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Aflatoxin Contamination of Maize Flour in Kenya

Results from Multi-City, Multi-Round Surveillance

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Notices

ABSTRACT

This research was undertaken to characterise the level and distribution of aflatoxin contamination of maize flour, a key food safety concern in Kenya. More than 1,200 samples of maize flour were collected and analyzed over the course of one year, allowing a robust characterization of relative risk across geography and product type. Informally milled flour was found to be significantly more contaminated than branded flour, a result attributable to the refining process applied to this flour. The results of this study can be used to inform messaging to consumers about the relative riskiness of informally versus formally milled flour, and for geographical targeting of resources for aflatoxin mitigation.

Key words: Aflatoxin; food safety; surveillance

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1. Introduction

Systematic food safety surveillance is critical for the identification of high-risk foods, regions and production processes, and ultimately for the implementation of a risk-based approach to management of food safety (Jaffee et al. 2018). However, food safety surveillance systems are underdeveloped in most low and middle-income countries (*ibid*). We developed and implemented a systematic sampling plan for the surveillance of the fungal contaminant aflatoxin in maize in Kenya and collected and analyzed maize samples collected in accordance with this plan over a one-year period in ten major metropolitan areas. This paper reports our findings and makes recommendations on how the results can be utilized by policymakers.

Numerous studies have documented high levels of aflatoxin in maize grown and marketed in Kenya (Mutegi et al., 2018). The contaminant is estimated to cause up to 26% of the global burden of the main type of liver cancer (Liu and Wu, 2010) and is implicated as a contributor to child stunting (Hoffmann, Jones and Leroy, 2018; Rasheed et al., 2021). Reducing exposure to aflatoxin is a food safety priority of the Government of Kenya, but there is currently a lack of systematic data on aflatoxin contamination. The goal of the present study is to fill this gap by providing comprehensive data, allowing for comparisons across location, time, and product type.

2. Literature and contribution

Previous studies have used informal hammer mills as sampling sites for collection of maize samples for aflatoxin monitoring. Mutiga and coauthors used this strategy to characterize the prevalence in two regions of Kenya during separate years (Mutiga et al., 2014; Mutiga et al., 2015). Three features distinguish the present paper from previous work. First, rather than selecting sampling sites based on agroecological conditions, as done by the above-referenced studies led by Mutiga, as well as others (Sirma, 2016; Mahuku et al, 2019), we take as our sampling frame the maize available for purchase in geographically diverse urban areas across Kenya. Second, our analysis is based on six distinct data collection rounds, spaced throughout one calendar year. This allows us to characterize seasonal patterns of contamination in marketed grain, which may be influenced by the time since maize was harvested, and the region from which it was sourced. Finally, our sample includes formally milled, sifted, and packaged maize flour in addition to the informally ground whole meal flour, enabling comparisons across these two product types. Comparing contamination across product type is the most policy-relevant contribution of this work, as it can be used to provide actionable food safety information to consumers. Assessing the robustness of such a comparison across time and location is critical, as the relative riskiness of alternative food products may vary over the course of the year and may not be applicable to consumers in all regions.

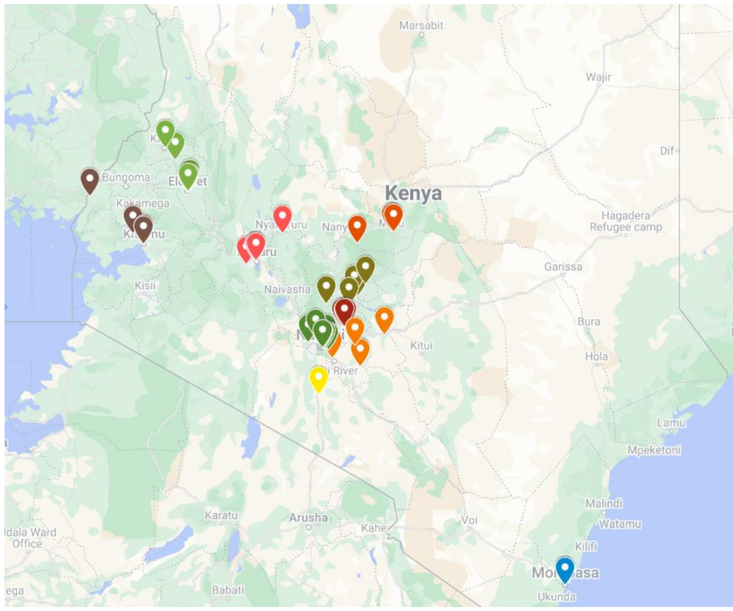
3. Methods

Sampling strategy

The sampling strategy was designed to capture variation in aflatoxin contamination across product category, time, and location in a cost-effective manner. Both formally milled and branded maize flour and maize milled in small-scale hammer mills (posho) were included. Posho mill samples include maize flour milled from grain provided by the miller, and flour milled from customers' grain (either purchased by the customer or home-grown). Samples were collected once every two months, over the course of a year, in ten urban centers. Locations were included based on their proximity to at least one industrial maize mill, and to achieve representation of maize-growing regions and international maize imports. While the urban focus of the sampling strategy implies some limitations, inclusion of rural sampling sites was not feasible within the budget available for this work.

To identify flour brands for sampling, the research team obtained a list of all grain milling firms formally registered with the Kenyan Bureau of Standards, and the maize flour brands associated with each of these. We aimed to link each brand to the maize-producing region or international port of entry from which at least some of the maize used to produce it was sourced, while acknowledging that maize is often transported across Kenya, with the pattern of this trade varying seasonally. The team used publicly available address data and Google Maps software to determine the GPS location associated with the identified firms. Each of the 64 firms for which geographic data were found were then assigned to one of 10 clusters associated with a metropolitan area based on geographic proximity.[1] . These metropolitan areas constituted the sampling sites for maize flour collection: Eldoret, Kajiado, Kisumu, Machakos, Meru, Mombasa, Nairobi, Nakuru, Nyeri, and Thika.[2]

Figure 1 – Mill locations, by sampling cluster



Source: Google Maps and authors' data

At each site, a listing of brands was conducted by an enumerator recruited from within or near that site. Enumerators visited a total of 363 retailers across sites, including supermarkets and smaller shops selling maize flour, and recorded the brands available for sale at each of these. These visits were carried out in December 2020 and were used to build a list of formal maize flour brands available at each of the ten sampling sites. For firms offering multiple brands, the lowest-priced brand was retained in the sample, as higher-priced brands tend to be more refined and thus at lower risk of aflatoxin contamination. Blended flour products containing ingredients other than maize were likewise dropped.

[1] We originally assigned firms to twelve clusters including Lamu and Kitui. However, as few or no mills were linked to these two sites, they were subsequently dropped.

[2] Firms with mills in multiple locations were mapped to multiple clusters. Samples associated with these mills were mapped to mill nearest to their location of purchase.

We then reviewed the availability of each brand to distinguish between brands sold nationally and regional brands. We defined a brand as nationally distributed if it was sold in at least half of the ten sampling sites; six brands met this threshold.[3] We refer to these six as "national brands" in the analysis, and all other brands as "regional brands".[4] Samples of national brands were collected from five randomly selected locations at which they had been observed during listing, with one sample targeted per location.

Samples of regional brands could be collected from up to three locations: the nearest to the location of the mill producing that brand, and up to two additional locations where the brand was observed during the listing exercise. The target number of samples of regional brands per site was 1 if the brand was available in at least three locations (for a total of 3 samples), 2 if the brand was linked to two locations (4 samples) or 3 if the brand was linked to only one location (3 samples). This strategy aimed to achieve variation in sampling sites within-brand to the extent feasible, in order to avoid collecting repeated samples from a single manufacturing lot.[5] If multiple samples of a brand were collected from a single site, enumerators were instructed to obtain these from different shops.

Maize flour collection

Every two months, enumerators visited retail locations, markets, and small-scale hammer mills (posho mills) in each of the 10 sampling sites. We refer to formally packaged samples as "branded" samples to distinguish them from samples purchased at posho mills. Posho mill samples include both maize flour milled from grain provided by the miller, and flour milled from customers' grain (either purchased by the customer or home-grown). Table 1 shows the schedule of maize flour collection visits completed in 2021.

[3] Of these, one was found for sale in nine sites, two in eight sites, two in six sites, and one in five sites.
[4] Regional brands were not necessarily limited to one location, with some found at up to three sites.
[5] Lot numbers are not typically printed on flour packaging, and thus could not be directly observed.

Table 1 – Calendar of data collection visits

Round	Months
1	February-March
2	April
3	June
4	August
5	October
6	December

Each round, enumerators were provided with a list of the maize flour brands for which they were to obtain samples, and the number of samples targeted for each brand. At each of five posho mills per sampling site, a 1 kg sample of flour from the miller's supply was obtained if available, or from purchased grain brought in by a customer if the miller did not have flour available at the time of the visit. Additionally, up to five samples of flour processed from homegrown maize were obtained from mill customers, if available,[6] for a total of up to 10 posho samples per enumerator per round. Customers were asked for only 200 g samples of their home-grown grain, based on the observation that customers typically brought small amounts of maize for milling, and were often not willing to part with grain they had grown even for generous compensation.

For each branded and posho flour sample, the enumerator purchased either a 1 kg (if available) or 2 kg bag and completed an electronic form on a tablet computer, through which data on the price, origin, and brand ID were recorded. Unique identifiers generated by the data collection software were recorded on flour samples, and these were sent to a laboratory at the University of Nairobi via courier within 48 hours of collection. Enumerators were also asked to record price data for each of the brands initially recorded as available at their site.[7]

[6] These samples could be collected at the same mill, though each sample came from a different customer.

[7] Enumerators were also asked to record prices at posho mills, however since it was known that they were visiting to obtain samples, the prices they recorded are likely to be above the true market rate. For our analysis we focus on prices for branded flour.

Laboratory analysis

An extraction solution of 70% of methanol was prepared using 30 mL of distilled water to 70 ml of methanol (reagent grade) for each sample to be tested. Each sample of maize flour was evenly mixed, 20 grams of the sample were weighed out, and 100 ml of the extraction solution was added and mixed in a shaker for 10 minutes. Particulate matter was allowed to settle and 5-10ml of the extract was filtered through a Whatman #1 filter paper. Analysis of total aflatoxins was then conducted on the extract using the Helica Biosystems Inc Total Aflatoxin ELISA Kit according to manufacturer's instructions.

4. Results

Coverage

The sample of brands identified through the initial listing consisted of 63 unique brands (including national brands). Of these, only 48 brands were found during the first round of data collection. Discussions with a milling industry association representative suggested that this was due to a greater variety of brands offered around the Christmas season when the brand listing was conducted, as demand is highest at this time of year. In subsequent rounds enumerators continued to look for the brands observed in December but not found during data collection in February-March, generally without success. The total number of brands for which samples were obtained per milling location was therefore relatively stable across data collection rounds, as shown in Figure 2 below.

Figure 2 – Number of samples of unique brands collected, by round and mill location

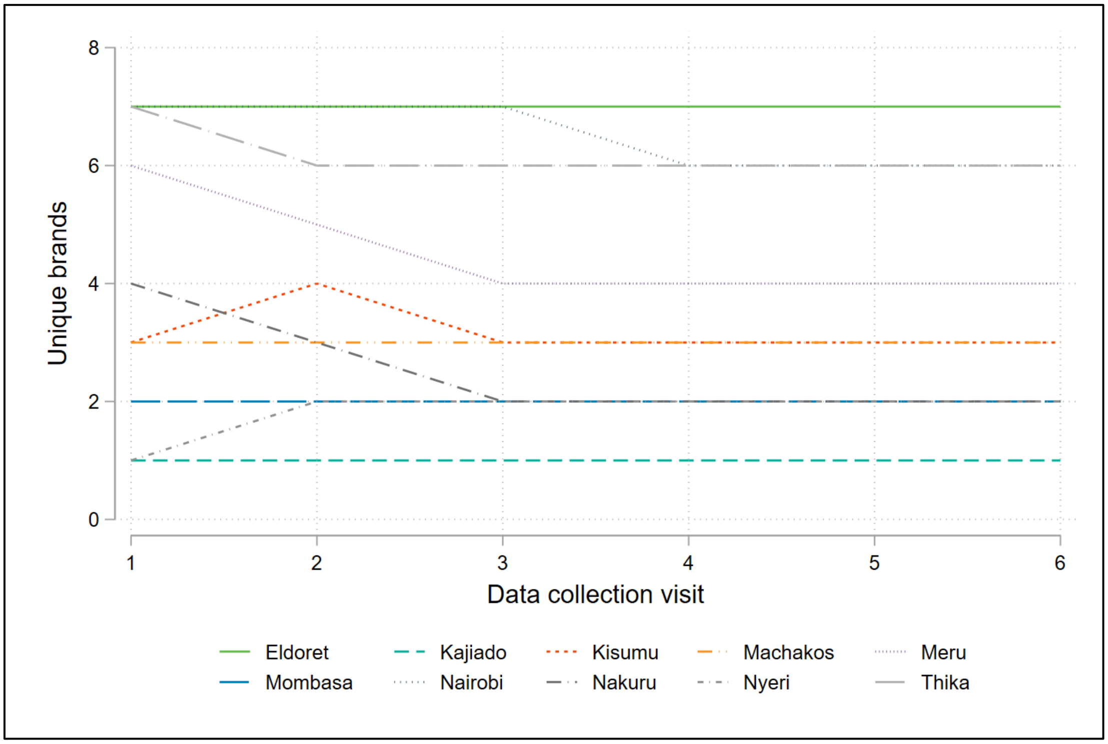


Table 2 summarizes the total number of maize samples collected and analyzed by the milling location to which the sample was linked. In total, 1377 samples were purchased, of which 1255 (91.1%) were successfully processed and analyzed.[8] These comprised 695 branded flour samples and 560 samples from posho mills.

[8] Due to delays or damage to samples or labels in transit, not all collected samples could be both identified and analyzed. In subsequent analysis we focus on these 1255 samples unless otherwise noted.

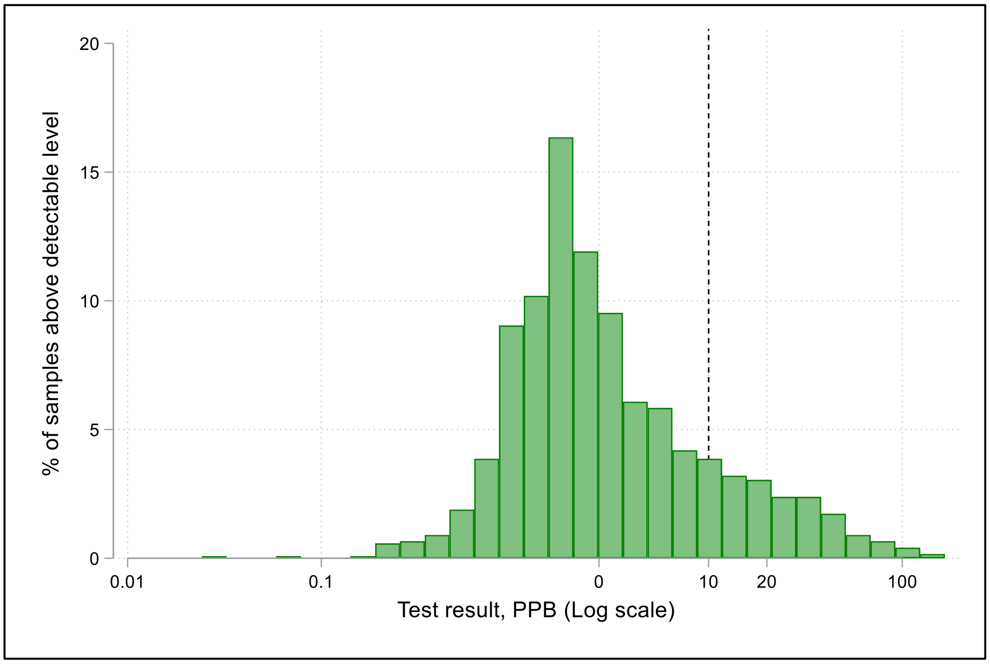
Table 2 – Total samples analyzed by mill location (Rounds 1-6)

	Packaged			Posho		
	All	*National*	*Regional*	**All**	*Purchased grains*	*Homegrown grains*
Eldoret	**95**	*0*	*95*	**60**	*55*	*5*
Kajiado	**17**	*0*	*17*	**57**	*30*	*27*
Kisumu	**47**	*0*	*47*	**53**	*41*	*12*
Machakos	**48**	*0*	*48*	**58**	*48*	*10*
Meru	**66**	*0*	*66*	**57**	*53*	*4*
Mombasa	**53**	*30*	*23*	**59**	*54*	*5*
Nairobi	**138**	*30*	*108*	**48**	*48*	*0*
Nakuru	**45**	*27*	*18*	**60**	*55*	*5*
Nyeri	**33**	*0*	*33*	**55**	*50*	*5*
Thika	**153**	*87*	*66*	**53**	*49*	*4*
Total	**695**	*174*	*521*	**560**	*483*	*77*

Contamination levels

Of the 1,255 samples analyzed, 97% showed a detectable level of aflatoxin, with 16% of all samples testing above the regulatory limit of 10 PPB. Figure 3 shows the distribution of results for samples above the detectable level of aflatoxin.

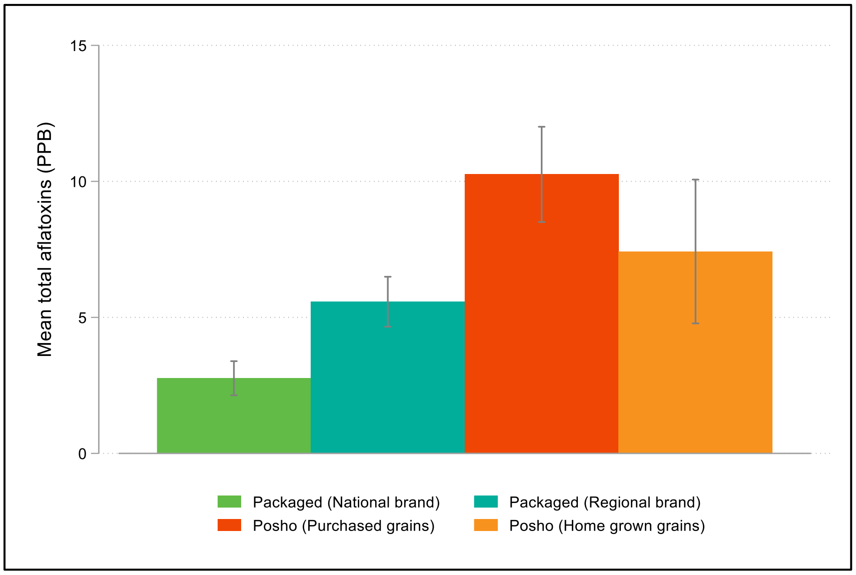
Figure 3 – Distribution of total aflatoxin contamination



Note: samples with aflatoxin below the lower limit of detection are excluded from this figure.

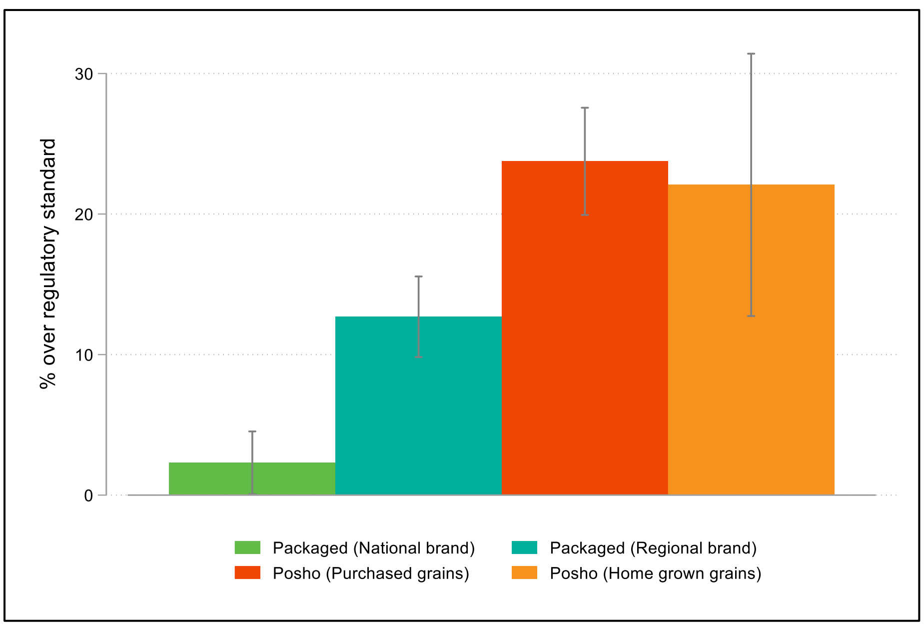
Figure 4 shows contamination rates by flour type, pooling all rounds of data collection and sampling sites. Contamination levels varied significantly between branded flour and informally milled posho flour (Figure 4). Pooling across brand types and sources, branded flour samples had an average contamination level of 4.9 parts per billion, compared to 9.9 ppb for posho mill samples ($p<0.001$). Contamination levels were lowest among national brands (2.8 ppb) compared to regional brands (5.6 ppb). This difference is statistically significant ($p=0.001$). Flour milled from home-grown grains was qualitatively less contaminated (7.4 ppb) than flour milled from purchased grains (10.3 ppb), but the number of home-grown samples was limited, and this difference is not statistically significant ($p=0.218$).

Figure 4 – Mean total aflatoxins, by flour type



Differences in contamination above the regulatory limit of 10ppb are also apparent. For branded samples, 10% were above this limit (2% of national brand samples, 13% of regional brand samples), whereas approximately one in four posho mill flour samples were above the limit (Figure 5). The proportion of posho milled from home grown grains over the limit was approximately the same as for posho milled from purchased grains.

Figure 5 – Share of samples above regulatory standard, by flour type



Figures 6 and 7 disaggregate these results by sampling round and location, pooling national and regional brands, and the grain source of posho samples.

Figure 6 – Mean total aflatoxins, by flour type and round

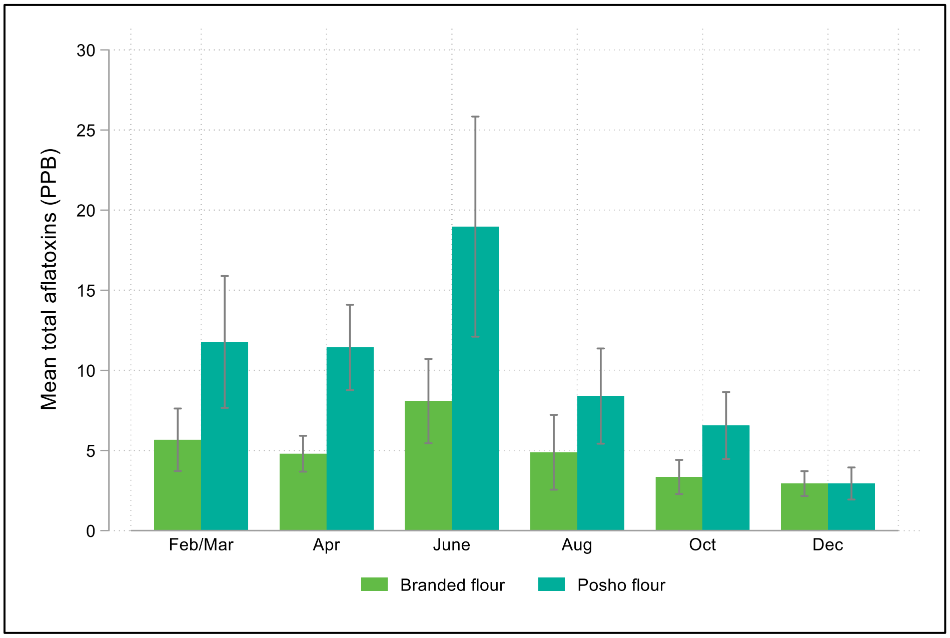
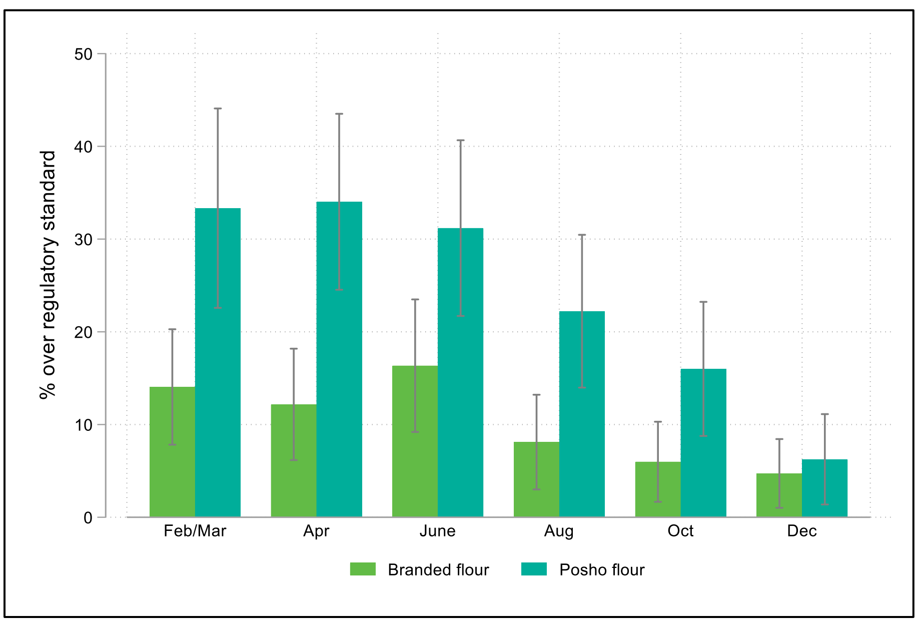


Figure 7 – Share of samples above regulatory standard, by flour type and round



The pattern of higher contamination in posho versus packaged flour is consistent throughout the year. Contamination is highest for both branded and posho flour in June, and dips in

October through December, as maize from the Rift Valley, a productive region with relatively low aflatoxin risk, comes onto the market.

We observe a high degree variation by milling location, with the highest levels of contamination observed in the eastern sample collection sites of Kajiado, Meru, and Thika. In sites where contamination levels differed significantly across flour types, posho flour was almost always more contaminated than formally milled flour. The exception is Kajiado, where more than 41% of formally milled flour samples (all of same brand) tested above the regulatory threshold. The 95% confidence intervals of mean contamination in branded flour in Kajiado and Meru, and for posho flour in Kisumu, Machakos, Meru, Mombasa, Nairobi, Nyeri and Thika all span the regulatory standard of 10 ppb, indicating a substantial risk of aflatoxin contamination in maize produced in these regions (Figures 8 and 9).

Figure 8 – Mean total aflatoxins, by flour type and mill location

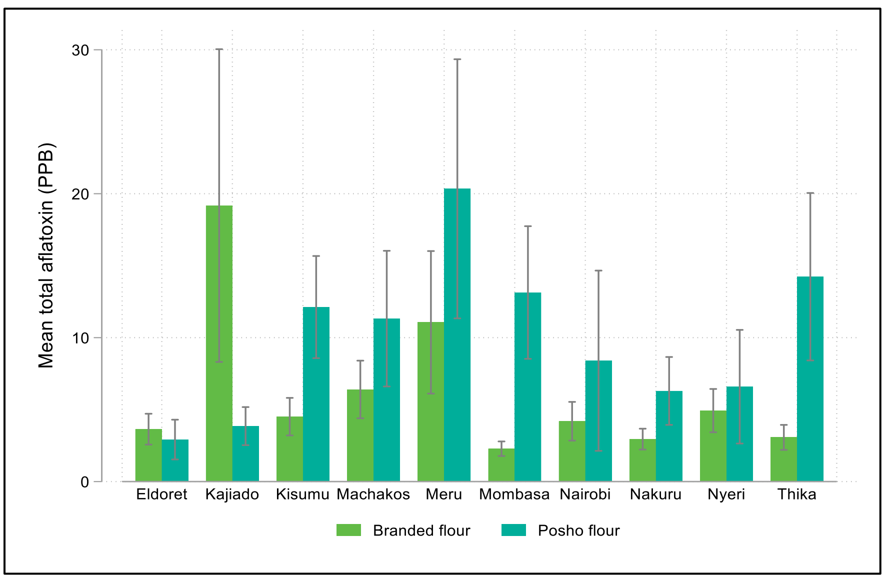
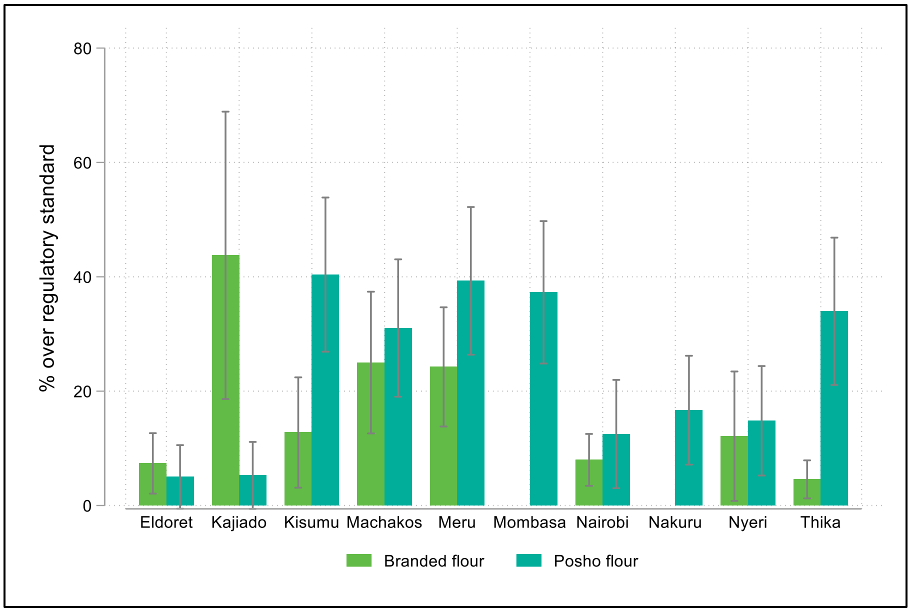


Figure 9 – Share of samples above regulatory standard, by flour type and mill location



Lastly, we consider how differential removal of the germ and bran during the milling process may explain the difference in aflatoxin contamination observed between posho and packaged maize flour. Packaged flour is generally more refined – meaning that more of the germ and bran have been removed – than posho flour. There is some variation in the degree of refining performed by posho mills, with many mills differentiating between grade 1 (less refined, cheaper flour) and grade 2 (more refined, higher priced flour). While processes are not uniform across posho mills, a majority of posho mills in our sample report selling multiple grades of flour. To test differences across grades, for the final two rounds of data collection, laboratory technicians assigned a grade based on visual inspection to each posho sample (Figures 10 and 11).

Figure 10 – Mean total aflatoxins, by flour type (Rounds 5 and 6)

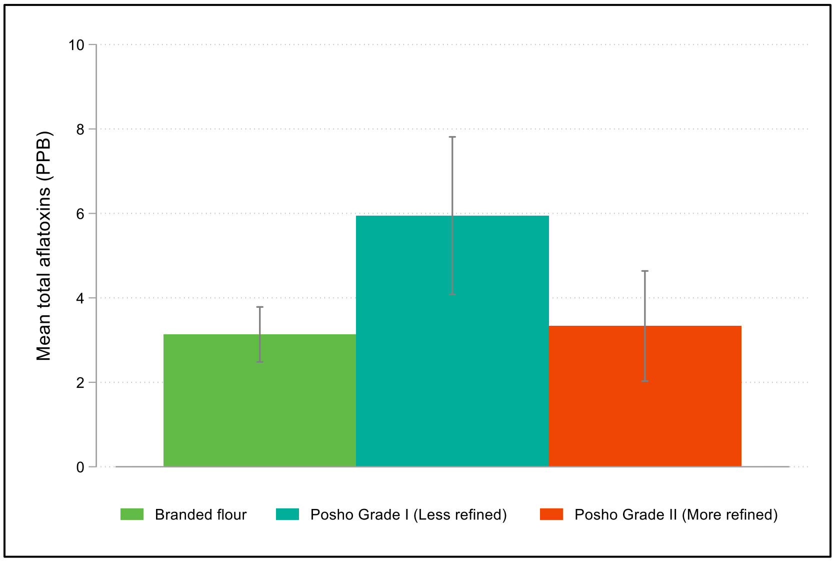
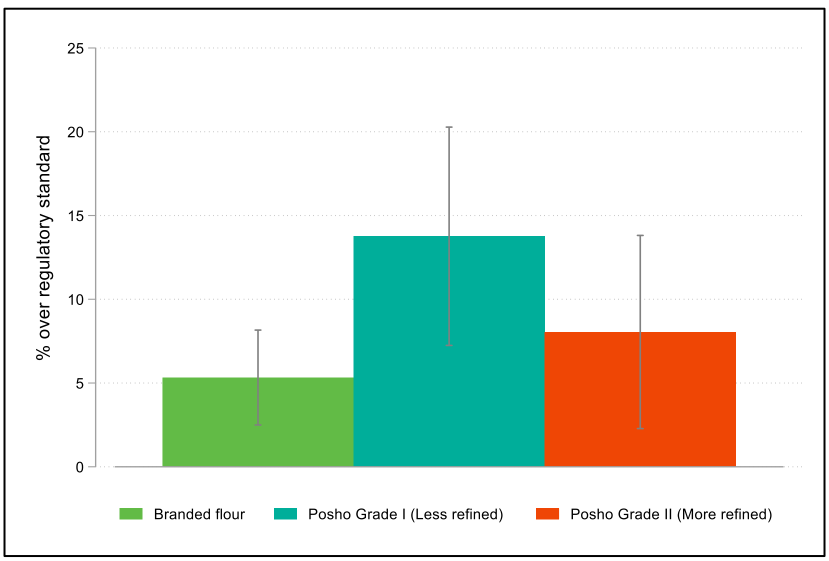


Figure 11 – Share of samples above regulatory standard, by flour type (Rounds 5 and 6)



The results for packaged flour and the more refined grade of posho are very similar, with an average contamination level of 3.1 ppb and 3.3 ppb respectively, and the difference between the two is not statistically significant ($p=0.815$). The difference in aflatoxin contamination levels across posho versus packaged flour for this sub-sample is therefore driven primarily by higher contamination in less refined posho flour, which exhibited an average contamination rate of 5.9 ppb ($p<0.001$). The share of samples above the regulatory limit is 5.3% for branded flour, 8.0%

for more refined posho flour, and 13.8% for less refined posho flour. The difference in proportions above the limit is not statistically significant between branded and more refined posho flour (p=0.364) but is significant when comparing branded and less refined posho flour (p=0.009).

These results suggest that that the lower level of aflatoxin contamination found in packaged maize flour is due to the fact that the non-starch components of the grain are more fully removed during the formal milling process, relative to typical posho milling. Aflatoxin tends to be most concentrated in the germ and bran of the maize kernel, the components sifted out the refining process (Nyangi et al., 2016). These are also the most nutritionally dense components of the whole grain, implying a potential tradeoff between nutrition and food safety. This tradeoff is mitigated by mandatory fortification of formally processed maize flour in Kenya. Compliance with micronutrient fortification requirements is far from perfect in Kenya, with the proportion of maize samples compliant with fortification standards ranging from 23% to 49% as of 2018 (Ministry of Health, 2018, p. 9). Even so, at these levels of compliance, the average levels of vitamin A, zinc, and iron would be higher in branded maize than in whole grains (Table 3).

Table 3 – Relative levels of key micronutrients in whole maize vs. fortified flour (mg/kg)

	(1) Fortification standard[1]	(2) Proportion compliant[1]	(3) Mean level in branded maize = (1) x (2)	(4) Whole grain[3]
Vitamin A	0.5	0.23	0.1	0
Zinc	33	0.34	11.2	2.21
Iron	21	0.49	10.3	2.71

Notes: Fortification standards and compliance data are taken from Ministry of Health (2018). These are multiplied to compute the mean level in branded maize. Levels in whole grain maize are taken from Gwirtz and Garcia-Casal (2014).

5. Limitations, discussion, and policy implications

Maize is transported across Kenya throughout the year from maize surplus to maize deficit regions. Which regions are in deficit and which are in surplus varies by season. As such, our methodology is expected to understate the extent of geographical variation in aflatoxin contamination. However, the variation the method does identify can point to areas of higher risk to which additional on-farm sampling can be targeted.

The results of this study confirm the previously observed spatial pattern of aflatoxin risk in Kenya, with the highest level of contamination in maize milled in the eastern part of the country, and lower levels in the high-productivity maize basket of Rift Valley (Yard et al., 2013). The finding that contamination in whole meal posho flour is higher than in formally milled, sifted flour is congruent with previous evidence based on samples collected in Meru town (Kariuki and Hoffmann, 2022). Our analysis of posho flour by grade suggests that the difference in contamination between branded, sifted maize flour, and whole meal maize flour ground at posho mills arises through the removal of germ and bran during the sifting process of packaged maize flour production.

Monitoring aflatoxin contamination levels across locations in Kenya throughout the year has the potential to better target public and private resources for aflatoxin control by directing resources to the parts of the country where, and seasons when, risk is highest. Further, information about the relative risk of aflatoxin contamination in alternative maize products could help consumers make safer food choices. While formally processed maize flour is becoming increasingly important in Kenya, informally milled posho flour remains the primary staple, especially in rural areas (Hoffmann and Moser, 2017). Previous research has shown that consumers respond to food safety information by switching to lower-risk substitutes (Kariuki and Hoffmann, 2022). Informing consumers that national brands are relatively safe, and that posho flour is relatively risky, could potentially expand the market share of the larger national brands and sifted maize flour in general, and in this way reduce population-level aflatoxin exposure. Currently, consumers are given only partial information, due to the regulatory focus on formally registered, branded products. Recalls of maize flour by national and county regulatory authorities in Kenya are increasingly common.[9] In the absence of comprehensive information on the relative risk of different products, such recalls could potentially lead consumers to switch to riskier posho flour. Providing more complete information on the relative risks across maize products could avoid this unintended consequence.

A similar surveillance strategy could be applied to other food types and hazards. For example, microbiological contamination in high-risk foods such as dairy or horticultural products could be systematically monitored by region through the purchase of formal sector packaged, formal sector unpackaged (supermarket, milk dispenser) and informal unpackaged samples.

[9] See, for example: Mutahi (2019), Agutu (2021), Omulo (2021).

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