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AFLATOXIN AND FUMONISIN MYCOTOXINS CONTAMINATION ALONG THE MAIZE VALUE CHAIN IN THE EASTERN DEMOCRATIC REPUBLIC OF CONGO

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ABSTRACT

Aflatoxin and fumonisin contamination was assessed in different samples along the maize value chain in different territories of South Kivu province. Kabare and Ruzizi Plain were chosen as they represent two different agroecological areas where maize is mostly produced. Twelve districts and one town were selected across the province. The stakeholders were randomly selected, and 215 maize (139 maize grain and 76 maize flour) samples were taken for laboratory analysis. The Q + kit was used to determine the total aflatoxins and fumonisins. Three categories of maize were examined: freshly harvested dry maize, stored maize (maize stored for 3 months ±1.5 month) and market maize. Aflatoxin was found in 100% of the maize samples with the least content of 0.3 µg/kg detected in freshly harvested dry maize with mean 3.2+0.3 and levels ranging from 0.3 to 18.5 µg/kg. The average level of aflatoxin in stored grain samples was 97.9±182 µg/kg within a range of 1.16 to 841.5 µg/kg, and the mean level of aflatoxin in stored flour was 148.9±164.5 µg/kg with levels ranging from 2.05 to 905.1 µg/kg. The mean level of aflatoxin maize collected from the market was 95.1 ±164 µg/kg, with levels ranging from 1 to 823.2 µg/kg. Almost all the maize flour collected from the three areas had a high contamination level that exceeded the maximum tolerable limit of 10 µg/kg. Fumonisin was detected in all samples. However, the levels of fumonisin do not follow a specific trend with the duration of storage. The freshly harvested dry maize concentration was 2.4±5.1 µg/g, with levels ranging from 0.03 to 20.9µg/g. About 37% of freshly harvested maize samples contaminated by fumonisin exceeded the maximum tolerable limit of 4 µg/kg. There was a difference between total fumonisin in grain and flour; the average level of fumonisin in stored maize grain was 1.4±0.9 µg/g with levels ranging from 0.18- 4.7 µg/g while in flour, the level was 2.1±1.3 µg/g with levels ranging from 0.3-4.5 µg/g. Almost all the maize samples collected from the three areas had a degree of contamination that did not exceed the maximum tolerable limit of 4 µg/g. These results indicate that the two mycotoxin levels, particularly aflatoxin, were high in the different samples collected at specific nodes. Therefore, preventing mycotoxins accumulation in maize by post-harvest prevention of contamination and growth of toxigenic moulds by promoting proper grain drying and storage should be encouraged among the actors of the maize value chain.

Key words: Aflatoxins, Fumonisins, Food value chain, Maize, South Kivu

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INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop used as an energy source by humans and animals in different parts of the world. In Africa, maize is a primary cereal grain [1]. Maize is the main dietary staple of the Congolese; South Kivu (234628.2 tonnes/year) and Kwilu (243046.5 tonnes/year) are among the main maize production zones in the Democratic Republic of Congo (DRC) [2,3]. In South Kivu, two-thirds of households consume maize flour daily. The maize value chain in South Kivu has encountered many challenges, and the most prevailing one is contamination by fungi that produce toxin due to the atmospheric rainfall (800-1000 mm) and high-temperature conditions (20°C-26°C), which are key factors in the development of the fungi, and the production of the mycotoxin. Contamination can start in the field, worsen during harvesting, handling, drying and processing. Also, the development of toxins can continue during the storage of maize and its derived products [4]. Additionally, maize is mainly produced in different rural areas before transportation throughout the province; the transportation of maize over long distances may create potential additional opportunities for exposure, contamination and growth of mycotoxigenic moulds.

The two main mycotoxins associated with maize in the tropics, especially in Africa, are aflatoxins and fumonisins [5]. Fungus *Aspergillus* spp. mainly produce aflatoxins in maize, but *A. flavus* and *A. parasiticus* are the common species, whereas *Fusarium verticillioides* is known to produce fumonisin [6-7]. Once formed, mycotoxins are not easy to remove or decompose from foodstuff and animal feed [8]. Therefore, when the mycotoxin contamination in a maize consignment is not controlled, the consignment ends up being destroyed or rejected, leading to a serious economic loss [9]. Considering health problems, the correlation between the level of exposure to aflatoxin and the incidence of hepatocellular carcinoma (HCC) is direct [10]. Research has shown that if there is a reduction in aflatoxin contamination to a level below the maximum tolerable limit in Asia and sub-Saharan Africa between 72,800 and 98,800 new HCC cases could be prevented [11]. The interaction between aflatoxin exposure and chronic hepatitis B virus infection in HCC formation is proven [12]. A survey was conducted, and the results showed that the chronic Hepatitis B infection is high in South Kivu, with 4.8% [13]; which means that individuals infected with Hepatitis B virus who live in South Kivu consumption of aflatoxins at a high level are more likely to develop the HCC. Fumonisin is produced by several *Fusarium* species and cause a potential threat to animal and human health throughout naturally infected grain used for feed and food. Fumonisin may modify cell morphology, cell-cell interactions, the behaviour of cell surface proteins, protein kinase activity, and cell growth and viability [14], and may induce apoptosis in animal and plant cells [15,16]. The knowledge to

date is that fumonisin and aflatoxins levels are not regulated in food and feed products in DRC.

The presence of mycotoxins in food consumed in most African countries is often undetected due to limited human and infrastructural capacity to determine mycotoxin presence and toxicity. In addition, maize is largely cultivated by small-scale farmers using low-cost technologies and non-improved maize varieties that are susceptible, and the regulation of control of exposure to mycotoxigenic fungi are non-existent. Likewise, many African countries lag behind industrialized countries in pre-and post-harvest management practices to minimize the consumption of mycotoxin-contaminated food [17]. Lack of sufficient food, especially in rural areas, contributes to food consumption with mould presence, even if the growth of mould has modified the sensory quality of the food. The drawback of consuming mycotoxin-contaminated food are well known [18]. Fumonisins specifically are known to cause oesophagal cancer and suppress immune function [19].

Despite these health risks, no study has assessed the prevalence and incidence of mycotoxins in foods along supply chains in South Kivu. Most research on mycotoxins analyzes the prevalence and incidence at specific points (for example, at farm level, food storage or marketing). In addition, very few studies have examined how the commodity supply chain might affect mycotoxin prevalence. However, the commodity structure is essential as the maize supply chain in DRC is mostly a long and fragmented supply chain with many actors engaged [20]. Therefore, the objective of this study was to assess the occurrence of aflatoxin and fumonisin in the supply chain of South Kivu maize for human consumption in two different agroecological zones.

MATERIALS AND METHODS

Study area

Two different agroecological zones and one town were considered. The study area is South Kivu province in Eastern DRC (Fig. 1). South Kivu province covers over 65,000 square kilometres with geographic coordinates 3°1'S 28° 16'E. This area was selected because it is a major maize producing area for human consumption, poultry and aquaculture production [21]. Ruzizi Plain and Kabare territories were chosen to represent the two different agroecological zones in South Kivu. These areas differ in rainfall, altitude and average temperature. Kabare is well known as a high-altitude area, while the Ruzizi plain represents the low altitude. Although the study area is not nationally representative, it covers the main maize consumption and production area in Eastern DRC.

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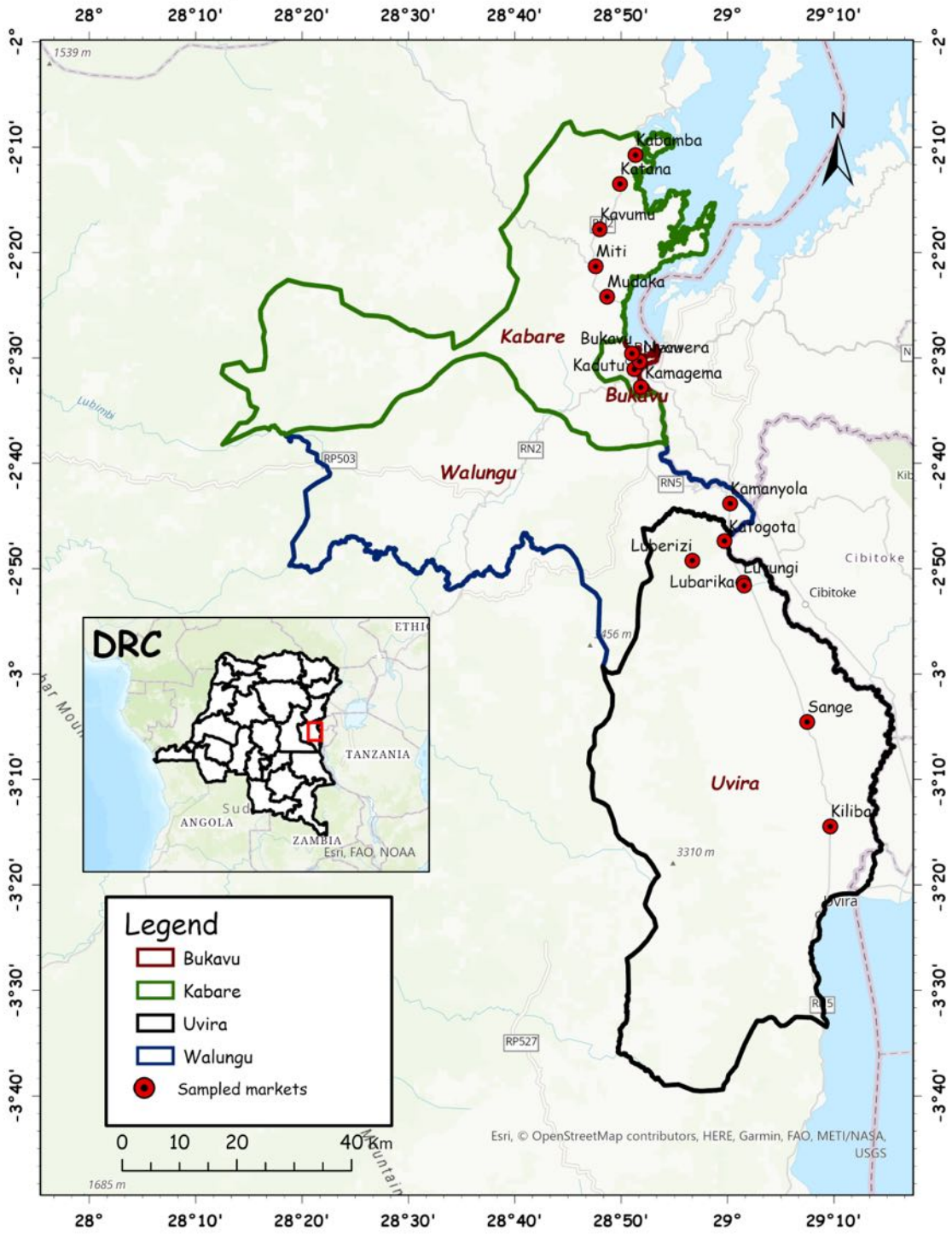

Figure 1: **Map of the study area, South Kivu Province**

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Sample collections

Samples collection focused on different stakeholders along the maize value chain; this included farmers (freshly harvested dry maize), stored and retailed maize. Sampling was done between May and September 2020 in Kabare, Ruzizi Plain, and Bukavu town. The representative data set was collected from a list of villages in each district. The list was obtained from Provincial Inspection for Agriculture and Livestock (IPAPEL). Five villages were selected based on maize consumption and production area in Kabare districts (Kabamba, Miti, Mudaka, Kavumu and Irhambi-Katana) and seven villages in Uvira district (Kamanyola, Luvungi, Katogota, Sange Luberizi, Kiliba, and Lubarika). In Bukavu town, three municipalities were selected, including Bagira, Kadutu and Ibanda. Different actors were chosen to be interviewed in each village using the probability proportional to size (PPS) sampling approach [22]. A total of 215 (freshly harvested dry maize, stored maize, and sold maize) samples were collected from farmers, stores and vendors using a random sampling approach simple random sampling; the samples were collected during visits for interview. Two samples were collected from each individuals stakeholders , depending on available samples.

Sample collection from farmers

Farmers with a field of 2500 acres±1000 were chosen for maize sampling. In each territory, freshly harvested maize cobs were collected from 32 randomly selected farms. The maize cobs were placed in a well-sealed polyethene bag and labelled. The maize grain on the cob was dehulled using an electric dehuller, mixed by hand, and 500-g grain was taken from each batch as a separate sample. The moisture content was determined by using the drying oven method [23]. This method implies weighing the sample before and after drying and determining the difference. During transportation, the samples were stored in well-sealed and labelled polyethene bag and then kept in a cool box. Then after reaching the laboratory, we took the moisture content and the samples were stored in a refrigerator at 4°C before analysis.

Sample collection from stores

The samples collected from different stores were kept in a sealed polyethene bag. Seventy-six samples, both flour (38) and grains (38), were collected from stores. Five hundred grams of each maize grain sample were ground separately using a laboratory blender (model 37BL85; Dynamics Corporation of America, USA). Sub-samples of 250 g were taken from the batches and placed in a tightly sealed and labelled polyethene bag for mycotoxin analysis. The samples were stored in the refrigerator at 4°C before analysis.

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Sample collection from the markets

Fourteen major maize wholesale markets in South Kivu province were selected to collect maize (37) and flour samples (38). Four wholesale markets were located in an urban area (Kadutu, Mashinji, Kamagema and Nyawera market), while 10 markets were located in a rural area (Miti, Mudaka, Kavumu, Katana and Kabamba in Kabare and Kamanyola, Kiliba, Luvungi, Luberizi and Sange in Uvira).

Samples of 500 g of maize grain or maize flour were bought from vendors. The maize grains were ground with a grinder, and 250 g sub-samples were taken from the batches and placed in tightly sealed and labelled polythene bags for mycotoxin analysis. The samples were stored at 4°C before analysis.

Sample preparation and mycotoxin extraction

For each grain sample, 250 g were ground to a fine powder using a laboratory blender. The analysis of total aflatoxin and total fumonisin of the maize samples was quantified using the manufacturer's instructions provided with the Reveal Q+ kits (Neogen®Corporation, Lansing, MI, USA). About 10 g of the mill sample was incorporated into 50 ml of 65% (v/v) ethanol in 100 ml. The obtained suspension was shaken (model HS 501 D Shaker; IKA, Germany) at 200 rpm for 3 min to extract the mycotoxins. The mixture was filtered using filter paper (Whatman No. 1, WHAT-MAN International Ltd, Mad Stone, England). For aflatoxin analysis, 500 µl of diluent was added into a well-labelled red dilution cup followed by 100 µl of sample filtrate and then mixed by pipetting up and down 5 times. The analysis of fumonisin was performed by adding 400 µl of diluent into a small cup followed by the addition of 200 µl of the sample extracted and then thoroughly mixed as said previously for aflatoxin. One hundred microliters (100 µl) of the diluted sample extract were transferred into the cartridge with a Reveal Q plus test strip. Results were obtained within 6 minutes for each sample. Aflatoxin concentration was quantified in µg/kg while fumonisin concentration was quantified in µg/g. Grain and flour samples were analyzed in duplicate.

Statistical analyses

Data processing and analysis were computed by using Excel and R software. Before analysis, the data were verified, compiled, coded and summarized. Then, the average and standard deviations for each area were then calculated using R software and Kruskal–Wallis non-parametric test to compare the means and distributions of aflatoxin and fumonisins among the samples collected. All tests were performed at 0.05 significance level.

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RESULTS AND DISCUSSION

Humidity, fumonisin and aflatoxin content in freshly harvested maize grain.
The humidity for freshly harvested maize samples was 19.2±0.8%. The total maize samples had detectable concentrations of aflatoxin and fumonisin. Maize from Ruzizi plain had a high level of fumonisin with 5.5±5.6 µg/g.

Maize harvested from the two territories sampled in the South Kivu province had an average aflatoxin content below 3 µg/kg. About 10% of the samples had an aflatoxin level that exceeded 10 µg/kg.

No significant difference was found in aflatoxin contaminations between the two locations, however there was a difference in fumonisin contamination between the two location (Table 1).

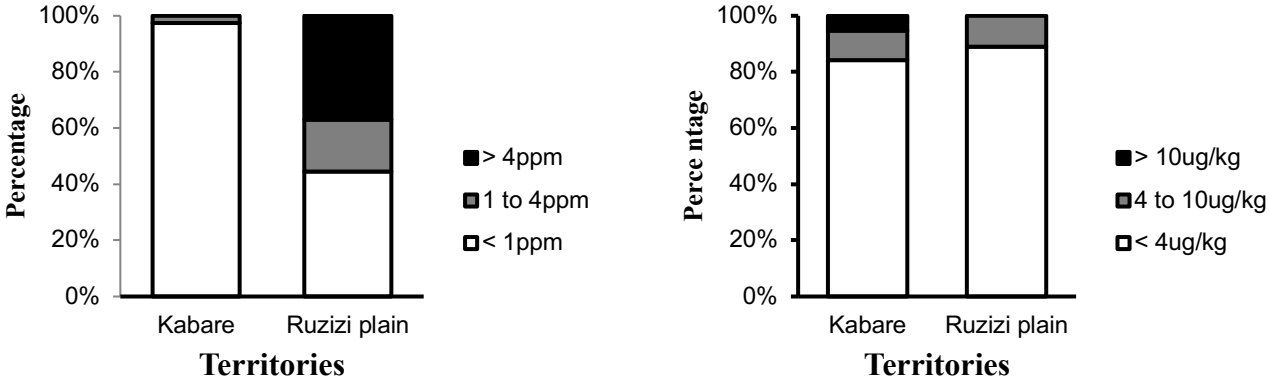

Figure 2: The proportion of samples at each concentration of fumonisin (a) and aflatoxin (b) in freshly harvested dry maize grain samples

The total maize samples had detectable concentrations of aflatoxin and fumonisin. Only about 37% of freshly harvested maize samples exceeded the maximum tolerable limit of 4 µg/kg of fumonisin (Fig. 2a). Maize samples harvested from farmers in the Ruzizi Plain had significantly higher ($P<0.05$) fumonisin concentrations than Kabare. For aflatoxin contamination, about 5% of samples collected from Kabare had high concentrations (Fig. 2b).

Thirsty-seven percent samples of freshly harvested maize from Ruzizi Plain contained detectable fumonisin concentrations (>4 µg/g). The high contamination observed in Ruzizi plain may probably be due to the attack of some fall armyworm *Spodoptera frugipeda* [24]. According to Miller [25], Fusarium grain rot (*F. verticillioides* and *F.*

proliferatum) is higher in hot environments and dry climates. In such environments, insect damage is well known as an essential factor. Additionally, the hot and dry weather conditions prevailing in Ruzizi Plain could favour *Fusarium* spp. Weather conditions influence the contamination of maïze, especially for aflatoxin and fumonisin. But *Fusarium* spp., the fumonisin producing fungus, is present under a large range of climatic conditions. The development of grain is crucial; heat stress during this period, especially night temperatures above 20ºC, is an important factor for mycotoxin contamination [26]. The optimal environment for *Fusarium* species that cause ear rot in maize tends to be warm and dry [27].

Fusarium spp. can produce fumonisin on maize kernels at different stages of reproductive development, even if the amounts produced differ significantly. Fumonisin production is influenced by substrate composition humidity. Most changes in kernel composition occur during maturation. These modifications may represent a developmental transition in signalling metabolites within the developing kernel that could also play a role in regulating fumonisin synthesis [28].

Drought and high temperatures during grain filling are factors that trigger aflatoxin production by *Aspergillus* spp. Nitrogen deficiency, excessive plant population, poor root development and insect damage to grains can also induce aflatoxin production in the field. When weather conditions are favourable for fungal development, aflatoxins can be produced at any stage of production and processing [29].

Freshly harvested maize can be exposed to a wide range of contamination inducing factors such as high temperatures, humidity, and other factors such as storage facilities and packaging, which can trigger re-contamination [30].

Fumonisin and aflatoxin content in stored maize grain and flour

All stored maize samples contained detectable concentrations of aflatoxin and fumonisin.

For the fumonisin, samples collected from Ruzizi Plain had the highest fumonisin concentration (Table 2). The overall mean of fumonisin of 1.4±0.9 µg/g was observed in maize grain, while 2.1±1.3µg/g was found in flour. As opposed to aflatoxin, almost all samples in storage had non-detectable concentration of fumonisin. The overall maximum concentration of aflatoxin in stored maize was 97.9±182 µg/kg with levels ranging from 1.16 to 841.5 µg/kg for maize and mean of 148.9±164.5 µg/kg with levels ranging from 2.05 to 905.1 µg/kg for flour. The high value for aflatoxin contamination was found in samples collected in Bukavu town (Table 2). There were significant differences ($p<0.05$) in aflatoxin contamination between flour and grain.

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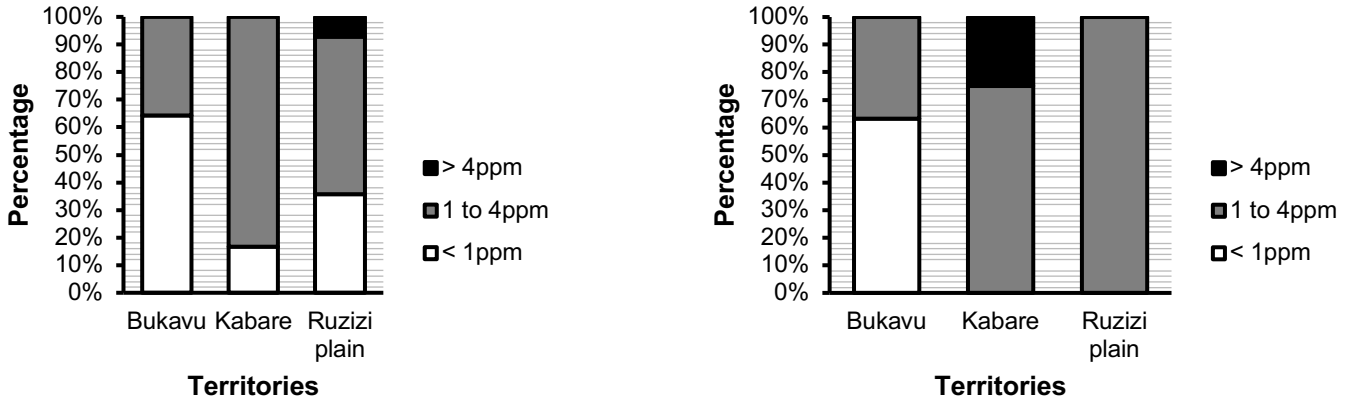
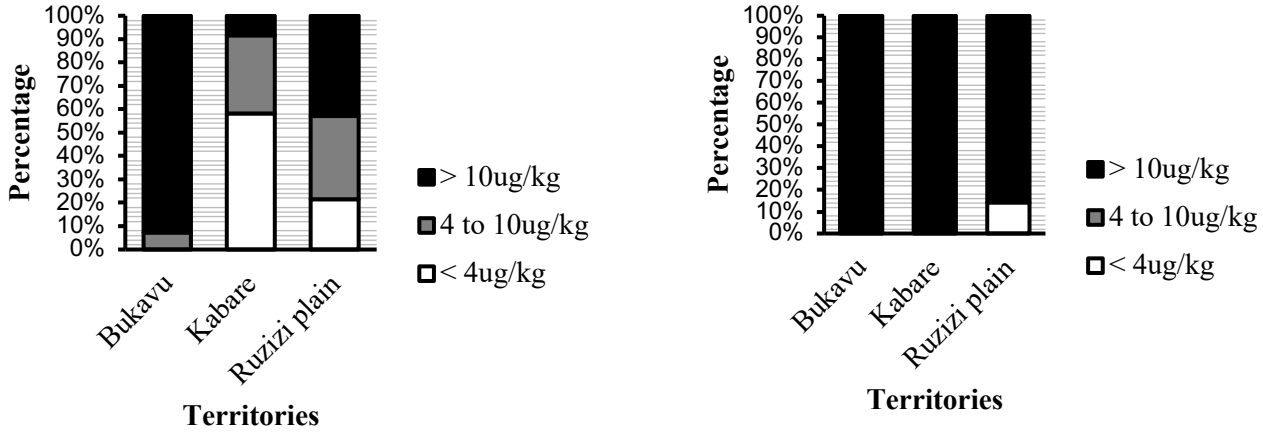


(a) **(b)**

Figure 3: The proportion of samples at each concentration of fumonisin in grain (a) and flour (b) from stored maize

About 9% of grain samples from Ruzizi Plain had fumonisin levels >4 mg/kg (Fig. 3a), while 22% for Kabare flour had the levels >4 mg/kg (Fig. 3b).

About 95% of grain samples from Bukavu had aflatoxin levels >10 µg/kg, while 100% of Bukavu flour had > 10 µg/kg (Fig.4a, 4b). Almost all the flour samples from the three areas had a high level of >10 µg/kg (Fig.4).



(a) **(b)**

Figure 4: The proportion of samples at each concentration of aflatoxin in grain (a) and flour (b) from stored

Samples collected from stores were taken from sacks of maize found in storage facilities, and the differences in contamination indicate the differences in handling and long-term storage practices (4 month ±1.5). For example, in a study conducted in Senegal, the improved bags controlled insect infestation and mycotoxins levels without using chemicals [31], while the storage length was associated with high aflatoxins contamination in Benin [32].

The fumonisin content does not follow any particular trend with the length of storage time. For the stored samples, the fumonisin contamination range from 0.18- 4.7µg/g, while for the market samples, it ranged from 0.02-7.6µg/g. Comparative results were also reported in Malawi with total fumonisins ranging from 0.1-4 µg/g [5]. Currently, there are no regulatory provisions regarding fumonisins in DRC, and, as a result, maximum permissible levels have not yet been set. In the meantime, for food, a maximum permissible limit for fumonisins of 4 mg/kg had been set by Codex Alimentarius. This maximum fumonisin concentration in maize was higher than the 6.54 mg/kg reported by [33] in Brazil; 2.4 mg/kg reported in Benin [34].

These results corroborate previous studies, which show that aflatoxin content increases with the length of storage in hot and humid countries, as the combination of heat and humidity favour the growth of *Aspergillus* fungi, which produce aflatoxins [35]. The results obtained compare very well with others [36], which showed that aflatoxin contamination in the DRC is real. Studies done in West DRC reported that aflatoxin contamination in Kinshasa is present throughout the maize value chain, with a considerable increase, up to 500-fold at the city store compared to the pre-harvest and haverst samples [37]. Another study done in Benin reported that higher aflatoxins levels were associated with a short storage period of 3–5 months [32], but on the other hand, an increase in aflatoxin levels in all storage systems throughout the storage period (8 months) in Benin [34].

A higher incidence of aflatoxins contamination was observed in maize stored for 6 months than in the freshly harvested maize at 0 months of storage in Benin[31]. Aflatoxin contamination was facilitated by long-term storage under unhygienic and non-ventilated conditions in Benin and Togo[38]. Thus, to reduce consumer exposure to aflatoxins, there is a need to focus on interventions targeting all players in the value chain. Mitigating contamination during maize production in the field does not guarantee product safety for the final consumer.

Fumonisin and aflatoxin content in market maize

All grain and flour samples from the market contained detectable concentrations of aflatoxin and fumonisin. The maximum concentration of fumonisin was 7.650 µg/g in

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grain and 5.150 µg/g in flour while aflatoxin from market samples were 823.2 µg/kg for maize and 1035.4 µg/kg for flour.

This high concentration of aflatoxin contamination in both grains and flour was found from samples collected from Bukavu Town (Table 3). On average, total aflatoxins in Bukavu samples exceeded the European regulatory limits for aflatoxins of 4 µg/kg.

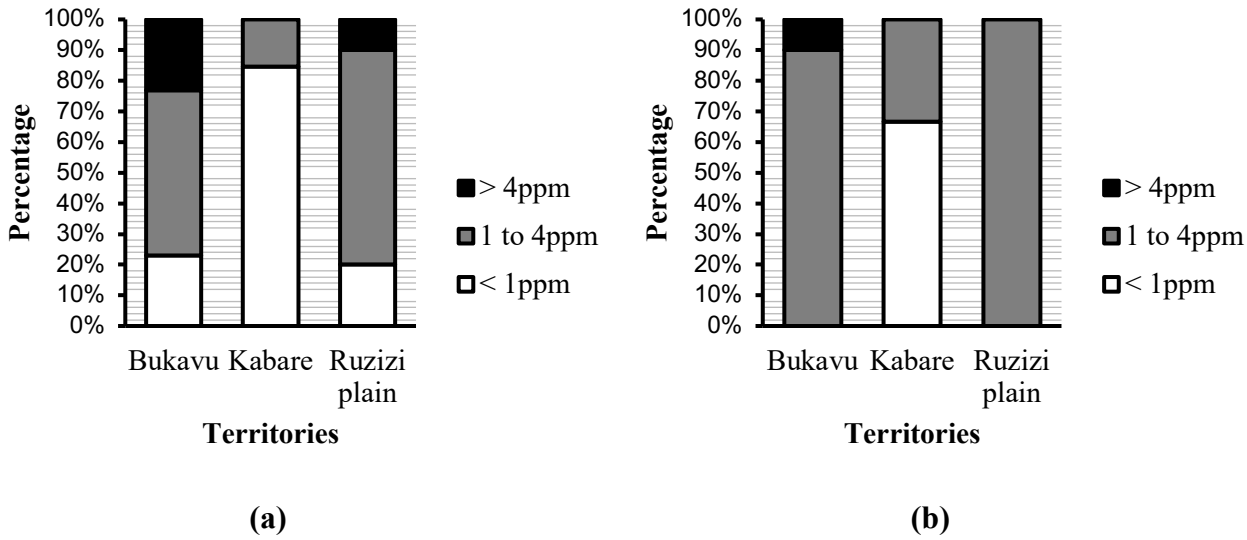

Figure 5: Percent of samples at each concentration of fumonisin from grain (a) and flour (b) collected from the market

From the result in Fig. 5a, it is noticed that 25% of grain from Bukavu had a value exceeding 4 µg/g. When the grain and flour results are compared, we realized that 10% of the flour from Bukavu had a level of fumonisin beyond the maximum limit set by the European Union (Fig. 5b). Results showed differences ($p<0.05$) in aflatoxin contamination between grains and flour among the territories ($p \leq 0.05$).

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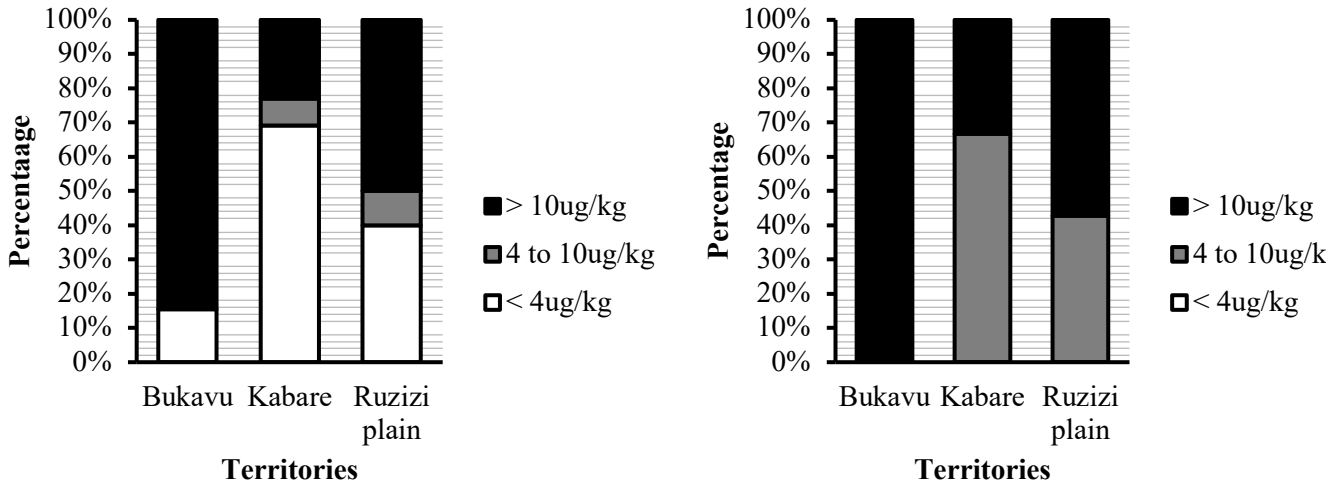

(a) **(b)**

Figure 6: Percent of samples at each concentration of aflatoxin from grain (a) and flour (b) collected from the market

About 92% and 100% of grain and flour, respectively (Fig. 6a, 6b) sold at Bukavu market were contaminated. There were significant differences ($p<0.05$) in aflatoxin contamination between grains and flour among the territories ($p \leq 0.05$).

Based on the product's origin, the results in Table 4 show maize grains and flour samples collected from the market originate in Kabare, Kalehe, Katanga, North Kivu, and the Ruzizi Plain. Most of these samples were contaminated by both forms of mycotoxin. Fumonisin-positive samples from maize ranged from 0.02-7.6 ug/g with the mean of 1.5±1.6, with a high value in grains from the Ruzizi Plain (2.1± 1.8) and the range of 0.1-7.6 Regarding aflatoxin contamination, the values vary from 1.07 to 823.2 ug/kg, the high value registered from samples collected in the Ruzizi plain with 823.2 ug/kg. In addition, high levels of aflatoxin were detected in maize flour from North Kivu with 1035.4 ug/kg.

The data from laboratory analysis (Fig. 7) show that total fumonisin in grain and flour distributions across different regions of origin of the product ranged from 0.02 for Kabare to 7.6 µg/g for North-Kivu, which had a 56% positive samples that were above the European limit.

About 100% of the grain and maize flour from Kalehe, Katanga, North-Kivu, and Ruzizi Plain were not fit for human consumption as aflatoxin contamination was

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beyond the maximum tolerable limit of 10 µg/kg. There were significant differences in aflatoxin contamination between grains and flour among the territories ($p \leq 0.05$).

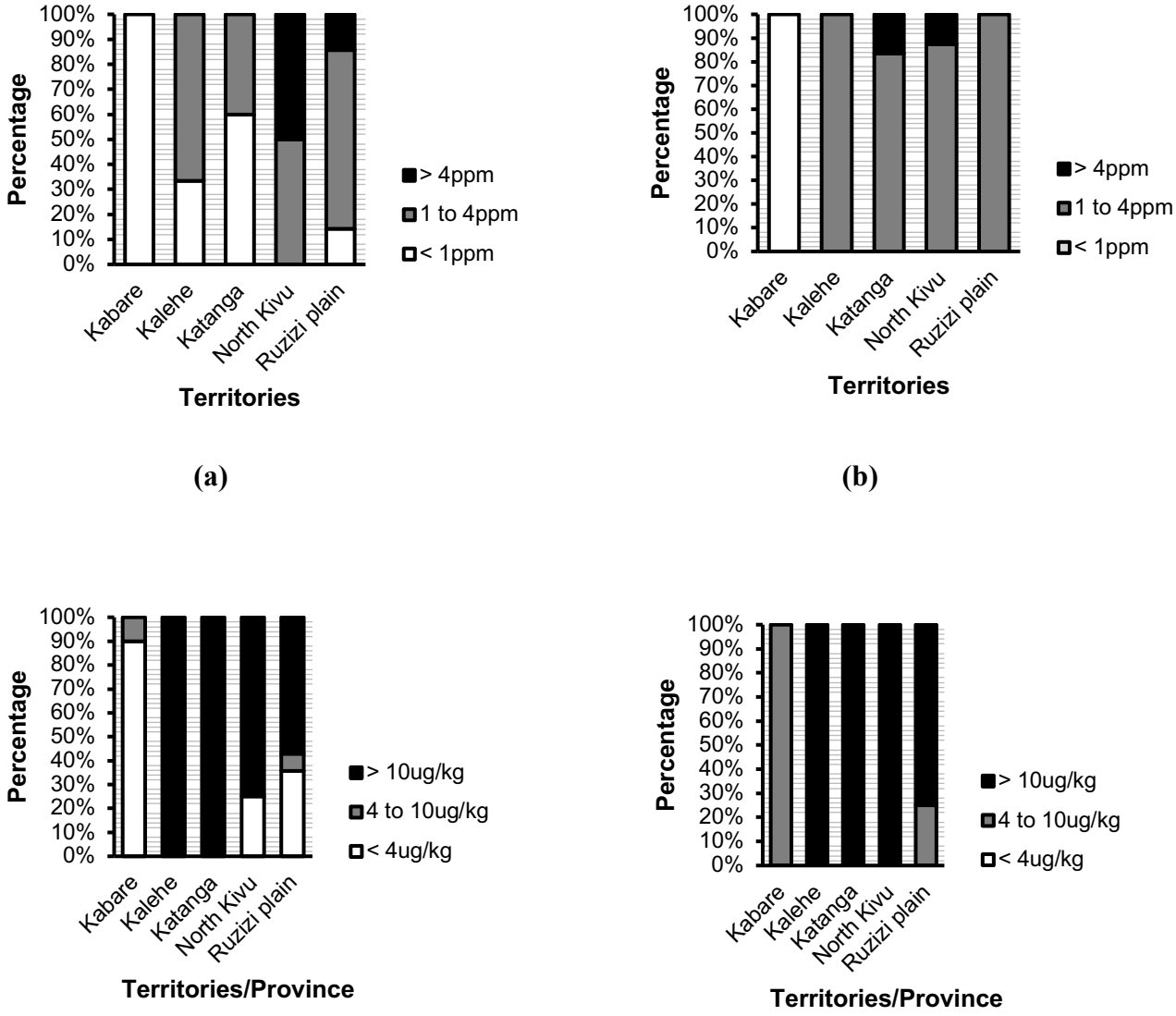

Figure 7: Percent of samples collected from the market at each concentration of fumonisin from grain (a) and flour (b) and of aflatoxin grain (c) and flour (d) according to their origin

There is limited information on the occurrence and the level of human exposure to mycotoxins except for aflatoxin in the Democratic Republic of Congo. However, the prevalence and level of human exposure to aflatoxins has been examined globally and has shown that about 4.5 billion people living in the developing world are exposed to large amounts of uncontrolled toxins [39]. These results mean that people living in

affected areas are exposed to some bad effects of mycotoxin ingestion. In addition, fumonisin has been detected in almost all the samples collected, indicating a likelihood of other fusarium mycotoxins [40]. Studies indicated that aflatoxins and fumonisins might remain a food safety issue. Therefore, any technology or methods used to reduce these contaminants should be accompanied by measures to prevent exposure to fungi throughout the value chain (fields, stores, markets and homes).

CONCLUSION

Based on the findings of this study, it was observed that freshly harvested, stored, and marketed samples were contaminated by aflatoxin and fumonisin to various extents. The mycotoxin contamination of maize can occur at any node on the value chain. However, the high contamination of aflatoxin can be found in stored and market maize products. Almost all the maize samples from Bukavu Town, had aflatoxin contamination beyond the acceptable levels set by the European Union and Codex Alimentarius. Consumption of mycotoxin-contaminated maize products increased the risk of aflatoxin exposure among people living in an urban area. There is, therefore, a need to put in place strategies for reducing mycotoxin contamination along the maize value chain, such as conducting training for all stakeholders involved on food handling, processing and storage techniques in order to reduce mould growth and mycotoxin contamination in maize. In addition, research and policy interventions that support the development and dissemination of improved maize varieties resistant to fungal infection and mycotoxin control on maize fields are important, unless there is a possibility of changing food preparation practices by using the nixtamilization process.

Author Contribution

Conceptualization, M.R.E and P.U Investigation and Formal analysis, YM and JA. Supervision, W.O.O, S.I, J.I and PU., Writing-Review & Editing of the manuscript, all authors.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Table 1: Incidence of mycotoxin contamination in freshly harvested dry maize grain samples

	Moisture (%)		Fumonisin (µg/g)		Aflatoxin (µg/kg)	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**
Kabare	19.1±0.8	17.8-21	0.25±0.2b	0.03-1.6	2.7±4	0.3-18.5
Ruzizi Plain	19.5±0.9	18-21	5.5±5.6a	0.2-20.9	2.3±1.2	0.5-5.2
Total	19.2±0.8	17.8-21	2.4±5.1	0.03-20.9	3.2±0.3	0.3-18.5

Means with the same letter are not significantly different from each other (P>0.05)

Table 2: Aflatoxin and fumonisin contamination in stored maize grain and flour

	Fumonisin (µg/g)		Aflatoxin (µg/kg)	
Stored	**Average**	**Range**	**Average**	**Range**
Grain	**1.4±0.9**	**0.18- 4.7**	**97.9±182**	**1.16-841.5**
Bukavu	1.1±0.8a	0.1-2.8	243.9±246a	9.3-841.5
Kabare	1.8±0.7b	0.7-2.9	3.8±2.3b	1.5-10.15
Ruzizi plain	1.5±1.1ab	0.2-4.7	32.5±55.4b	1.1-169.1
Flour	**2.1±1.3**	**0.3-4.5**	**148.9±164.5**	**2.05-905.1**
Bukavu	1.3±1.1a	0.3-3.5	193.9±206.5a	70.5-905.1
Kabare	2.6±1.2b	1.5-4.5	129.4±27.5a	81.7-172.7
Ruzizi plain	3.2±0.7b	1.5-3.9	49±38.7b	2-87.2

Means with the same letter are not significantly different from each other (P>0.05)

Table 3: Aflatoxin and fumonisin contamination in marketed maize grain and flour

	Fumonisin		Aflatoxin	
Market/Product	**Average**	**Range**	**Average**	**Range**
Grain	**1.5±1.6**	**0.02-7.6**	**95.1 ±164**	**1-823.2**
Bukavu	2.2±1.6a	0.2-5.2	205±230.2a	2.6-823.2
Kabare	0.4±0.5b	0.02-1.6	25.6±44.2b	1-116.3
Ruzizi plain	2±2.1b	0.19-7.6	42.6±62.1b	2.4-187
Flour	**2.3±1.1**	**0.05-5.1**	**415.8±377.4**	**4.1-1035.4**
Bukavu	2.8±0.8	1.5-5.150	610.1±312.8	96.05-1035.4
Kabare	0.4±0.5	0.05-1.155	35.6±52.7	4.6-96.5
Ruzizi plain	1.7±0.7	1.030-2.850	23.8±19.3	4.1-52

Means with the same letter are not significantly different from each other (P>0.05)

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Table 4: Aflatoxin and fumonisin contamination in marketed maize grain and flour by the product's origin

	Fumonisin		Aflatoxin	
Origin	**Average (µg/g)**	**Range**	**Average(µg/kg)**	**Range**
Maize	**1.5± 1.6**	**0.02-7.6**	**95.1± 164**	**1- 823.2**
Kabare	0.1± 0.1a	0.02-0.5	2.5± 1.1a	1.0-4
Kalehe	1.2± 0.3ab	0.9-1.6	102.8± 12.8b	90.8-116.3
Katana	1.3± 1.2ab	0.2-3.2	197± 190.7b	67.4-520
North Kivu	3.0± 2.1b	1.1-5.2	126.9±116.6b	2.6-237.7
Ruzizi plain	2.1± 1.8b	0.1-7.6	114.1±216.2b	2.4-823.2
Flour	**2.3±1.3**	**0.05-5.1**	**415.8±377.4**	**4.1-1035.4**
Kabare	0.1± 0.1a	0.05-0.2	5.2± 0.8ab	4.6-5.8
Kalehe	1.4± 0.4ab	1.1-1.8	549.4±640.5ab	96.5-1002.4
Katana	3± 0.6b	2.5-4.2	588.8±303.5ab	178.2-1031
North Kivu	3.1± 0.9b	2.2-5.1	613.4± 338.3a	96-1035.4
Ruzizi plain	2.1± 0.8b	1.0-3.9	243.8± 335.6b	4.1-1009.5

Means with the same letter are not significantly different from each other (P>0.05)

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