International Livestock Research Institute

Food safety landscape analysis: The maize value chain in Kenya

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Abbreviations and acronyms

AOAC	Association of Official Analytical Chemists
CIMMYT	International Maize and Wheat Improvement Center
EAC	East African Community
ELISA	enzyme-linked immunosorbent assay
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
ha	hectare(s)
IARC	International Agency for Research on Cancer
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
ISO	International Organization for Standardization
KEBS	Kenya Bureau of Standards
KES	Kenya shillings
kg	kilogram(s)
KNBS	Kenya National Bureau of Statistics
NCPB	National Cereals and Produce Board
NGO	non-governmental organization
ppb	parts per billion
ppm	parts per million
UNEP	United Nations Environment Programme
USD	United States dollars
WHO	World Health Organization

Executive summary

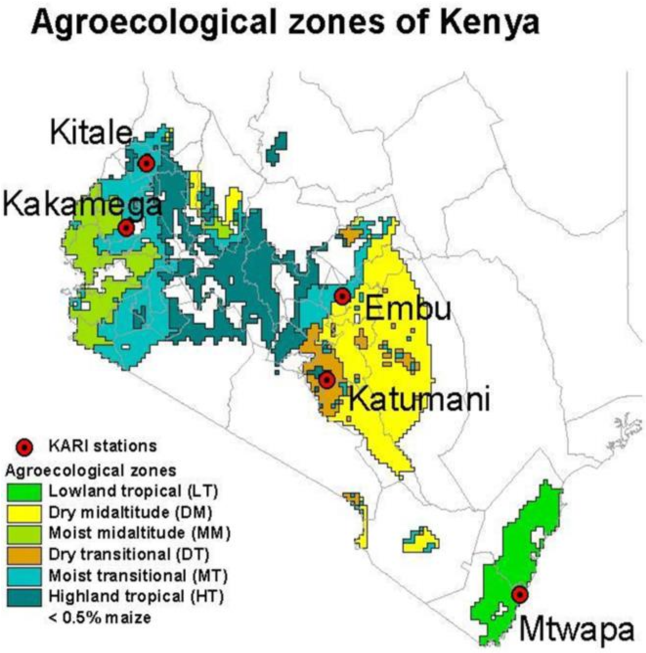
Maize is the main staple food in Kenya; per capita consumption is 98 kg per year. As it is the most important crop in the country's strategic food reserve, failure of the maize crop has a significant impact on national food security. Foodborne hazards in the maize value chain contribute to food loss are a threat to public health and trade. Analysis of the maize value chain landscape is needed to understand the practices which may lead to pre- and post-harvest losses and affect food safety. It also helps to identify areas along the value chain where interventions are needed to make the sub-sector sustainable.

This review discusses various practices that can increase the risk of maize contamination, recognizing that pre-harvest practices may have an impact on the post-harvest safety of maize. Mycotoxins, especially aflatoxins and fumonisins, are the most important foodborne hazards in the maize value chain and can occur in maize both before and after harvest. Aflatoxins are known to cause liver cancer and are associated with stunting, immunosuppression and teratogenic effects. Fumonisins are associated with oesophageal cancer. The cost of managing aflatoxin and fumonisin contamination of maize is higher for public health compared to trade.

Another concern is insecticide contamination of maize from the use of chemicals to prevent damage by insect pests during storage; however, no studies have been carried out to show the effects of insecticide residues on humans. Contamination can occur at any level along the value chain. Therefore, interventions to prevent and control contamination and improve food safety should take a value chain approach from farm to consumer. Capacity building has the potential to influence behaviour change and improve food handling practices.

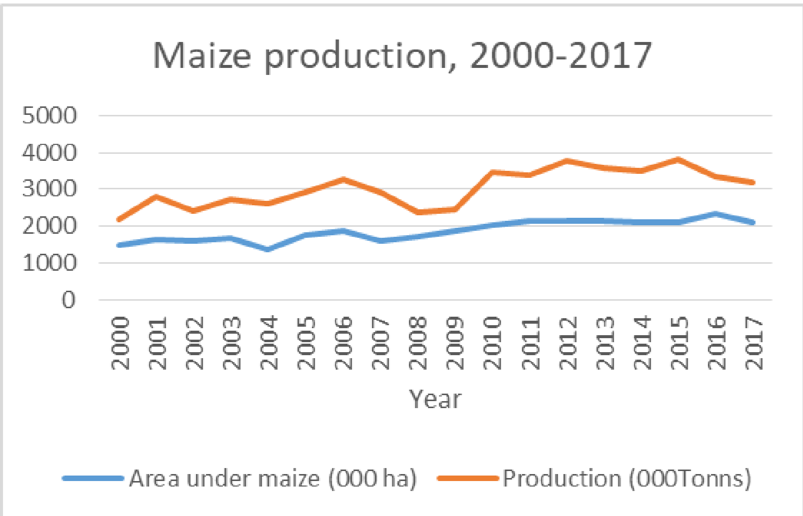
Introduction

In Kenya, maize crop occupies 48.5% of arable land (FAOSTAT 2019) and accounts for 0.3% of the world's maize production. Maize supplies about 365 kilocalories per 100 grams and accounts for 35% of the total caloric intake (FAOSTAT 2019). Maize is the staple crop in Kenya, contributing up to 3% of the agricultural gross domestic product and 21% of the total value of primary agricultural commodities. It is grown in six agro-ecological zones: highland tropical, moist transitional, dry transitional, moist mid-altitude, dry mid-altitude and lowland tropical (Figure 1).



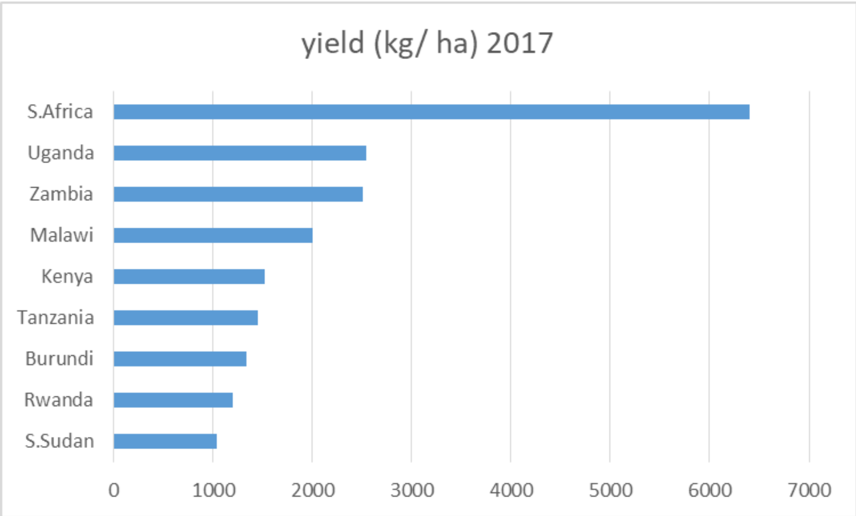
Source: Ouma and De Groote (2011)
Figure 1: Agro-ecological map of Kenya showing the major maize-growing locations.

Smallholder farmers account for 70% of the country's maize production. Production fluctuates despite increased maize acreage mainly because of unfavourable weather (in rain-fed areas) and high costs of seeds and fertilizers (Figure 2).



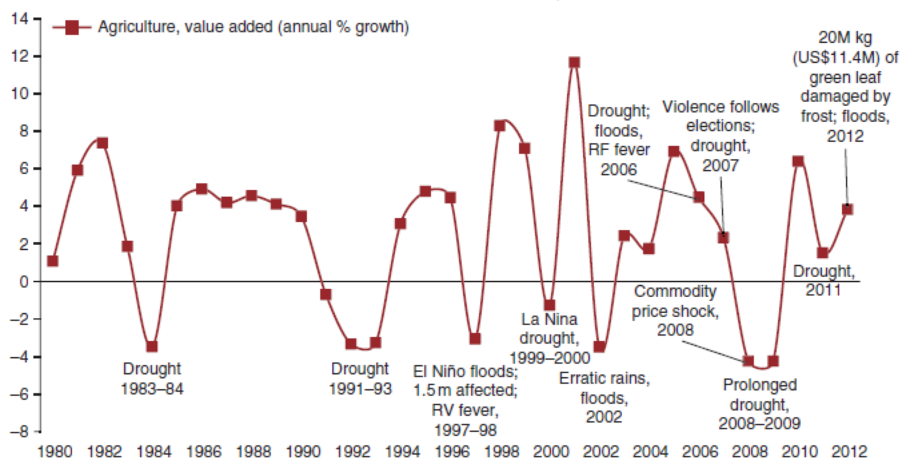
Source: FAOSTAT (2019)
Figure 2: Maize production trends, 2000–2017.

Maize yield per hectare in Kenya is low: 1,440 to 1,836 kg compared to 5,751 kg globally and 2,070 kg elsewhere in Africa (FAOSTAT 2019). In eastern and southern Africa, South Africa has the highest maize yield per hectare (an estimate of 6,399 kg/ha was reported in 2017) (Figure 3).



Source: FAOSTAT (2019)
Figure 3: Maize yield per hectare in selected countries in eastern and southern Africa.

Kenya experiences extreme rainfall events twice every three years. The country has also faced severe droughts in the last decade as well as variable year-on-year rainfall. This, together with high dependence on rain-fed agriculture, makes Kenya particularly vulnerable to food insecurity (Figure 4). Extreme weather can have a profound impact on crop and livestock production. In addition, the global financial and economic crisis, high food and fuel prices and a tense and at times uncertain political environment in recent years have repeatedly disrupted agricultural supply chains and markets, jeopardizing growth and the sector's ability to provide food security and reduce poverty (D'Alessandro et al. 2015).



Source: D'Alessandro et al. (2015)
Figure 4: Historical timeline of major agricultural production shocks in Kenya, 1980–2012.

The country consumes about 270 million kg every month (Kang'ethe 2011). The per capita consumption of maize in Kenya is 98–103 kg (compared to 73, 52 and 31 kg in Tanzania, Ethiopia and Uganda, respectively) (CIMMYT 2015).

Maize standards

The East African Community has a standard for maize grain in the region (Table 1). The standard, EAS 2:2013, specifies the acceptable limits of characteristics including foreign matter, damaged grains, moisture and mycotoxins. The standard has been adopted by the Kenya Bureau of Standards (KEBS) to evaluate the suitability of maize for consumption in the country (KEBS 2019). The Government of Kenya has set limits for aflatoxins in food and feed to reduce exposure. The legal limit of total aflatoxin in cereals is 10 parts per billion (ppb), whereas that of aflatoxin B1 is 5 ppb. The total aflatoxin limit in feed is 10 ppb.

Table 1: East African Standard for maize grains (EAS 2:2013)

Characteristic	Maximum limit			Testing method
	Grade 1	Grade 2	Grade 3	
Foreign matter (% by weight)	0.5	1.0	1.5	ISO 605
Inorganic matter (%by weight)	0.25	0.5	0.75	ISO 605
Broken kernels (% by weight)	2.0	4.0	6.0	ISO 605
Pest-damaged grains (% by weight)	1.0	3.0	5.0	ISO 605
Rotten and diseased grains (% by weight)	2.0	4.0	5.0	ISO 605
Discoloured grains (% by weight)	0.5	1.0	1.5	ISO 605
Moisture (% by weight)	13.5	13.5	13.5	ISO 711/712
Immature or shrivelled grains (% by weight)	1.0	2.0	3.0	ISO 605
Filth (% by weight)	0.1	0.1	0.1	ISO 605
Total defective grains (% by weight)	3.2	7.0	8.5	ISO 16050
Total aflatoxin (B1 + B2 + G1 + G2) (ppb)	10	10	10	ISO 16050
Aflatoxin B1 (ppb)	5	5	5	AOAC 2001.04
Fumonisin (ppm)	2	2	2	AOAC 2001.04

AF: aflatoxin; ppb: parts per billion; ppm: parts per million; ISO: International Organization for Standardization; AOAC: Association of Official Analytical Chemists
The parameter 'Total defective grains' is not the sum total of the individual defects; it is limited to 70% of the sum total of individual defects.
Source: EAC (2013)

Maize trade

Depending on the year, Africa generally accounts for 1.5–3.5% of global maize exports. In 2013, the value of the continent's maize flour exports was about 20.1% of global exports. Between 2004 and 2013, the value of the continent's maize flour exports increased by close to 400% (FAOSTAT 2019). In the last decade, Kenya experienced heightened food insecurity, dependence on imports and emergency humanitarian assistance. The large deficit is met through import of maize from other countries. Imports are allowed when supply cannot meet the internal demand and are meant to bridge the gap and stabilize market prices. The amount of maize that is imported fluctuates depending on the weather. However, aside from the weather, maize imports have increased to keep up with local consumption patterns, increasing from 2.9% to over 12% between 1970 and 1991 (Kang'ethe 2011). Significant increases in maize imports were observed between 2014 and 2018 (Table 2). With the country's population being about 46 million in 2020, the demand for maize is likely to be over 5 million metric tonnes. Based on the prevailing rates of maize production, the maize deficit is projected to be around 1.2 million metric tonnes in 2020 (Kang'ethe 2011). With increased reliance on imports, it is likely that foreign exchange reserves and resources earmarked for development will be diverted to procure food for Kenyans.

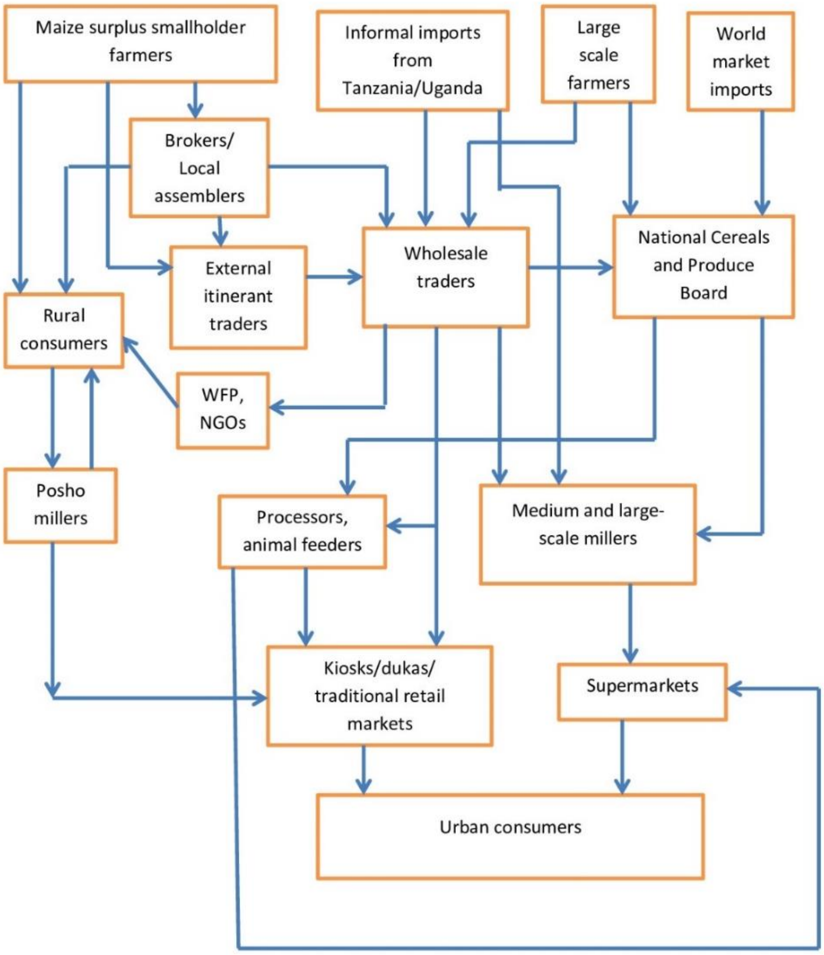
Table 2: Maize imports and exports in Kenya, 2014–2018

Year	Quantity (tonnes)		Value (KES million)	
	Imports	Exports	Imports	Exports
2014	458,940.1	1,667.6	9,308.5	323.6
2015	490,023.7	2,006.9	8,378.3	312.3
2016	148,558.1	3,191.5	3,636.6	510.8
2017	1,327,971.1	5,419.7	40,265.0	766.4
2018	529,558.3	2,673.3	12,008.4	513.8

Source: KNBS (2019)

Value chain actors

The maize value chain in Kenya is complex and involves many players including input suppliers, farmers, marketers and consumers (Figure 5). Within these broad categories, there are numerous sub-players that integrate either horizontally or vertically. This integration complicates food safety along the value chain due to different practices among the players.



Source: Modified from Kirimi et al. (2011)

Figure 5: Maize marketing channels.

Input suppliers

The Eastern Africa Grain Council is a regional organization of grain value chain stakeholders. Its membership includes farmers, traders, millers and service providers such as banks, warehouse operators and input suppliers from the East African Community (EAC) and the Common Market for Eastern and Southern Africa. Extension service providers are responsible for delivering extension services including dissemination of appropriate technologies (Tiongco 2011).

Farmers

About 96% of farming households grow maize mostly for home consumption with the surplus sold to assemblers. On average, 45% of household-grown maize is sold (Kirimi et al., 2011). Most rural households own small farms (less than five acres) and are therefore unable to produce enough maize to meet their own needs, forcing them to buy maize. About 18% of farmers sell and buy maize within the same year (Kirimi et al. 2011); the majority are unable to meet their maize needs throughout the year. Only 20% sell maize and these are mainly large-scale farmers. Medium-scale farmers produce medium volumes on 5–20 acres of land. Large-scale farmers produce large volumes on more than 30 acres of land and sell their grain to the National Cereals and Produce Board (NCPB) and large commercial millers (Tiongco 2011). Farm practices such as land preparation, choice of seeds, planting, harvesting, drying, storage and shelling can influence the occurrence of foodborne hazards like aflatoxins.

Marketers

Assemblers

Assemblers are the first commercial purchasers of maize from the field. They buy maize directly from several farmers, bulk it to capture economies of scale in transport to local markets and then sell it to wholesalers and retailers and sometimes directly to consumers (Figure 5). In some cases, they also act as purchasing agents of large commercial millers. They account for about 55% of sales by farmers (Kirimi et al. 2011). These traders do not store their grain but instead offload and sell it quickly to large-scale traders for fear of their capital being tied up in inventory. They make small profit margins ranging from KES 400–500 per 90-kg bag (Kirimi et al. 2011). External traders travel long distances on trucks, vehicles and donkeys to purchase maize from farmers not within their vicinity. Chamberlain and Jayne (2009) observed that the intensity of assemblers in Kenya increased over time as the distance between farmers and assemblers decreased from 0.9 km to 0.7 km.

Wholesale traders

Wholesale traders buy maize from assemblers in bulk, store and fumigate it and then sell it to retailers or millers. They usually buy maize from surplus areas and sell it to deficit areas and in large marketplaces (Tiongco 2011). They command about 23% of the market (Kirimi et al. 2011). The NCPB is a cereal purchasing, marketing and price regulatory agency that ensures a year-round supply of cereals for the nation. It purchases maize from large-scale farmers, co-operatives and wholesalers. The NCPB commands 1.5% of the maize market in Kenya. In addition to being the major buyer of maize in Kenya, it owns advanced storage facilities that are open for renting by farmers (Kirimi et al. 2011).

Dis-assemblers

Dis-assemblers are maize trader who buy maize mainly from large wholesalers in deficit areas and break down the volumes for re-sale to small-scale retailers and consumers. Dis-assemblers are usually local traders who raise their initial capital from either salaried employment or from their involvement in other business activities (Kang'ethe 2011). Primary and secondary traders are local maize traders who buy maize from large wholesalers and assemblers and sell it to smaller-scale retailers and consumers. Secondary traders are also retailers in small marketplaces from where maize is stocked and sold in small volumes (Tiongco 2011).

Millers

Milling of maize is the main form of its value addition. Globally, processing of maize occurs either as dry or wet milling. The main dry milling products include maize flour (for making maize meal, bread and pancake mixes, infant foods, biscuits and porridge), fine meal flaking grits (for making ready-to-eat breakfast cereal cornflakes), coarse and medium grits (for cereal products and snack foods) and fine grits (for brewing). Wet milling products include corn starch (which can be processed into a variety of products such as baked products and candies), corn syrup (which is mainly used in confectioneries and bakery and dairy products), high fructose syrup, dextrose and corn oil (Kang'ethe 2011; Tiongco 2011). Maize is also used to process oil and by-products for animal feed.

The most predominant form of maize processing is dry milling to make maize meal, flour and maize grits. The average extraction rate among medium to large industrial millers is 80% for grade 1 and 95% for grade 2, implying that 2.5 kg of maize are needed to produce 2 kg of flour.

Millers are characterized based on the technology used, available employed capital, packaging technique used and source of maize. There are large-scale and small-scale millers in the value chain. Formal commercial or large-scale millers deal with large volumes of maize and package their own maize. These millers are capital intensive and use roller milling technology that produces a more refined meal. They purchase maize from wholesalers, NCPB stores and large farmers (Tiongco 2011). Small-scale millers depend on maize that comes directly from farmers and process it into whole maize meal (posho). They use a simple hammer milling technology where both the germ and bran are milled together with the kernel to produce flour. These posho millers are divided into small-scale millers that are involved in custom milling and large-scale millers who have higher production, packaging and retailing capacities. They also stock maize for resale to consumers (Tiongco 2011).

The NCPB estimates the total national maize milling capacity at 1.77 million metric tonnes per year. Data from the Cereal Millers Association indicate that the combined maize milling capacity of medium to large maize millers and micro to small maize millers (posho millers) is in the order of 1.62 million metric tonnes per year. Of this amount, the association estimates that 19 of the medium to large millers have a combined milling capacity of about 1.41 million metric tonnes per year or 85–90% of total national maize milling capacity. The association also estimates that posho millers have a combined milling capacity of about 0.21 million metric tonnes per year or about 10–15% of total national maize milling capacity (Kang'ethe 2011).

Supermarkets

Two leading supermarkets were visited and products containing maize were sought from the shelves. The products were both imported (from France, Germany, the United Arab Emirates and the United Kingdom) and locally processed. The products identified as containing maize included popcorn (eight brands), cornflakes (five brands), corn chips (six brands), tortillas (four brands), biscuits (three brands) and maize flour (eight brands).

Consumers

Consumers in urban areas purchase their maize from open-air markets. They buy maize meal from supermarkets and kiosks. Consumers in rural areas get maize from farm stores, open-air markets and kiosks, and buy their maize meal from posho millers, supermarkets and kiosks (Tiongco 2011).

Food safety hazards along the maize value chain

Mycotoxins and pesticides are the main food safety hazards along the maize value chain. Mycotoxins are a group of secondary fungal metabolites produced by certain fungal species under special conditions of temperature, humidity and moisture. The mycotoxins of major concern in maize are aflatoxins and fumonisins.

Aflatoxins

Aflatoxins are a group of mycotoxins produced primarily by strains of *Aspergillus*, i.e. *Aspergillus flavus* Link, *A. parasiticus* Speare, *A. nomius* Kurtzman, Horn and Hesseltine, and *A. tamarii* Kita, and *Emericella* spp. (Muthomi et al. 2012). While all these species produce aflatoxins, it is *A. flavus* that frequently colonizes maize and produces high amounts of aflatoxin contaminating the grain (Mutegi et al. 2012). The aflatoxins are grouped into aflatoxin B1, aflatoxin B2, aflatoxin G1 and aflatoxin G2 (IARC 1993) based on the colour they produce under ultraviolet radiation (B for blue and G for green). Naturally, different strains produce aflatoxins and other mycotoxins. Aflatoxin B1 is the most abundant of the aflatoxins produced and the most toxic (Probst et al. 2011).

Based on a study in Nandi, Kenya by Nyongesa et al. (2015), four fungal genera colonize maize in the region: *Aspergillus*, *Fusarium*, *Penicillium* and *Trichoderma*. Five sections of *Aspergillus* (section *Flavi*, section *Nigri*, section *Fumigati*, section *Circumdati* and section *Clavati*)have been identified from maize and soil samples. *Aspergillus* section *Flavi* was the most predominant followed by section *Nigri*. Two other sections (section *Nidulantes* and section *Candidi*) were identified from samples of soil from Kaptumo (Nyongesa et al. 2015). Although *A. flavus* is the most toxigenic, the strain has been shown to produce two types of sclerotia. Those that produce large sclerotia (the L type) are not as toxigenic as those that produce small sclerotia (the S type); the difference is in the amount produced by the two types (Okoth et al. 2012). Sirma et al. (2016) tested maize samples from different agro-ecological zones for aflatoxin. Those with aflatoxin levels exceeding the regulatory limit of 10 ppb were from the humid and sub-humid zones (17–20% of samples), temperate zones (22–25.4%) and the semi-arid region of Isiolo (20%). Table 3 summarizes the status of aflatoxin contamination of maize and maize products in Kenya, based on findings from previous studies.

Table 3: Levels of aflatoxin in maize and maize products in Kenya

Study site	Number of samples tested	Samples positive for aflatoxin (%)	Samples with aflatoxin above acceptable limit (%)	Acceptable limit for aflatoxin (ppb)*	Method of analysis	Reference
Makueni	91		65	20	Modified immunoaffinity method based on AOAC method 991.3	Lewis et al. (2005)
Kitui	73		62			
Machakos	102		34			
Thika	76		51			
Machakos		20	70	20		Probst et al. (2007)
Makueni		37	70			
Kitui		38	55			
Makueni	104	36	20	100	Immunoaffinity column (AflaTEST; Vicam, Milford, MA, USA) method 977.16 by AOAC	Mwihia et al. (2008)
Eastern province	144		590	20	USDA/GIPSA certified ELISA (ELISA, Mycochek Strategic Diagnostics Inc, Nevak, DE, USA)	Probst et al. (2011)
Coast province	18		25			
Rift Valley province	13		0			
Kitui	30	10	33	10	Low matrix competitive ELISA (Helica Biosystems, Fullerton, California)	Gachara (2015)
Trans Nzoia	40	58	53			
Nakuru	60	83	4			
Makueni and Kitui	716		35	20	Immunoaffinity column (AflaTEST; Vicam, Milford, MA, USA) method 977.16 by AOAC	Daniel et al. (2011)
Nairobi	144		83			Okoth and Kola (2012)
Meru Central	150	80	60	10	Low matrix competitive ELISA (Helica Biosystems, Fullerton, California)	Mutiga et al. (2014)
Mwala	150	85	55			
Meru North	150	73	45			
Meru South	150	78	43			
Mwingi	150	65	58			
Kitui	150	73	37			
Mbeere	150	61	33			
Embu	150	58	31			
Machakos	150	50	23			
Kathiani	150	46	22			
Rachuonyo	104	77	55	10	Low matrix competitive ELISA (Helica Biosystems, Fullerton, California)	Mutiga et al. (2015)
Homa Bay	113	69	29			
Kisii	125	45	9			
Bungoma	309	43	3			
Trans Nzoia	192	42	4			
Uasin Gishu	142	25	6			
Korogocho and Dagoretti West	186	95	4	20	Low matrix competitive ELISA (Helica Biosystems, Fullerton, California)	Kiarie et al. (2016)
Makuyuni	15	33	0	20	Immunoaffinity column (AflaTEST; Vicam, Milford, MA, USA) method 977.16 by AOAC	Maina et al. (2016)
Kilala	15	93	7			
Kwale	20	95	20	5	Low matrix competitive ELISA (Helica Biosystems, Fullerton, California)	Sirma et al. (2016)
Isiolo	40	50	25			
Tharaka Nithi	53	75	17			
Kisii	63	78	25			
Bungoma	57	72	23			
Nandi (home)	272	68	0	10	Competitive ELISA (r-biopharm-Germany)	Kang'ethe et al. (2017b)
Nandi (market)	42	73	0			
Makueni (home)	325	80	25			
Makueni (market)	55	91	45			

*The acceptable limit of total aflatoxin in maize changed from 20 ppb to 10 ppb; authors used either the Codex Alimentarius (10 ppb) or the United States Food and Drug Administration (20 ppb) standard.
ppb: parts per billion; AOAC: Association of Official Analytical Chemists; ELISA: enzyme-linked immunosorbent assay

Fumonisins

Fumonisins are toxic metabolites produced by *Fusarium verticillioides* and *Fusarium proliferatum* (Fandohan 2006). Fumonisins have been identified in corn, corn flour, dried milled maize, dried figs (Karbancioglu-Güler and Heperkan 2009), herbal tea and medicinal plants (Omurtag and Yazicioglu 2004). Six types of fumonisins have been identified: fumonisin B1, B2, B3, B4, A1 and A2 (Burger et al. 2010). The B series fumonisins contain a free amine while the A series fumonisins have an amide. Fumonisin B1 is the most frequent in maize (Ritieni et al. 1997). Contamination of maize with fumonisins mainly occurs before harvest.

Fusarium section *Verticillioides* and section *Moniliforme* have been identified in Kenya; *Fusarium* section *Verticillioides* is predominant in Nandi, Makueni and western Kenya (Kedera et al. 1999; Kang'ethe et al. 2017a). These genera of fungi produce fumonisins that have various harmful effects on humans. A study by Kedera et al. (1999) in western Kenya found 47% of maize samples contained fumonisin (> 100ng/g), with 5% containing fumonisins above the acceptable level in maize for human consumption (1,000 ng/g). In Kisii County, the same study reported fumonisin B1 levels of 3,600–11,600 ng/g. Alakonya et al. (2009) reported fumonisin B1 levels of 22–348 µg/kg in healthy maize. Table 4 summarizes the status of fumonisin contamination in maize and maize products in Kenya, based on findings from previous studies.

Table 4: Levels of fumonisin in maize and maize products in Kenya

Study site	Number of samples tested	Samples positive for fumonisin (%)	Samples with fumonisin levels above 2 ppm (%)	Method of analysis	Reference
Kitui	42			cELISA (Rindascreen, r-biopharm)	Bii et al. (2012)
Makueni	44			cELISA (Rindascreen, r-biopharm)	Bii et al. (2012)
Makueni (home)	285	91.9	28.9	cELISA (Rindascreen, r-biopharm)	Kang'ethe et al. (2017a)
Makueni (market)	49	94.2	38.2	cELISA (Rindascreen, r-biopharm)	Kang'ethe et al. (2017a)
Nandi (home)	219	84.2	5.5	cELISA (Rindascreen, r-biopharm)	Kang'ethe et al. (2017a)
Nandi (market)	40	95.2	7.1	cELISA (Rindascreen, r-biopharm)	Kang'ethe et al. (2017a)
Western Kenya	197	47		High-performance liquid chromatography	Kedera et al. (1999)

ppm: parts per million; cELISA: competitive enzyme-linked immunosorbent assay

Impacts of aflatoxin and fumonisin contamination

Public health impacts

Outbreaks of aflatoxin poisoning have occurred in Kenya since 1960 (Table 5). Exposure to aflatoxins has negative effects on animals and humans (Table 6). Aflatoxins were first reported in Kenya in 1960, when 16,000 turkeys died from feeding on aflatoxin-contaminated groundnut feeds (Peers and Linsell 1973). Humans are exposed when they consume contaminated products (cereals, pulses or nuts).

In Kenya, aflatoxin exposure ranges between 3.5 and 133 ng/kg body weight per day (assuming 60 kg body weight per individual) (Shephard 2008). Acute toxicity occurs following exposure to high doses of aflatoxins and may lead to death due to liver failure (Lewis et al. 2005). Acute aflatoxicosis outbreaks in humans in Kenya were first described in 1978 and later in 1981, 1982 and 2001 (Muthomi et al. 2012). The 1982 outbreak occurred in Machakos, Makueni and Kitui counties, which are now known as aflatoxin hot spots following outbreaks from 2004 to 2006 (Korir and Bii 2012). The outbreak of 2004 recorded 317 cases of acute aflatoxin poisoning and 125 deaths (Okoth and Kola 2012).

Chronic aflatoxin toxicity occurs when small doses are consumed over a long time and manifests as stunting in children below five years of age, immunosuppression which lowers immunity to infections, induction of hepatocellular carcinoma, reduced fertility and teratogenic effects (Wu et al. 2014). The risk of hepatocellular carcinoma is increased in people exposed to chronic doses of aflatoxin with concurrent hepatitis B virus infection (Wild and Gong 2009). A study by Ly et al. (2016) in Kenya found 31.5% (n = 1091) exposure to hepatitis B virus, corresponding to an estimated 6.1 million people with past or present infection; of these, about 400,000 people had chronic infection. Wu et al. (2011) estimated the number of liver cancer cases in women and men in Kenya at 4.9 and 8.9 per 100,000, respectively. The estimated incidence of hepatocellular carcinoma attributable to aflatoxin ranged from 0.04 to 1.33 cases per 100,000 in hepatitis-B-negative populations and from 1.05 to 39.9 cases per 100,000 in hepatitis-B-positive populations in Kenya (Hall and Wild 1994; Shephard 2008). The annual global burden of hepatocellular carcinoma cases attributable to aflatoxin exposure in Kenya was estimated to range from 11 to 450 in hepatitis-B-negative populations and from 44 to 2,270 in hepatitis-B-positive populations (Liu and Wu 2010).

All domestic animals can be affected by aflatoxins but sensitivity is influenced by several factors including the species of the animal (dogs and chickens are more sensitive than ruminants). Aflatoxin causes reduced feed conversion efficiency, reduced productivity and immunosuppression (Wogan 1973; Richard et al. 1978). In poultry, aflatoxins are associated with liver damage, impaired productivity, decreased egg production, inferior carcass quality and increased susceptibility to disease (Edds and Bortell 1983).

Fumonisins are carcinogenic and have been linked to oesophageal cancer (Kimanya 2015) and neural tube defects in the foetus (Missmer et al. 2006). Wakhisi et al. (2005), using hospital data, reported high incidences of oesophageal cancer in patients seeking medical care at the Moi Teaching and Referral Hospital; the incidence was higher in patients from the Nandi community compared to those from other communities. In animals, fumonisins cause leukoencephalomalacia in horses (Marasas et al. 1988), pulmonary oedema in swine (Haschek et al. 2001) and hepatocarcinoma in rats (Gelderblom et al. 1991).

Table 5: Reported aflatoxin poisoning cases in Kenya, 1960–2010

Year	Subject affected	Numbers affected	Locality	Source of aflatoxin	Observed effects	Reference
1960	Ducklings	16,000	Settler farm in Rift Valley	Contaminated groundnut feed	Death	Peers and Linsell (1973)
1977	Dogs and poultry	Large numbers	Nairobi, Mombasa and Eldoret	Contaminated products due to poor storage	Death	FAO and UNEP (1979)
1981	Humans	12	Machakos	Contaminated maize	Death	Ngindu et al. (1982)
1984–85	Poultry	Large numbers	Poultry farms	Contaminated imported maize	Death	Ngindu et al. (1982)
1988	Humans	3	Meru North	Contaminated maize	Death; acute effects	Autrup et al. (1987)
2001	Humans	3	Meru North	Mouldy contaminated maize	Death	Probst et al. (2007)
2001	Humans	26	Maua	Mouldy contaminated maize	16 deaths	Probst et al. (2007)
2002	Dogs and poultry	Large numbers	Coast	Contaminated feed	Death	Njapau et al. (2007)
2003	Humans	6	Thika	Mouldy maize	Death	Onsongo (2004)
2004	Humans	317	Eastern, Central, Makueni, Kitui	Contaminated grains	Acute poisoning; 125 deaths	Lewis et al. (2005)
2005	Humans	75	Machakos, Makueni, Kitui	Contaminated maize	75 cases of acute poisoning; 32 deaths	Azziz-Baumgartner et al. (2005)
2006	Humans	20	Makueni, Kitui, Machakos	Contaminated maize	Acute poisoning, 10 deaths	Muture and Ogana (2005)
2007	Humans	4	Kibwezi, Makueni	Contaminated maize	2 deaths	Wagacha and Muthomi (2008)
2008	Humans	5	Kibwezi, Kajiado, Mutomo	Contaminated maize	3 hospitalizations, 2 deaths	Muthomi et al. (2009)
2010	Humans		29 districts in Eastern Kenya	Suspected contaminated maize	Downward price spiral; breakdown of grain trade; unconfirmed dog cases	Muthomi et al. (2010)

Source: Kang'ethe (2011)

Table 6: Mycotoxins in maize and their health effects

Fungus	Mycotoxin	Health effects
Aspergillus flavus and *A. parasiticus*	Aflatoxin B1	Carcinoma, immunosuppression, retarded child growth and development
Fusarium verticillioides	Fumonisin B1	Oesophageal cancer and neural tube defects leading to abortion
Fusarium graminearum	Zearalenone	Oestrogenic effects in animals not of puberty age
Fusarium graminearum	Deoxynivalenol	Immunosuppression
Fusarium verrucosum	Ochratoxin	Chronic renal disease

Source: Mahuku and Nzioki (2011)

Economic impacts

According to IITA (2013), about 1.2 billion United States dollars (USD) are lost annually worldwide due to aflatoxin contamination; African countries are estimated to contribute about 38% of this loss (which amounts to USD 456 million). In the United States of America, the annual cost of aflatoxin contamination has been estimated at USD 500 million (Wu and Munkvold 2008), with management costs of USD 20 million to USD 50 million per year (Robens and Cardwell 2003). Lubulwa and Davis (1994) reported social costs of USD 1 billion annually associated with aflatoxin contamination in maize and peanuts in Indonesia, Thailand and the Philippines. These costs could be higher if the effects of aflatoxin on product taste, odour, texture and colour, as well as the opportunity cost of forgone crop production (due to soil contamination) and trade, are factored in. Developed countries are increasingly using aflatoxin risk as a non-tariff barrier to trade under the precautionary principle (Otsuki et al. 2001). A reduction of the limit of aflatoxin in cereals, dried fruits and nuts by the European Union from 5 ppb to 4 ppb would cost African countries about USD 670 million dollars in lost earnings per year (Otsuki et al. 2001).

Although no study has so far estimated the cost of aflatoxin contamination and management in Kenya, the cost is believed to be high. For instance, Okoth and Kola (2012) found that 120 (83%) of 144 food samples screened for aflatoxin contamination in their study had levels greater than the regulatory limit of 10 ppb. Additionally, at least 207 million kg of maize were found to be unfit for human and livestock consumption and trade during the aflatoxin outbreaks in Kenya in 2004 to 2006 (Atser 2010). Some of this study's key informants in Kitui County indicated that maize prices dropped from KES 1,800 to KES 900 following an aflatoxin alert in the area in 2009.

Apart from the significant monetary costs associated with aflatoxin contamination, aflatoxins disproportionately affect the poor and particularly women. For instance, food-insecure resource-poor households (which are predominantly headed by women) are more likely to consume contaminated food rather than sell or discard it. Additionally, owing to income constraints, such households may not be able to adopt costly control strategies, thereby reducing crop productivity, particularly if the household is located in an aflatoxin hot spot. Furthermore, although well-intentioned aflatoxin awareness campaigns can reduce prices of aflatoxin contaminated food, they may inadvertently result in direct market losses for the poor; it is unlikely that poor farmers can afford to throw away crops that cannot be sold due to aflatoxin contamination. This leads to more severe health impacts associated with farmers' consumption of their own low-priced, contaminated food.

Food safety concerns at nodes along the value chain

Mycotoxin contamination in the maize value chain is associated with both pre- and post- harvest farm practices. In the pre-harvest stage, maize may be colonized by the fungal species due to artisanal farming practices. This review will focus on off-farm practices.

Drying

Drying of maize is usually done either on the cob or as shelled grains. On-cob drying of maize directly on the ground without a canvas sheet increases the risk of contamination with fungal spores from the soil which may lead to aflatoxin contamination in the stored crop. Kang'ethe et al. (2017a) found that 39.1% of farmers in Makueni County and 37.1% of farmers in Nandi County dried their cobbed maize on the ground without a canvas sheet. Such practices, as observed by Mejía (2003), are likely to lower grain quality and present risks to public health. The expected moisture content in properly dried maize is ≤ 13.5%. Higher moisture levels favour the growth of fungi and make the maize crop more susceptible to aflatoxin contamination if the maize was already colonized by aflatoxigenic mould species.

Shelling (threshing)

Shelling of maize grains from the cob is achieved by manual shellers, shelling machines or pounding with sticks. Pounding maize with sticks or improperly calibrated shelling machines can damage the grains and make it easier for fungal hyphae to penetrate the grains and cause aflatoxin contamination if conditions are favourable for mould growth. Kang'ethe et al. (2017a) report that 76.1% and 75.1% of respondents in Makueni and Nandi, respectively, pounded maize with sticks.

Sorting

Sorting of maize can result in a 40–80% reduction in aflatoxin levels (Fandohan et al. 2005). It is commonly done before the grains are cooked but rarely before storage. Kang'ethe et al. (2017a) report that women were able to detect and sort out discoloured grains (which are likely contaminated with moulds), thereby reducing the risk of exposure when the food is consumed.

Storage

Farmers store maize either as cobs or shelled grains. They use cribs that are well ventilated and raised from the ground to store the maize on the cob. Although there is good air flow, the pre-harvest and harvesting practices will affect the levels of aflatoxin at this stage. In the cribs, the grains are expected to dry and are only threshed when market is assured. When maize is stored as shelled grains, farmers use nylon bags which build up moisture and this exposes the maize to aflatoxin contamination (Mutegi et al. 2013). The bags are on many occasions stored on the ground instead of on pallets. This continues to expose the shelled grains to fungal spores and risk of aflatoxin accumulation (Mutegi et al. 2013).

Use of pesticides

Pest infestation is a common problem that farmers have to deal with. Several pesticide brands exist in the market and farmers rely on these to control weevils that can damage grains and result in post-harvest losses. Majority of these have pyrethrins as the active compound. They include pirimiphos-methyl, an organophosphate compound mixed with permethrin (a pyrethroid, common name Actellic), malathion (organophosphate), permethrin (pyrethrin), fenitrothion (organophosphate) and fenvalerate (pyrethrin). Aluminium phosphide is commonly used in large warehouses by large-scale traders and millers. Users should observe the recommended withholding periods to make sure the product is safe, in addition to taking safety precautions during application. Organophosphate-based insecticides may leave residues because of their bioaccumulation tendency; however, these are being replaced by organic and synthetic pyrethrins that are thought to have lower environmental and non-target toxicity than organophosphates (Kang'ethe, 2011; Chesang et al. 2016). Although initially thought to have no adverse effects, a study by Chrustek et al. (2018) reports that deltamethrin has adverse effects on fertility, the immune system and cardiovascular and hepatic metabolism; deltamethrin has nephron and hepatotoxic effects while alpha-cypermethrin impairs the immune system and increases glucose and lipid levels in blood. While these effects are new findings, research is needed on the side effects of pyrethrins.

Use of other preservatives

In a study in Nandi and Makueni, farmers reported using wood ash and hanging maize over fire as local methods of preserving produce (Kang'ethe et al. 2017a). The effectiveness of wood ash in preventing weevil attack, fungal infection and aflatoxin contamination is unknown. However, hanging maize over fire exposes it to smoke that contains antifungal and antibacterial compounds that lengthen the shelf-life of the produce. In addition, the smoke aids in drying the maize.

Warehouse receipting system

This is a system whereby farmers rent storage space in registered warehouses in which storage practices are optimized to control pests and aflatoxin contamination. Maize from a warehouse receipting system would be traded through a commodity stock exchange with certification that the produce is free from aflatoxin. Kenya's parliament has not assented to legislation on commodity stock exchange trading; the Bill is in parliament for discussion.

Trading

This stage of the value chain includes assemblers, dis-assemblers and large-scale or wholesale traders. Here, food safety risks include the use of inappropriate storage bags (polypyrene) instead of sisal or hermetic bags. Polypyrene or nylon bags build up moisture and create a microclimate that favours fungal growth and toxin production. Hermetic bags and silos are effective by creating anaerobic environments which do not favour fungal growth and toxin production (Ben et al. 2006). In the warehouses, the products are fumigated to prevent fungal growth; it is important to maintain the fumigation regime and use recommended products that leave no residue. The effectiveness of fumigation is hampered by the resistance of insects to the active compounds.

Processing

Maize processors use either wet milling or dry milling. The main difference is in the products obtained. In wet milling, the maize grain is separated into its four constituent parts: corn oil, starch, fibre and protein. The maize is first steeped in water at 52–54°C for 40 hours. The steep water is then drained, concentrated and used as animal feed (given its high protein content). The next step is recovery of germ for oil extraction; the residue is used as animal feed protein. This is followed by recovery of starch.

Dry milling separates the grain into flour, germ, fine grits and coarse grits; these are processed into human food or animal feed. The grain is tempered by adding water to separate the germ and endosperm. De-germination allows the kernel to break down into germ, pericarp and endosperm. Aspiration is done to separate the pericarp from the mixture of germ and endosperm. Roller/hammer mills grind the different products.

The main food safety concern is to make sure the steep water which may contain aflatoxins is disposed of properly and not used in subsequent steps. In dry milling, the whole grain is milled without separation of the kernel parts and water and chemicals which would help to wash out some of the toxins are not applied. If the products of wet or dry milling are not well dried, the moisture content will support mould growth and increase the risk of aflatoxin production and accumulation.

Interventions to reduce aflatoxin and fumonisin contamination

This review has analysed the maize value chain in Kenya and identified practices or omissions with the potential to cause contamination with aflatoxins and fumonisins. Table 7 indicates potential food safety interventions along the value chain and the appropriate stakeholders to intervene or fund the activities. In each case, research is crucial to identify trade-offs for adoption and upscaling.

Table 7: Potential food safety interventions in the maize value chain

Level and node of value chain	Current practices	Recommended best practices	Interventions	Best suited to intervene
Farm				
Land preparation	Limited land tillage Shallow tillage	Tilling land before planting Deep tillage using tractors	Train farmers on best tillage methods and their benefits in aflatoxin control	County government; local non-governmental organizations (NGOs)
Application of Aflasafe	No application by many farmers	Application of Aflasafe	Train farmers on the benefits of Aflasafe application	County government, NGOs and research organizations
Certified seeds	Use of local seed varieties	Use of recommended certified seeds	Train farmers on benefits of certified seeds	County government, local NGOs and seed companies
Crop rotation and intercropping	No seasonal rotation of maize with other crops Failure to intercrop maize with other crops	Rotation of maize with other crops Intercropping maize with other crops	Train farmers on benefits of intercropping	County government, local NGOs
Soil amendments	Planting maize on sandy soils Failure to use amendments to improve soil fertility	Planting maize on loam soils if accessible Use of lime, farmyard manure and cereal crop residues to improve soil fertility	Train farmers on best soil amendments and their benefits in aflatoxin control	County government, local NGOs and fertilizer companies
Harvesting and drying	Cutting maize stovers Delayed drying of maize	Drying on cob or as shelled grains on canvas Drying maize within 24–48 hours	Train farmers on best practices in harvesting and drying	County government and local NGOs
Shelling (threshing)	Pounding maize with sticks Poorly calibrated threshing machines	Well calibrated threshing machines	Train farmers on best shelling methods and adverse effects of damaged maize grains	County government and local NGOs
Storage method	Storage of maize and bags in the house on the floor Storage of shelled grain in the house Poorly ventilated granaries Use of granaries that are not raised and have no pest control measures Use of inappropriate polypyrene/nylon bags	Storage of maize bags on a raised platform in the house Storage of maize in well-ventilated, raised granaries with effective pest control measures Use of hermetic improved bags and metal silos	Train farmers on optimal storage of maize (method, bags, design) Invest in improved hermetic bags and metal silos	County government and local NGOs
Preservatives	Failure to use preservatives Failure to observe withholding periods Use of un-approved preservatives (thiamethoxam, imidacloprid and clothianidin)	Use of approved and efficient preservatives Observing recommended withholding periods before consumption of maize grains	Train farmers on use of approved preservatives, their efficiency and risks posed by banned substances	County government, local NGOs and preservative manufacturing companies
Sorting of mouldy grains	Failure to sort and remove physically damaged and mouldy maize grains	Manual sorting of mouldy and damaged grains Use of electric sorters (E-nose) to isolate and remove damaged and mouldy grains Use of ultra-violet detectors to detect and isolate mouldy grains which are removed magnetically	Train farmers on identification and sorting of mouldy grains before storage, cooking and milling and the effect of sorting on aflatoxin control	County government and local NGOs
Marketing and processing				
Small-scale traders Storage	Storage of maize grains in the house on the floor Use of polypropylene bags to store maize	Storage of maize on a raised platform Use of hermetic improved bags	Train marketers and processors on proper storage of maize and maize products Invest in hermetic improved bags	County government and local NGOs
Large-scale traders Storage Storage method Preservation	Use of poorly designed warehouses Use of polypropylene bags to store maize grains Failure to use approved preservatives Failure to adhere to withholding periods of preservatives Poor fumigation procedures	Use of well-designed ventilated warehouses Use of improved hermetic bags for storage Proper use of approved preservatives Adhering to withholding periods of preservatives before consumption of maize Proper fumigation procedures	Train processors on design of warehouses, optimal fumigation procedures, use of preservatives and withholding periods for preservatives before consumption of maize Develop and implement fumigation protocols	County government, local NGOs Processors
Artisanal processing	Poor processing techniques to make muthokoi (no soaking, no use of Magadi soda)	Proper techniques to make muthokoi (soaking, use of Magadi soda)	Train traditional millers on proper techniques to make muthokoi	County government and local NGOs
Formal processing	Poor quality and maintenance of milling equipment Poor calibration of milling equipment	Use of good quality, well maintained and well calibrated equipment	Invest in and maintain good quality equipment Development of calibration manuals	Processors
Packaging	Use of weak packaging material susceptible to leakage	Use of approved packaging materials that are not easily torn	Invest in quality packaging material	Processors

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