



Received: 11 October 2016
Accepted: 06 November 2016
First Published: 08 November 2016

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Reviewing editor:
Fatih Yildiz, Middle East Technical University, Turkey

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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Economic advantage of sorghum harvest at soft dough grain stage to prevent bird damage

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Abstract: Sorghum grain yield is highly reduced by birds in most areas in Africa where these avian pests are abundant. After much consideration on the physiological maturity of the sorghum grain, we designed an approach of early harvest of sorghum grain. The late grain soft dough was identified as the suitable stage to harvest white sorghum as it turns cream white. As the results showed it was possible to salvage over 90% of the grain yield even when high bird infestations were observed in the production plots. A test on seed germination rate showed over 80% grain viability after sun-drying the grain in the open in three different study sites. These results give hope and provide relief on sorghum production where birds are a menace.

Subjects: Environment & Agriculture; Bioscience; Earth Sciences; Environmental Studies & Management; Food Science & Technology

Keywords: bird damage; yield loss; soft dough; hard dough; economic value

1. Introduction

The sorghum crop, *Sorghum bicolor* (L.) is an important cereal staple worldwide known for its carbohydrate quantity. In the years of 1980s and 1990s most breeding programmes in Africa developed improved varieties for the major production regions of sorghum (Ahmed, Sanders, & Nell, 2000; Kilambya & Witwer, 2013). In eastern Africa sorghum is among the food security crops (Kilambya &

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PUBLIC INTEREST STATEMENT

Bird menace in sorghum production has led to most farmers not growing the cereal in most areas in the African Continent. Various methods of biological, chemical and physical control have been tried with minimal results. Farmers in eastern Africa region have resulted into avoidance of growing the crop especially where production clusters are few. Where everybody grows the crop little damage occur as the birds share the fields. We came up with the “early grain harvest” to deny the birds the chance to damage the crop yield. Through the evaluation study we found that over 90% of the grain can be salvaged from the birds by harvesting at soft dough and sun-drying in the open sun for 3–4 weeks. This is the technology being disseminated in Kenya to prevent yield loss by birds. Farmers in isolated farms experiencing bird menace will definitely benefit from this new approach of sorghum production.

Witwer, 2013; Muui, Muasya, & Kirubi, 2013). Much of the Sub-Sahara Africa (SSA) can achieve high levels of food security by increased sorghum production even in an event of seemingly low rainfall amounts aggravated by climate change scenarios (Gichangi et al., 2015; Kilambya & Witwer, 2013). Though human consumption has remained stagnant probably due to little value addition the new option of use of white sorghum in the brewing industry has awakened demand for sorghum grain for economic gains (Mutisya & Willis, 2009; Ogola & Mungai, 2011; Van Wajk & Kwakkenbos, 2011). In the SSA production levels differ from country to country depending on socio-economic and government policy factors (Muui et al., 2013). New improvement on agronomy technologies and development of high yielding varieties have increased volumes of production levels of the cereal in the presence of irregular and insufficient rainfalls (Gichangi et al., 2015; Ndjeunga & Bantilan, 2005). As increased variability of rainfall amounts occur in most areas in Africa there was need to develop a technology to reduce the major production constraints for sustainable production (Gichangi et al., 2015; Pretty, Toulmin, & Williams, 2011).

Bird damage leads as the major constraints of sorghum production in most SSA countries (Masters, Bedigarb, & Oehmke, 1998). Besides field scaring efforts like use of scarecrows and production of loud noises (explosives) to chase away these vertebrate pests little other options have been tried and evaluated at field level (Hiron et al., 2014; Oehmke & Crawford, 1996). In Kenya the assumed most sorghum grain destructive bird species is *Quelea quelea* though doves and other species are reported by farmers from one region to another (Brooks et al., 2009). In eastern Kenya sorghum production constraints include bird damage which can lead to 60% yield loss even when human scares are present in the field (Hiron et al., 2014; Orr, Mwema, & Mulinge, 2013). A solution to reduce drudgery in production to the most minimum in terms of reduced bird scaring is the most desirable option to improve incentives of sorghum production in SSA region.

To date no reliable control measure has been developed for bird management. The objective of the present work was to determine at what physiological stage it would be safe to harvest sorghum grain and achieve highest yield at specific sites. Three sites were selected and assumed to reflect different densities of bird species as they infested the fields sourcing for food. These were necessary to measure damage levels and assess risk status and economic advantage.

2. Materials and methods

2.1. Establishment of study plots

The study was started at the beginning of long and short rains of March–July 2015 and repeated in October 2015–January 2016. The study plots established were of 8 m × 10 m subplots of three replicates in rain-fed production systems at Katumani in Machakos County, Kampi-Mawe of Makueni County and Ithookwe of Kitui County of eastern Kenya. Spacing of the crop at the sites was 30 cm-intra row × 60 cm inter row. The field plots were ploughed by tractor before harrowing to get a fine seed bed. A four metre path separated the plots from each block. Fertilizer application of di-ammonium phosphate (DAP) was carried out at the rate of 40 kg/ha for uniform nutrition. Crop top dressing with calcium ammonium nitrate (CAN) was carried out once at the rate of 30 kg/ha after plant attained eight leaves at the sites. Weeding by hand hoe was done three times before crop maturity during each season. Duduthrin (Lambdacyhalothrin 17.5 g/L as active ingredient), a synthetic pyrethroid insecticide was applied once at the rate of 200 ml/ha three weeks after crop emergence against shoot fly and stem borers (http://twigachemicals.com/index.php?option=com_content&view=article&id=23:duduthrin-175-ec&catid=10:insecticides&Itemid=9). The amount of rainfall (mm), temperature, days to crop maturity and soil samples to gauge fertility residual levels were analyzed for comparable production potential of sorghum at the sites.

2.1.1. Machakos site

The plot at KALRO-Katumani (01° 20'51" S, 037° 16'56" E, Elev.1,609 m asl) was established on a former cassava plot. Around the plot were two trees which harbored some nests of White browed sparrow weaver (*Plocepasser mahali*) bird species.

2.1.2. Makueni site

The Kampi-Mawe KALRO-Sub-Centre Station is located (01° 50' 54" S, 037° 39' 29" E, Elev. 1,164 m asl), 10 km east of Wote Town. The field was sparsely populated with acacia tree species where some bird species of Cut throat finch (*Amadina* sp) were frequenting the surrounding areas for breeding. Further, some one kilometer away were acacia trees where African weaver birds (*Q. quelea*) bred in hundreds.

2.1.3. Kitui site

The Ithookwe KALRO-Sub-Centre Station is located (01° 22' 34" S, 037° 58' 43" E, Elev. 1,147 m asl) three kilometres in the western side of Kitui Town. The field was surrounded by acacia tree vegetation where birds of varied species were prevalent as they occupied the trees breeding in nests.

2.2. Sorghum grain harvest intervals

The first sample of sorghum crop at the plot sites was harvested when panicle had full grains (early soft-dough) but still green in colour. Some 10 randomly picked panicles from the three middle rows were cut from stems and secured in khaki papers for drying in the open sun. This sample was marked as Day 0 and sun dried throughout for one month. Another 10 panicles were covered with the khaki papers and left for full grain development. The next sample was taken five days later (Day 5) and subjected to similar drying conditions like the first one. Third sample (Day 10) was taken on tenth day and dried as the proceeding ones. Similarly, fourth, fifth, sixth and seventh samples were taken on Day 15, 20, 25 and 30 as the grain colour changed from green, cream, full white and dry dough grain, respectively. Collected samples were sun dried to attain 11–12% moisture content, confirmed with a moisture metre (www.tdsmakina.com/en/prdetail/48/LAW-grainDryers). Some Khaki papers (No. 6) were used in storing the panicles while 90-kg aerated sisal gunny bags were used for specific assembling of samples of harvest interval dates. Market price of sorghum grain per kilogram was sourced at Machakos Municipal Market stores from some five grain dealers. The exchange rate of Kenya shillings (KES) to US Dollars (\$) was sourced from the day of data compilation during analyzes of sorghum grain in Kenya.

2.3. Bird species counts

Number and species of birds visiting each site were recorded cumulatively per week. These would be translated to each species abundance at the sites. A specialist from National Museums of Kenya was invited at the peak of bird infestations to identify to species level. This would enable more literature review and reporting on each species.

2.4. Economic yield loss at sites

It was important to measure the economic yield loss of sorghum grain damage by birds. This enabled elucidating risk factor at each site. Consideration of each site potential on sorghum yield and the yield economic value was important to find out how much would be lost at each site. The yield loss per hectare was converted to monetary value to show loss of incomes on the part of the farmers engaged in sorghum production.

2.5. Grain seed viability test

To measure viability of the grain at each harvest interval, 100 seeds from each sample harvest time interval were wetted with tap water in paper tissue in Petri-dishes and kept in normal room temperature (24–26°C) and then counts of rate of germination were recorded after a week. This test was aimed at right harvest time of ripening sorghum grain at the different sites (www.dramanski.com/agri/moisture meters/dramansk-gmm/?).

2.6. Data analyses

Weighing of the threshed grain samples was carried out with electronic balance (sartorius basic-BA 310s) and recorded for comparable ANOVA analyses. A statistical analysis system (SAS) software (2001) for General Linear Model (GLM) Procedure was used to separate (fisher's least significant difference) parameter means for significant difference test on treatments of different days' interval

yield levels. Mean bird species numbers visiting the site plots' counts at weekly periods were analyzed to elucidate abundance and occurrence significance levels. Germination rate (%) of seed at each site interval was calculated for comparative presentation on graph.

3. Results

3.1. Prevailing sites conditions

The site at Kitui received highest amount of rainfall during the production periods with a mean of 742 mm. The least amount of rainfall was realized at Machakos of 368 mm (Table 1). The warmest site was Makueni at 25°C and hence leading in the shortest period of crop production of 98 days to grain maturity. All site soils had low Nitrogen and Phosphorous nutritive elements, but Potassium element was adequate in the production plots.

3.2. Bird species abundance

A total of five bird species were observed visiting and feeding on sorghum at the sites as the grain developed to ripening stage (Figure 1(A)). In 2015, the highest number of bird species was the Yellow rumped-seedeater *Serinus reichenowi* Salvodori (Passeriformes: Fringillidae) on weekly basis at 448, 470 and 348 at Machakos, Makueni and Kitui site plots. The second most abundant species was the White browed sparrow weaver *P. mahali melanorhynchus* Smith (Passeriformes: Passeridae) at 16, 356 and 428 at Machakos, Makueni and Kitui plots respectively. The least bird species at the sites was the Ring-necked dove *Streptopelia capicola* Sundsvall at weekly visits of 3, 6 and 8 at Machakos, Makueni and Kitui sites. Of the remaining other two bird species, the Red-billed *Quelea quelea* Linneaus (Passeriformes: Ploceidae) was scored at 0, 72 and 519 and the Cut-throat finch *Amadina fasciata alexanderi* Neumann (Passeriformes: Estrildidae) at 22, 158 and 41 in the same order of sites of Machakos, Makueni and Kitui, respectively. Site bird weekly abundance irrespective of species were 489, 1,062 and 1,344 at Machakos, Makueni and Kitui respectively.

In 2016, *Q. quelea* species was most abundant at 273, 653 and 463 at Machakos, Makueni and Kitui respectively (Figure 1(B)). The second abundant species was *S. reichenowi* at 567, 172 and 62 at Machakos, Makueni and Kitui correspondingly. As in the previous year (2015) *S. capicola* was the least abundant at six, three and two at Machakos, Makueni and Kitui sites. At weekly levels, bird abundance was 918, 912 and 560 at Machakos, Makueni and Kitui sites.

3.3. Site economic yield loss

Highest grain yield loss by birds was realized at Machakos plot at 80% in 2015, translating into monetary value of \$11, 5792.2 (KES 1,177,600) (Table 2). The preceding year (2016) had lower loss of 19% of \$2,660.3 (KES 227, 360). In 2015 least bird damage was scored at Kitui plot of 14% worthy

Table 1. Sorghum production conditions (± standard deviation) in eastern Kenya 2015–2016

Locality site	AEZ	Rainfall (mm)	Temperature (°C)	Grain days	Fertility status
Machakos	LM4	368 (42)	21 (6)	120 (14)	Low N, P
Makueni	LM3	403 (49)	25 (5)	98 (9)	Low N, P
Kitui	LM2	742 (64)	22 (4)	116 (7)	Low N, P

Figure 1. Weekly bird species occurrence on ripening sorghum grain in eastern Kenya in 2015–2016 production period.

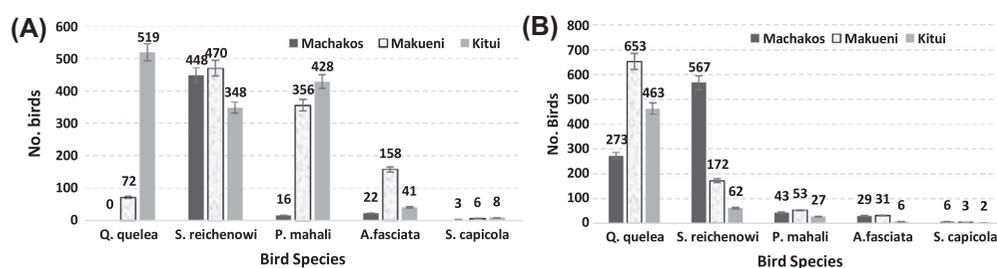


Table 2. Sorghum grain yield two year (2015–2016) loss due to bird damage in three production sites in Machakos, Makueni and Kitui

Year	Site location	Yield B-dam. (t/ha)	Yield-protected (t/ha)	Yield loss (%)	Value loss/ha	
					\$ (USD)*	KES*
2015	Machakos	3.6 ^b	18.4 ^a	80	11,579.2	1,177,600
	Makueni	11.6 ^a	23.7 ^a	51	9,507.9	966,960
	Kitui	17.4 ^a	20.3 ^a	14	2,235.6	227,360
	F, P	14.8, 0.0142	4.5, 0.0962			
2016	Machakos	14.4 ^a	17.7 ^b	19	2,660.3	270,560
	Makueni	16.9 ^a	24.3 ^a	40	8,904.6	905,600
	Kitui	8.6 ^b	15.6 ^b	45	5,522.1	561,600
	F, P	12.4, 0.0194	40.1, 0.0023			

Notes: Similar transcript letters denote no significant ($p > 0.05$) difference of yield among sites (fisher's least significant difference, $df = 2, 8$) at 5% level.

*1 kg of sorghum grain costs \$ (USD) 0.79; equivalent to KES 80.00: exchange rate \$ to KES 101.7 (Daily Nation Newspaper, 22/7/2016, p. 36).

\$2,235.6 (KES 227,360). In 2016 Kitui and Makueni sites had 45 and 40% yield loss, translatable to \$5,522.1 and \$ 8,904.6 respectively. Makueni site appeared most profitable for sorghum production at 23.7 and 28.3 t/ha during the two year production periods which reflected sale revenue of \$18,643.0 (KES 1,896,000) and \$22,261.2 (KES 2,264,000) per hectare respectively.

3.4. Economic advantage of early harvest

Grain harvest at deep-green and light-green showed yield loss of 25 and 21% loss due to kernel immaturity, translating to value yield loss of \$2,488 and \$2,594 (Table 3). This was found to change as birds become the main risk factor damaging the grain from full-cream (colour), cream white, full white and hard dough (dry grain) at 7, 10, 16, and 45% respectively. The monetary bird damage loss was \$876 (KES 89,040), \$1,329 (KES 135,200), \$2,354 (KES 239,360) and \$9,929 (KES 806,400) for the grain stages of full green, cream white, full white and dry grain respectively. At full white, yield salvage of 18.7 t/ha was achieved after removing the 16% loss of monetary value of \$16,289 (KES 1,307,680). Thus, early harvest at full white of the soft dough stage was found most suitable to harvest sorghum grain and dry in the open to deter economic loss.

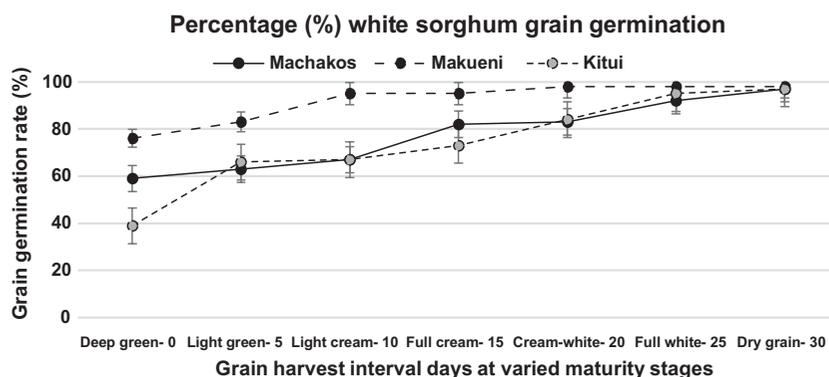
Table 3. Mean sorghum yield at various grain harvest stages in eastern Kenya 2015–2016 protected and under bird attack

Grain stage	Yield on-bird attack (t/ha)	Protected yield (t/ha)	Yield loss (%)	Value loss \$ (USD)*	Risk factor (cause of loss)
Deep-green	9.5 ^c	12.6 ^c	25	2,488	Grain immature
Light-green	12.4 ^b	15.7 ^b	21	2,594	Grain immature
Full-cream	14.6 ^a	15.9 ^b	7	876	Birds damage
Cream white	15.2 ^a	16.9 ^b	10	1,329	Birds damage
Full white	15.8 ^a	18.7 ^b	16	2,354	Birds damage
Dry grain	12.3 ^a	22.4 ^a	45	7,929	Birds damage
SE	1.0	1.2			
F	1.9	14.9			
P	0.0004	0.0002			

Notes: Similar transcript letters denote no significant ($p > 0.05$) difference of yield among sites (fisher's least significant difference, $df = 5, 53$) at 5% level.

*1 kg of sorghum grain costs \$ (USD) 0.79; equivalent to KES 80.00: exchange rate \$ to KES 101.7 (Daily Nation Newspaper, 22/7/2016, p. 36).

Figure 2. Site grain germination performance at the stages of light-cream, full cream, cream white and full white.



3.5. Grain germination rate

Makueni site demonstrated the best grain quality where 95, 95, 98 and 98% germination rates were achieved in light-cream, full cream, cream white and full white grain stages (Figure 2). Second best site performance was at Machakos of 67, 82, 84 and 95% of light-cream, full cream, cream white and full white grain stages. Comparatively, Kitui site had germination rate of 67, 73, 84 and 95% for the stages of light-cream, full cream, cream white and full white grain. The grain stages of cream white and full white demonstrated germination rate performance of between 84–98% at the three sites.

4. Discussion

Weather conditions in the production sites showed that poor rainfall amounts led to low yields of sorghum. Further, the results from the study showed sorghum production has low risk of failure and hence can be relied upon to achieve higher income levels in the indicated test localities. Nevertheless, sorghum crop gives higher yields in higher soil fertility where in the Australia soils it could be as high as 70 kg N/ha and 100 kg P/ha (Grains Research & Development Corporation, 2015). The high torrent rainfall amounts fertilizer applied at planting of 20 kg N/: 20 kg P/ha was simply micro dosing with the subsequent low CAN application of 30 kg/ha. Coupling the low fertility and rainfall amounts could have led to the low yield of 15.6 t/ha at Kitui site. Another factor could have been the seed spacing where in the present work was within 40,000 plants/ha but in other optimum fertility and moisture conditions could be as high as 75,000 plants/ha. In the selected experimental plots it was not prior established what spacing was most suitable. Gadam is an improved sorghum variety sourced from Kenya Agricultural and Livestock Research Organization (KALRO). Gadam is reported to yield between 16–20 kg/ha in spacing of 25 × 75 cm under good agronomic management. This meant that Gadam being a moderate yield producing variety in comparison to others developed by KALRO, it has other attractive attributes to farmers in the marginal areas hence its preference. The variety has ability to mature early in low rainfall regime areas than other varieties. Labour and production input costs considered, it would appear the moderate yield of Gadam variety provides a sustainable yield in most advance conditions of the semi-arid regions.

Though the soft dough grain was most attractive to most granivorous birds the considerably higher damage occurred when the crop continued longer in the field at hard dough stage. It was observed that species *S. reichenowi*, *P. mahali* and *Q. quelea* were the most abundant in the study sites in 2015. In the following year (2016), *Q. quelea*, *S. reichenowi* and *P. mahali* were most abundant at the sites. Two species, *Q. quelea* and *S. reichenowi* are reported to feed on highest quantities of sorghum and millets in Africa (Berruti, 2000; Zuccon, Prÿs-Jones, Rasmussen, & Ericson, 2012). Hiron et al. (2014) has demonstrated the huge yield loss turnout of up to 60% of sorghum in western Kenya when two bird species visited a human guarded plot within the lapse of reporting early or late to scare the avian pests. In the same study it was determined that *Ploceus cucullatus* and *Streptopelia decipiens* (Hautlaub & Finsch) consumed 16 and 32 grain seeds per one feed session which could double as the birds fed twice per day.

As the results have shown grain harvest at deep-green and light-green showed yield loss of 25 and 21% loss due to kernel immaturity, translating to low value yield. This was found to change as birds became risk factor of production damaging the grain up to 45%. The monetary bird damage loss was \$876 (KES 89,040), \$1,329 (KES 135,200), \$2,354 (KES 239,360) and \$9,929 (KES 806,400) for stages of full green, cream white, full white and dry grain correspondingly. A net value of \$16,289 (KES 1,307,680) was attained when grain was harvested at full white soft dough stage. Thus, early harvest at full white of the soft dough stage was found most suitable to harvest sorghum grain and dry in the open to deter economic loss.

While sorghum is not one of the high value crops due to its low preference for human diet and the low uptake for animal feed in Africa, it still presents good opportunity for industrial use in the emerging brewery industry reported in Kenya (Mutisya & Willis, 2009). The option of growing sorghum fodder for animal silage is another opportunity for farmers especially where irrigation water is available as in the USA (Lacy, 2008). Profits on milk production increase by 64% when dairy animals are fed sorghum silage in USA and as in India the grain can be utilized for various cuisines (Lacy, 2008; Ratnavathi & Patil, 2013). If the findings here on the ideal novelty of early sorghum grain harvest is adopted where over 90% of grain will be saved from loss by birds and the remaining green fodder harvested for animal feed or silage processing, then a combined double benefits could be achieved from sorghum. It will no longer be a crop for the poor but an important crop able to sustainably provide basketful of grain in minimal rainfall amounts and also feed the animals of the farming communities in sub-Saharan Africa (Pretty et al., 2011; Ratnavathi & Patil, 2013). Further, it has been found that sorghum gives sustainable yield where rainfall amounts are low. The risk of bird damage and yield is real and has led to fewer farmers growing sorghum due to the drudgery of bird scaring period. The option of new emerging markets in brewery and animal feed industry will most likely attract more farmers to sorghum production. As found out from the present study the novelty of early grain harvest at soft dough stage saves over 90% yield loss by birds. This new approach gives an environmentally sound management technique which if most farmers adopt could yield higher earnings at farm level.

Acknowledgement

Mr Benson Kioko of National Museums of Kenya is acknowledged for assisting on identification of the bird specimens from the three sites. Meteorological persons serving at Kampi-Mawe (ICRISAT), Ithookwe- KALRO Sub-Centre and KALRO-Katamani are acknowledged for providing climatic data of the sites.

Funding

We acknowledge the financial support from European Union (EU) presented by European Commission (EC) grant (Contract NO.FED/2012/291-241) project name: Agricultural Productivity Rural Project (APRP) and Government of Kenya (GoK) which enabled the timely carrying out of the evaluation activities at the three sites at Machakos, Makueni and Kitui.

Competing Interests

The author declares no competing interest.

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Citation information

Cite this article as: Economic advantage of sorghum harvest at soft dough grain stage to prevent bird damage, Daniel L. Mutisya, David R. Karanja & Rachael K. Kisilu, *Cogent Food & Agriculture* (2016), 2: 1259141.

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