.8
6	81.5
LSD ($p < 0.05$)	10.55

Effect of storage form on the quality parameters of maize dried using the biomass dryer and on bare ground: The values presented in each parameter are means computed for all the six months of storage. Storage form had a significant effect on all quality parameters of maize. For both bare ground and biomass-dried maize, it was established that grain stored unshelled on cobs, had significantly ($p < 0.05$) higher moisture content, insect damage and aflatoxin as well as mould contamination. Among the moulds, however, the occurrence of *Fusarium* species did not differ significantly between the shelled and unshelled maize grain during storage (Table 5).

Effect of biomass drying of maize on kernel viability: Drying maize using the biomass-heated natural convection dryer did not significantly reduce viability of the kernels although there was a ten percent reduction in germination potential (Table 5).

DISCUSSION

The maximum temperature achieved during drying in the biomass natural convection dryer was 52.4°C at the fourth hour agreeing with the findings of Mutyaba (2000). Changes in temperature within the dryer were related to the burning efficiency of the charcoal stove (sigiri) used

to heat the dryer. The stove takes some time to burn to maximum after lighting and its burning efficiency reduces after four hours when the charcoal burns to ashes. This explains why temperature of the dryer reduced to 39°C at the end of the drying period. However, immediately after introducing the burning stove into the dryer, the temperatures rose above ambient till the end of the experiment thus facilitating faster drying than open-sun method.

In the biomass dryer, mean moisture content decreased steadily during the six-hour drying period, from 24.8 to 13.2% agreeing with Agona *et al.* (1999), who reported that drying of maize cobs in the biomass natural convection dryer takes between five and six hours to reduce the moisture content to 14%. In the current study, the results of the final moisture content achieved (13.2%) imply that the maize did not require further drying for short-term safe storage. Maximum moisture content for safe storage of maize is 14% (Cassel *et al.*, 2001). However, moisture content at or below 12% is ideal for storage of maize, because growth of and toxin production by *Aspergillus flavus* cannot occur (Grybauskas *et al.*, 2000; Cassel *et al.*, 2001).

During drying of maize cobs on bare ground, there was consistent drying as indicated by the mean moisture content values which reduced from 24.8% on day one to 14.2% on day five of drying. The high average day temperatures as can be seen in Fig. 2 could have facilitated faster drying. In addition, there was no rain during the drying period as often experienced by farmers in Uganda. According to Odogola and Henriksson (1991), the most common traditional method of drying maize in Uganda involves spreading the crop on bare ground taking up to a week to dry late harvested cobs, depending

on the initial moisture content and weather conditions. The maize used during this study was harvested late by three weeks thus the reason for drying within one week.

Harvesting maize when it is above the 20% moisture content and drying it within 24 to 48 h to at least a moisture content of 14 percent greatly reduces the growth and aflatoxin production by *Aspergillus* (Grybauskas *et al.*, 2000; Cassel *et al.*, 2001). According to FAO (2000) prompt and proper drying are the best means to avoid fungal growth and mycotoxin production in grain after harvest. Indeed, in the current study, the mean aflatoxin levels in bare ground-dried maize was 22.54 ppb which was higher than the 20 ppb regulatory levels recommended by FDA/WHO (Mphande *et al.*, 2004; Duangpatra *et al.*, 2005) while the aflatoxin levels of the grain dried using the biomass dryer were lower than 20 ppb. The findings of the current study thus support earlier studies. FAO (2000) added that at times, when sun drying is not possible or unreliable, some form of mechanical drying may be necessary. Nagler *et al.* (1986) also reported that mechanical drying of maize to a moisture content of 14%, commencing within 2.5 days of harvest, has been shown to effectively control the level of aflatoxin in maize produced in Thailand during the rainy season. Mechanical dryers whether direct or indirect, according to FAO take a shorter drying time and have a cleaner product compared to traditional methods. In the current study, it was noted that maize dried on bare ground was more contaminated with soil than that dried in the natural convection dryer. In addition, Kaaya *et al.* (2006) reported that aflatoxin contamination of maize was positively related to drying maize on bare ground which confirms why the aflatoxin levels in maize grain dried on bare ground was significantly higher than that dried using the natural convection biomass dryer.

Open sun drying of produce may be a difficult task due to the high rainfall at the time of harvest. Thus, a lot of work has been done on the design of solar and mechanical dryers for use by farmers in the tropics (Axtell and Bush, 1991; Carruthers and Rodriguez, 1992). However, some of these dryers are not in use by farmers because of the large capital investment involved. According to FAO (2000), mechanical dryers need not be expensive. Nagler *et al.* (1998) stressed that in order to make the mechanical drying more practical and less costly, it was found necessary to use maize cobs that had been partially dried to a moisture content of less than 22% by natural field-drying, a process whereby maize is left standing unharvested in the field for a period after field maturity. In the current study, the maize cobs used had been field-dried as above but their average moisture content was 24.8%. In addition, the natural convection

biomass dryer used in the study is easy to construct and affordable by the majority of Ugandans (Mutyaaba, 2000) and therefore should be recommended for use by the farmers.

Data collected at the end of every month during the study showed that moisture content, insect damage, aflatoxin levels and mould contamination of the grain dried on bare ground or in a natural convection biomass dryer significantly increased during the six month storage period, irrespective of the storage form. The most important factor in controlling insect, mould and mycotoxin contamination of grain in storage is moisture content (Sauer and Burroughs, 1980) Fungi cannot grow (or produce mycotoxins) in properly dried foods, so efficient drying of commodities as done using the biomass dryer and maintenance of the dry state is an effective control measure against fungal growth and mycotoxin production. According to FAO (2000) while it is possible to control fungal growth in stored commodities by controlled atmospheres or use of preservatives or natural inhibitors, such techniques are almost always more expensive than effective drying and are thus rarely feasible in developing countries.

Moisture content at or below 12% is ideal for storage of maize, because growth and toxin production by *Aspergillus* cannot occur (Cassel *et al.*, 2001). However, simply reducing moisture content to as low as 12% (Grybauskas *et al.*, 2000) does not kill the fungus and does not reduce the levels of toxins that have already been produced. If moisture levels rise again above 12% any time during storage and temperatures are high enough, then mould growth and toxin production will resume. In the current study increase in moisture content of the grain stored in a shelled or unshelled form could have led to increased insect damage, mould infection and aflatoxin contamination in maize grain dried on bare ground or in the biomass dryer.

During the storage of maize, it was observed that grain dried on bare ground was infested with both the maize weevil (*Sitophilus zeamais*) and *Angoumois* grain moth (*Sitotroga cerealella*) while that dried using the biomass dryer was only infested with *Angoumois* grain moth implying that the dryer suppressed the most important insect pest of stored maize in Uganda. According to Kyamanywa (1994) *Angoumois* is more rampant in properly dried maize than *Sitophilus zeamais*. In addition, it was established that insect damage in the grain dried using the biomass dryer was not observed until the forth month of storage agreeing with the findings of Muyinza in 2000 who in her unpublished data, established that the biology of *Angoumois* grain moth takes 2-3 months to show in properly dried maize. Grain

dried on bare ground however, showed insect infestation signs after one month of storage implying that insect control measures in this grain need to be applied much earlier than grain dried using a biomass dryer.

As far as aflatoxin levels are concerned, it was observed that by the four months' storage time, grain dried on bare ground and stored unshelled had aflatoxin levels increased beyond 20 ppb. A similar observation was established in the grain stored in a shelled form by the end of the fifth month of storage. However, for grain dried using the biomass dryer, the aflatoxin levels were only higher than 20 ppb in grain stored on cobs at the end of the storage period. Since majority of farmers in Uganda store maize in unshelled form these results suggest that a biomass dryer could be very effective in protecting them against the risk of aflatoxin poisoning. In any case, however, this will depend on the initial aflatoxin levels, mould contamination as well as the storage environment of the grain.

Drying maize using the biomass-heated convection dryer did not significantly reduce the germination potential of the grain agreeing with Agona *et al.* (1999) who reported that grain dried using the natural convection dryer technology is good for seed. However, the germination percentage of grain dried from two to six hours was less than the minimum recommended 90% level in Uganda (USP, 1973).

CONCLUSIONS

The study has established that drying maize grain with the biomass-heated natural convection dryer reduces drying time and greatly improves the quality of the grain in terms of moisture content, insect damage and mould and aflatoxin contamination compared to drying grain on bare ground. However, the subsequent storage quality of the grain highly depends on the storage form, time and environment. Grains stored in a shelled form are likely to have a better quality than that stored unshelled as long as moisture content remains within the safe storage levels.

From this study therefore, we recommend that use of the biomass-heated natural convection dryer should be disseminated to farmers while bare ground drying of maize should be discouraged. This will enhance improved quality of maize grain during storage in Uganda thus assisting to expand the marketability of the crop.

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