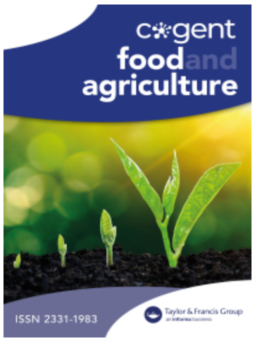

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Nutritional profile and food safety of raw and value-added food products of sorghum and millets in sub–Saharan Africa and South Asia

Tafadzwa J. Musidzaramba[a], Brighton M. Mvumi[b], Loveness K. Nyanga[c], Irene Kadzere[d], Milka Kiboi[d], Makhosi Mahlangu[e], Gracious Chingoma[b], Mgciniwethu Mazula[e] and Lesley Macheka[a]

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ABSTRACT

This study reviewed the nutritional composition and safety of sorghum, pearl, and finger millet in sub-Saharan Africa and South Asia, focusing on raw and value-added products. Using PRISMA guidelines, 35 peer-reviewed articles published between 2000 and 2023 were analysed. Data were extracted from Scopus, PubMed, and Google Scholar. Most studies (51.4%) were conducted between 2016 and 2020, with 53.3% focusing on macronutrients and 46.7% on micronutrients. Sorghum and millets were found to be rich in protein content ranging from 7.3% to 12.1% and carbohydrates exceeding 70%. Sorghum recorded the highest zinc levels (24.23 mg/kg), while finger millet had highest calcium content (344 mg/kg). Iron levels were significant in both grains, reaching 61.41 mg/kg in sorghum. Aflatoxin contamination ranged from 0.021 to 20.33 mg/kg, with microbial hazards reported in 83.3% of the studies. Fermentation was the most common processing method used to develop value-added products like porridge, beverages, and flour. Most of the studies on value-added products were from Zimbabwe (50%) and followed by India at 21.4%. This review highlights the potential of sorghum and millet to enhance nutrition and food security in drought-prone areas. However, research gaps remain on chemical and allergen hazards within the value chain, pointing to need for further studies.

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1. Introduction

Climate change, including abrupt rainfall patterns, changes in maximum and minimum average annual temperature, and prolonged dry spells and droughts, is increasing globally (IPCC, 2023). Climate change is one of the major challenges facing tropical regions including sub-Saharan Africa and South Asia, and is already having adverse impacts on food and nutrition security, particularly in rural areas where the majority of the population lives and relies mainly on agriculture-based livelihoods (Apraku et al., 2019; Chandra Manna et al., 2018). The impacts are more severe in the arid and semi-arid agroecozones, which are vast regions of the tropics, leading to declining crop productivity or total crop failure (Misra, 2014). The increased incidences of droughts have given rise to the need for alternative food crops, which may be suitable for semi-arid and drought-prone areas. Traditional grains, which in the context of our paper, are sorghum (*Sorghum bicolour* L. Moench) and millets (pearl millet, *Pennisetum glaucum* (L.) R. Br. and finger millet, *Eleusine coracana* L.), have been identified as drought tolerant and more ecologically compatible with semi–arid areas compared to maize (Dube et al., 2018). Therefore, there has been an increasing call for the production of traditional grains, instead of maize, to enhance food security against the background of climate change (Phiri et al., 2019).

Traditional grains have multiple uses within society, notably the important role of dietary diversification in enhancing food and nutrition security (Akinola et al.,

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2020). Sorghum and millets are important food sources for arid and semi-arid tropics, especially sub-Saharan Africa and the South Asia sub-continents, where there is also an increasing occurrence of malnutrition and non-communicable disease (Bhuiyan et al., 2024). Sorghum and millet grains are highly nutritious, containing high dietary fibre, protein, vitamins, essential minerals, and are rich in antioxidants (Hassan et al., 2021; Tanwar et al., 2023). Antioxidants have been linked to several health benefits, such as low glycemic index, improved digestion, better blood sugar control and reduced risk of heart disease (Dixit-Bajpai & Ravichandran, 2024).

In addition, traditional grains are excellent sources of carbohydrates, contain significant amounts of protein, B vitamins (thiamine, riboflavin, niacin), and antioxidants (Akplo et al., 2023; Maurya et al., 2023). As such, the consumption of sorghum and millets has been associated with several health benefits such as improved: cardiovascular health, diabetes management, digestive health, and weight management (Tripathi et al., 2023). Sorghum and millet grains have a low glycemic index, which means they release glucose into the bloodstream slowly, helping regulate blood sugar levels (Kumar et al., 2018). According to Šmídová and Rysová (2022), sorghum and millets are naturally gluten-free, making them suitable alternatives for individuals with coeliac disease or gluten sensitivity. More so, the high fibre content of sorghum and millets supports digestive health and may reduce the risk of chronic diseases such as obesity, diabetes, and cardiovascular diseases (Tanwar et al., 2023). While traditional grains are known to be highly nutritious (Hassan et al., 2021), there is a need for more awareness creation for the general public to fully understand the nutritional content of these grains and how they can best be incorporated into diets and nutrition-related programs to improve overall human and livestock health. Sorghum and millets are considered climate-resilient crops due to their ability to withstand and adapt to various stressful environmental conditions (Hossain et al., 2022).

However, there is limited information on the nutritional profile, potential contaminants, microbiological risks, and storage practices specific to sorghum and millets (Akello et al., 2021). These grains are commonly grown by small-scale farmers who may have limited access to resources and knowledge on proper production, handling, storage, and processing techniques. Consequently, there is a higher risk of contamination during the production, harvesting, transportation, and storage of traditional grains (Kebede et al., 2020). For instance, according to Adeyeye et al. (2022), sorghum and millets are mostly contaminated with several mycotoxins produced by diverse fungi across Africa. However, the specific levels of these contaminants in sorghum and millet are not extensively studied, leaving consumers largely unaware of the potential risks associated with these grains and their products. Furthermore, there is limited awareness and knowledge regarding the potential of traditional grains for developing value-added products. Many farmers and producers are not aware of the different types of value-added products such as flour, malt, and beverages that can be made from these grains. Inadequate infrastructure and technology for processing traditional grains into value-added products are additional challenges (Breslauer et al., 2023). This includes the lack of processing equipment, storage facilities, and transportation infrastructure.

With the increasing incidences and frequency of droughts, traditional grains are a good alternative to other cereal staple grains such as maize, mainly due to their drought tolerance and high nutritional value, especially minerals. Therefore, the objective of this review paper was to understand and have in-depth knowledge on the nutritional composition and food safety of traditional grains, particularly sorghum, and pearl - and finger millet. Moreover, the review was aimed at understanding the diversity, nutritional composition and food safety of the value-added products of these grains. Findings from this review paper may be used in designing sustainable and safe value chains for traditional grains and in new food product development. The focus of the literature review was on sub–Saharan Africa and South Asia, regions greatly affected by droughts and where the traditional grains of interest (sorghum, pearl and finger millet) are grown for food.

2. Data retrieval and analysis

A structured literature search was conducted to find published literature from sub-Saharan Africa and South Asia focusing on the objective of this review. The reporting of this systematic review was guided by the standards of the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) Statement. The systematic search was carried out using keywords: 'traditional grains', 'sorghum', 'pearl millet', 'climate resilient crops', 'nutrition analysis', 'food safety', 'aflatoxin', and 'value-added food products. The search was conducted from the following sites: Google Scholar, Scopus, Google, Web of Science, AGORA, and PUBMED.

The literature was selected from peer-reviewed articles published in journals and relevant book chapters. Literature published from known university online libraries, international bodies, recognised research institutions, and conference proceedings reports were also reviewed. The inclusion criteria comprised English scientific articles published between 1 January 2000 and 31 July 2023 with study or research in the geographical coverage of sub-Saharan Africa and South Asia only. In addition, only peer-reviewed scientific articles were considered in this review. The search gave an initial count of 683 papers. Screening for duplication resulted in 28 articles being removed. A quick screening by reading through the abstracts of the remaining 655 reduced the papers to 49 articles. The exclusion criteria included articles outside the period of interest (i.e. before 1 January 2000 to 31 July 2023), those written in languages other than English, articles on other cereals not sorghum, pearl millet or finger millet, articles that just mention 'millets' without specifying if the grain is pearl or finger millet, articles outside the regions of interest (sub-Saharan and South Asia), and articles not peer-reviewed. Further screening through reading for the full articles resulted in a final list of 35 articles. A summary of the inclusion and exclusion criteria is shown in the PRISMA 2020 flowchart diagram (Figure 1) and the PRISMA 2020 checklist is given in (Supplementary 1 File). The reported data were extracted from figures, tables, and text of the selected studies. After the selection of scientific papers, the relevant data was extracted from each included study and summarised in thematic tables and graphs.

3. Results and discussion

3.1. Characteristics and distribution of identified articles (studies)

Thirty-five (35) relevant scientific articles were identified as indicated in Figure 1. Of these 35, 65.7% were from studies conducted in sub–Saharan Africa and 34.2% were from studies done in South Asia. In addition, of the 35 identified articles 60% (21 articles) were on nutritional profile and food safety of raw (sorghum and millets) (Table 1) and 40% (14 articles) were on value-added products (Table 3). The results presented in Table 1 reveal that the oldest article on nutritional profiling and food safety of raw (sorghum and millet) grains was published in 2006 in South Asia (Rao et al., 2006) and in 2011 for sub-Saharan Africa (Matumba et al., 2011 and Chitindingu et al., 2011). Figure 2 indicates that the number of published articles on the traditional grains of interest increased from 2016 to 2020 as the number of scientific articles rose to 18. Of these 18 publications, 12 were from sub-Saharan Africa and six (6) from South Asia. For the period under review, Zimbabwe had the highest number of articles (6) in sub-Saharan Africa, followed by Ethiopia (2) and Nigeria (2). In South Asia, India had eight (8) articles and Nepal had one (1).

The high number of publications from sub-Saharan Africa over the last decade can be attributed to the increased frequency of adverse weather conditions, such as droughts, low and erratic rainfall, and increased temperature ranges (Branca & Perelli, 2020). Sorghum and millet are believed to be more ecologically compatible with semi–arid areas compared to maize because of their drought tolerance (Ngetich et al., 2022). Hence, it is based on their strong adaptive advantage to climate change and lower risk of crop failure compared to maize that there is increased research and promotion as a suitable crop for semi-arid regions in sub-Saharan Africa. In addition, traditional grains require little input during growth and with the increasing population and decreasing water supplies, they are crucial crops for future use as human food (Mukarumbwa & Mushunje, 2010). This could also be another reason for the increasing research interest in traditional grains. According to Ndlovu et al. (2020), improving the productivity of traditional grains is the key to food and nutrition security in the context of climate change and variability.

3.2. Nutritional profile of traditional grains

The nutritional composition of small grains, including sorghum and millet, revealed significant variability in both macro- and micronutrient content, reflecting their potential as staple foods with diverse health benefits. The results presented in Table 1 reveal that 53.3% of the articles were on macronutrients analysis of raw and value-added grains of traditional grains (sorghum and millets) while 46.7% of the studies focused on micronutrients.

3.2.1. Macronutrients

The results presented in Table 2 show sorghum to be rich in carbohydrates, with levels ranging from 70.7% to 74.52% (Kulamarva et al., 2009; Mohapatra et al., 2019), while its protein content ranged from 8.08% (Shegro et al., 2012) to 12.13% (Mohapatra et al., 2019). Millet, in particular finger millet, had lower protein levels (7.3%) but exhibited a higher crude fibre content of 3.6% (Regmi et al., 2023). Fat content

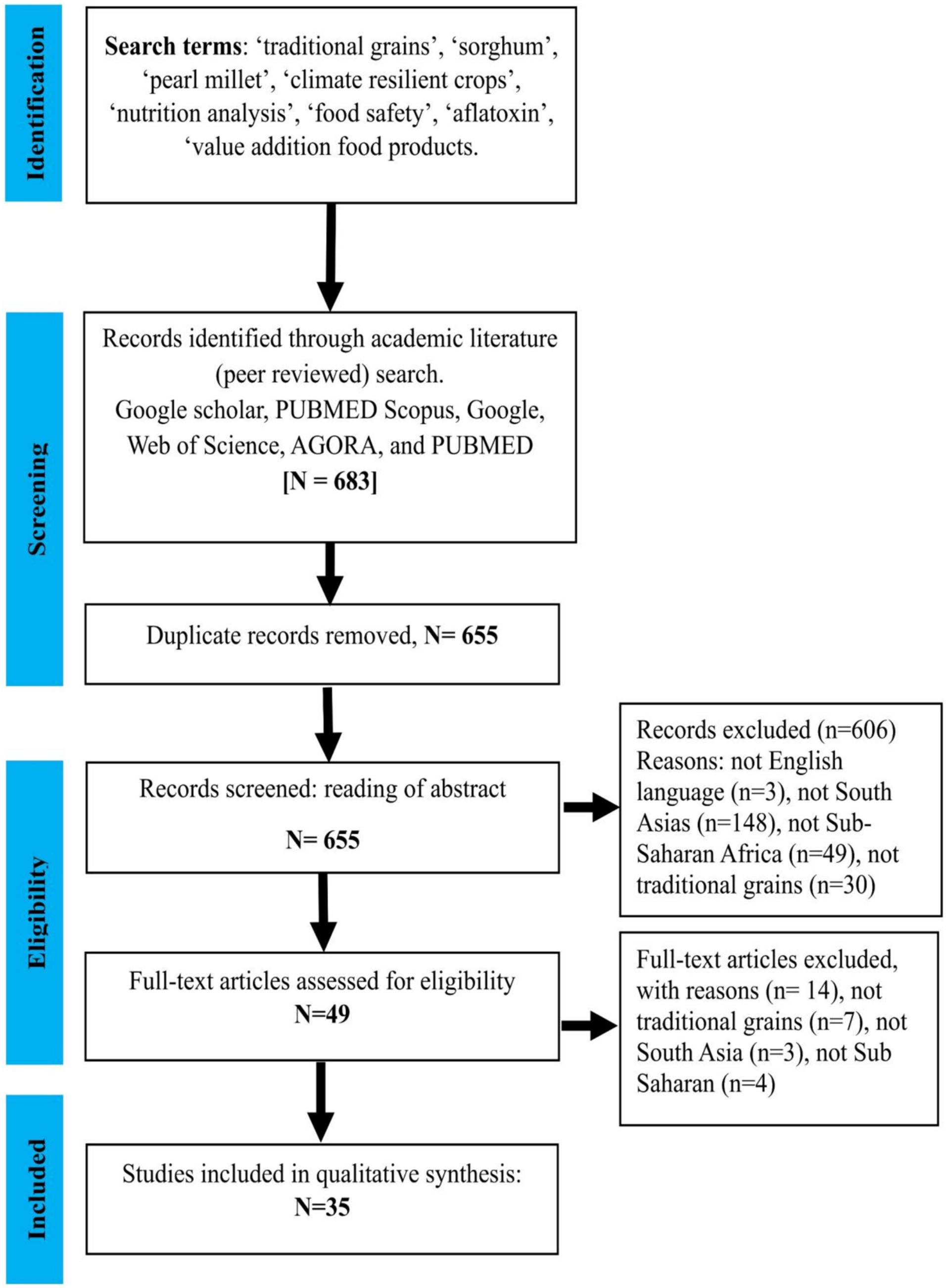

Figure 1. Steps used to identify relevant literature.

in sorghum ranged from 3.1% to 4.7% (Kulamarva et al., 2009; Mohapatra et al., 2019), indicating its contribution to dietary energy, while the ash content varied from 1.12% to 3.17% (Jimoh & Abdullahi, 2017; Mohapatra et al., 2019). The variability in the content of mineral elements may be associated with genetic aspects, geographical location, and soil fertility level (Zeffa et al., 2021).

3.2.2. Micronutrients

The results further reveal that traditional grains serve as excellent sources of micronutrients. Table 2 shows that sorghum had high levels of iron (61.41 mg/kg) and zinc (24.23 mg/kg) (Shegro et al., 2012), underscoring its potential to address micronutrient deficiencies, particularly in sub-Saharan Africa. However, sodium content in sorghum was modest at 22.97 mg/kg, while phosphorus was high at 2893.44 mg/kg (Shegro et al., 2012). Sorghum also demonstrated substantial calcium content, reaching 2500 mg/kg (Kulamarva et al., 2009), a characteristic that enhances its role in supporting bone health. In addition, Table 2 reveals finger millet as an excellent source of calcium (344 mg/kg), surpassing many other cereals,

Table 1. List of scientific studies on nutritional profiling and food safety of raw traditional grains (sorghum and millets) in sub-Saharan Africa and South Asia.

		Nutritional profile		Food safety hazards B = biological, C = chemical, P = physical and A = allergen			
Author	Grain type	Micro-nutrient	Macro-nutrient	B	C	P	A
Sub-Saharan Africa							
Ethiopia							
1. Shegro et al. (2012)	Sorghum	+	–	–	–	–	–
2. Ayelign and De Saeger (2020)	Sorghum	–	–	+	–	–	–
Malawi							
3. Matumba et al. (2011)	Sorghum	–	–	+	–	–	–
Namibia							
4. Kaela et al. (2023)	Sorghum, pearl millet	–	–	+	–	–	–
Nigeria							
5. Utono (2013)	Sorghum and millet	–	–	–	–	+	–
6. Seetha et al. (2017)	Sorghum	–	–	+	–	–	–
Uganda							
7. Tibagonzeka et al. (2018)	Sorghum and millet	–	–	+	–	–	–
Zimbabwe							
8. Chitindingu et al. (2011)	Sorghum, Finger millet	+	+	–	–	–	–
9. Jiri et al. (2017)	Sorghum, Finger millet Pearl millet	+	+	–	–	–	–
10. Manandhar et al. (2018)	Sorghum	–	–	+	–	–	–
11. Mapfeka et al. (2019)	–	–	–	+	–	–	–
12. Phiri et al. (2019)	Sorghum, Millet	–	–	+	–	–	–
13. Silas et al. (2021)	Sorghum	–	–	–	–	+	–
Asia							
India							
14. Rao et al. (2006)	Sorghum Pearl millet	–	+	–	–	–	–
15. Sreenivasa et al. (2008)	Sorghum	–	–	+	–	–	–
16. Kulamarva et al. (2009)	Sorghum	+	+	–	–	–	–
17. Jimoh and Abdullahi (2017)	Sorghum	+	+	–	–	–	–
18. Astoreca et al. (2019)	Sorghum	–	–	+	–	–	–
19. Mohapatra et al. (2019)	Sorghum	+	+	–	–	–	–
20. Tamilselvan and Kushwaha (2020)	Sorghum	–	+	–	–	–	–
Nepal							
21. Regmi et al. (2023)	Finger Millet	+	+	–	–	–	–
Total		7	8	10	0	2	0

Notes: +: present; -: absent.

and contains 3.9 mg/kg of iron, contributing to its nutritional value (Regmi et al., 2023). According to White et al. (2023), there is dominance in micronutrient deficiency in Southern Africa and South Asia. Therefore, the rich mineral content of traditional grains highlights their potential for biofortification initiatives to combat micronutrient deficiencies. This corroborates recommendations by Galani et al. (2022) that traditional grains can be a good source of micronutrients to address micronutrient deficiency in sub-Saharan Africa, especially in women of childbearing age children. However, the presence of anti-nutritional factors, such as phytic acid and tannins, presents challenges. These compounds bind to essential minerals, including zinc and iron, thereby reducing their bioavailability (Dey et al., 2022; Kutman, 2023). This limitation underscores the necessity for processing methods that can alleviate antinutrient effects and enhance nutrient accessibility.

The variability observed in nutrient composition reflects differences in grain type (Kumar et al., 2022), geographical origin, and environmental factors influencing cultivation (Anitha et al., 2024). Addressing these disparities through targeted agricultural and breeding practices is essential for optimising the nutritional benefits of sorghum and millet. Moreover, fostering increased public awareness regarding the nutritional advantages of these grains is imperative for promoting their incorporation into daily diets and nutrition programs, particularly for vulnerable populations, including children and pregnant women (Galani et al., 2022).

3.3. Food safety

3.3.1. Physical hazards

Figure 3 shows that physical hazards were identified in a limited number of studies (16.1%). In Nigeria, Utono (2013) reported the presence of physical contaminants in sorghum and millet, which may be attributed to potential gaps in cleaning and sorting procedures during processing (Table 1). However, most studies from Sub-Saharan Africa and Asia

Table 2. Results of scientific studies on nutritional profile and food safety hazards of raw grains (sorghum and millet) in sub-Saharan Africa and South Asia.

Author/Region/Country	Grain type	Nutrient profile											Aflatoxin level*B1* (mg/kg)
		Crude Fibre (%)	*Zinc* (mg/kg)	*Iron* (mg/kg)	*Sodium* (mg/kg)	*Phosphorus* (mg/kg)	*Calcium* (mg/kg)	*Protein* (%)	*Ash* (%)	*Fats* (%)	*Carbohydrate* (%)	*Moisture* (%)	
Sub-Saharan Africa													
Ethiopia													
1. Shegro et al. (2012)	Sorghum	–	24.23	61.41	22.97	2893.44	311.27	8.08	–	–	–	–	–
2. Ayelign and De Saeger (2020)	Sorghum	–	–	–	–	–	–	–	–	–	–	–	0.033
Nigeria													
3. Seetha et al. (2017)	Sorghum	–	–	–	–	–	–	–	–	–	–	–	0.021
Uganda													
4. Tibagonzeka et al. (2018)	Sorghum and millet	–	–	–	–	–	–	–	–	–	–	–	20.33-28.62
Zimbabwe													
5. Chitindingu et al. (2011)	Sorghum & finger millet	2.51	–	–	–	2400	–	7.84	2.28	–	–	–	–
South Asia													
India													
6. Kulamarva et al. (2009)	Sorghum	2	–	5400	–	–	2500	10.4	1.6	3.1	70.7		
7. Jimoh and Abdullahi (2017)	Sorghum	1.65-7.94	0.04	0.02	–	–	0.019	6.23-13.81	1.12-1.68	–	–	9.75-6.32	–
8. Mohapatra et al. (2019)	Sorghum	2.76-3.41	–	–	–	–	–	11.36-12.13	3.17-2.59	3.6-4.7	71.9–74.52	–	–
Nepal													
9. Regmi et al. (2023)	Finger millet	3.6	–	3.9	–	283	344	7.3	–	–	–	–	–

Notes: mg/kg: milligrams per kilogram; '-" data not available.

Table 3. Common sorghum and millet grain-based value-added products and their nutritional and food safety profiles.

Authors	Type of product(s)	Type of grain	Processing method	Nutritional profile		Food safety issues			
				Micro-nutrient	Macro-nutrient	Biological	Chemical	Physical	Allergen
Sub-Saharan Africa									
Nigeria									
Ajiboye et al. (2014)	*Pito, Obiolor*	Sorghum, millet	Steeping, germination, cooling, filtration, boiling, stirring, soaking, malting, fermentation	–	+	–	–	–	–
Multiple countries:	Botswana, Burkna, Cameroon, Ethiopia, Eritrea, Ghana, Nigeria, South Africa, Somalia, Sudan, Uganda, Zambia, Zimbabwe								
1. Adebiyi et al. (2018)	Alcoholic beverage, gruel, porridge, liquid drink, non-alcoholic, beverage, pancake,	Millet	Fermentation, malting, soaking, germination, drying, sieving	+	+	–	–	–	–
Multiple countries:	Cameroon, Ethiopia, Nigeria, South Africa, Uganda, Zimbabwe								
2. Ezekiel et al. (2018)	alcoholic beverage,	sorghum, millet,	germination, milling, fermentation, boiling, distillation, malting, roasting, filtration, malting, steeping, mashing	–	–	+	–	–	–
Zimbabwe									
3. Mugochi et al. (2001)	*Masvusvu, mangisi, mahewu*	finger millet	Malting, germination, fermentation, straining	–	+	–	–	–	–
4. Chiweshe et al. (2012)	Cereal	Millet, and sorghum,	Roasting and milling	+	–	–	–	–	–
5. Adebiyi et al. (2018)	*Masvusvu*, opaque beer, ndlovo, porridge, dumplings, gruels	Millet	sorting, cleaning, fermentation, draining, inoculation	+	+	–	–	–	–
6. Gabaza et al. (2018)	Sour porridge	pearl millet, finger millet, sorghum	Fermentation, drying, milling	+	–	–	–	–	–
7. Gabaza et al. (2018)	Sour porridge	Finger millet	Fermentation	+	+	–	–	–	–
8. Musundire et al. (2021)	Instant porridge	Millet	oven drying, dry milling, sieving, blending, extrusion	+	+	–	–	–	–
9. Chinyama et al. (2023)	Flour	Finger millet	Cleaning, grading, steeping, drying, fermentation and milling	+	+	–	–	–	–
South Asia									
Bangladesh									
10. Abedin et al. (2022)	Flour	Foi	Washing, drying, grinding, sieving	+	+	–	–	–	–

(*Continued*)

Table 3. Continued.

Authors	Type of product(s)	Type of grain	Processing method	Nutritional profile		Food safety issues			
				Micro-nutrient	Macro-nutrient	Biological	Chemical	Physical	Allergen
India									
11. Chavan et al. (2016)	unleavened pancake (*bhakri/roti*)	Sorghum	Milling, Kneading, Cooking	+	+	–	–	–	–
12. Chavan et al. (2016)	Flour	Sorghum	Cleaning, Roasting, Grinding Mixing, Frying	–	+	–	–	–	–
13. Tamilselvan and Kushwaha (2020)	Flour	Sorghum	Fermentation, Malting, Roasting	–	+	–	–	–	–
Total				**9**	**11**	**1**	**0**	**0**	**0**

Notes: (+: present; - =:absent).

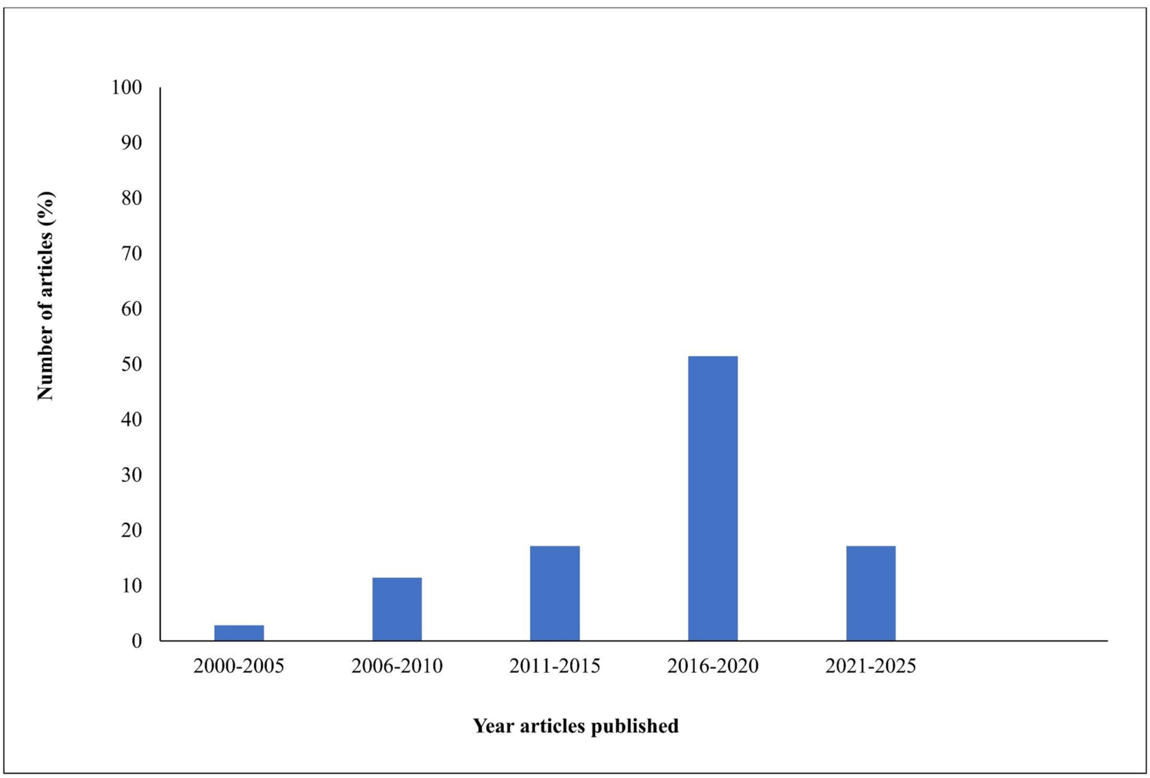

Figure 2. Distribution of reviewed articles from 2000 to 2023 for both SSA and SA (n = 35).

reported no physical hazards. For instance, Shegro et al. (2012) found no evidence of foreign object contamination in sorghum in Ethiopia. These results suggest that either there are limited studies on physical hazards or processing techniques, including sieving and sorting, are generally effective in minimising physical hazards. There is a need for studies on physical hazards in the traditional grain value chain.

3.3.2. Microbiological hazards

The results presented in Figure 3 indicate microbial contamination is of significant concern, appearing in 83.3% of the reviewed studies with raw grains being the primary focus. For example, Table 1 shows that Ayelign and De Saeger (2020) reported microbial contamination in sorghum from Ethiopia, and Matumba et al. (2011) observed similar safety issues in sorghum from Malawi. Kaela et al. (2023) highlighted microbial risks in both sorghum and pearl millet in Namibia, and similar findings were reported in Nigeria, Uganda, and Zimbabwe. These findings

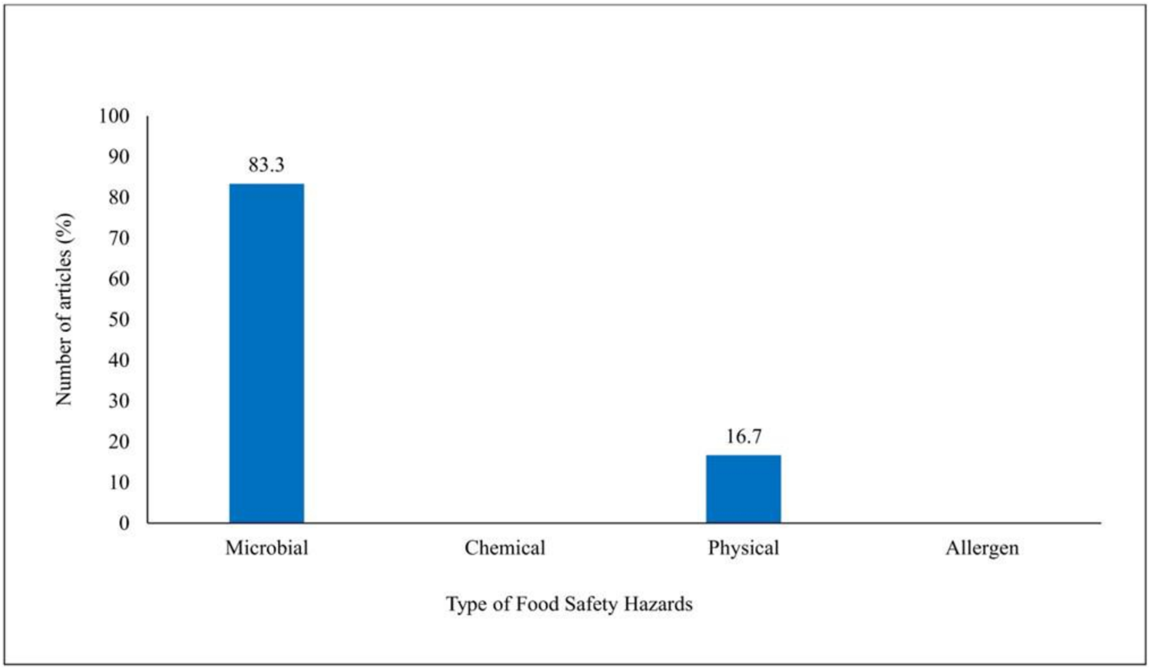

Figure 3. Food safety hazards of raw traditional grains.

indicate the importance of maintaining hygiene and sanitation throughout the processes of harvesting, processing, and storage of traditional grains. The presence of microbiological hazards could be linked to inadequate post-harvest handling, improper storage conditions, or contamination during processing. While the prevalence of microbial risks is considerably reduced in value-added products due to processing interventions such as fermentation, ongoing monitoring and strict adherence to safety standards remain essential (Kebede et al., 2020).

3.3.3. Chemical hazards (aflatoxins)

Table 2 presents the food safety results based on aflatoxin levels in traditional grains. The results indicate that in sub-Saharan Africa, aflatoxin levels in sorghum were reported by Ayelign and De Saeger (2020) in Ethiopia at 0.033 mg/kg, while Seetha et al. (2017) indicated slightly lower levels at 0.021 mg/kg in Nigeria. For Uganda, Tibagonzeka et al. (2018) reported a wider range of aflatoxin levels, from 20.33 to 28.62 mg/kg, in both sorghum and millet. These findings suggest significant geographic differences, with aflatoxin contamination appearing more severe in Uganda compared to Ethiopia and Nigeria. There was however limited data from studies in South Asia, with Jimoh and Abdullahi (2017) reporting aflatoxin levels in Indian sorghum ranging from 0.019 mg/kg. Compared to sub-Saharan Africa, aflatoxin contamination appears to be relatively lower in South Asia. This difference may be due to differences in reporting and sampling methodologies.

The results point to the need for robust aflatoxin mitigation strategies. These strategies to minimise aflatoxin contamination include good agricultural practices (such as good harvesting and handling procedures), using improved seed, use of fertilisers, use of biological control (Asante et al., 2024), use of improved storage facilities such as hermetic bags, storing properly dried grain. The use of drought-tolerant varieties, timely harvesting during physiological maturity, drying properly to 13% moisture content, storage in suitable conditions to keep the crop clean, and under conditions with minimally proper aeration have been reported to reduce aflatoxin contamination (Xu et al., 2022). According to Subramanyam et al. (2003), soil moisture conservation through deep ploughing and cultivation across the slope, judicious application of potassic fertilisers, and gypsum ($CaSO_4$) application at the time of flowering, reduce *A. flavus* invasion of pods and subsequent aflatoxin contamination. Moreover, implementing proper handling and storage, such as using clean containers, avoiding cross-contamination, and rotating stock, can help prevent aflatoxin contamination (Gong et al., 2024).

When comparing grain types, the available data indicate no consistent trend of either sorghum or millet being better in terms of lower aflatoxin contamination, as both grains had higher contamination range reported in Uganda (Table 2). This suggests that environmental factors and storage conditions, rather than inherent differences between sorghum and millet, likely play a more significant role in aflatoxin contamination. This is supported by Medina et al. (2015) who reported that environmental conditions such as high humidity and temperatures exceeding 25 °C provide favourable conditions for fungal proliferation, particularly in inadequately stored grains. The growth of *A. flavus* and the production of aflatoxins have been found to be influenced by various environmental that include water activity (aw), temperature, storage time, substrate composition, carbon and nitrogen sources, pH, light, oxygen (O_2) and carbon dioxide (CO_2) levels, as well as damage to the grains caused by insects or mechanical/thermal factors (Astoreca et al., 2014; Medina et al., 2015).

The lack of studies on other chemical hazards besides aflatoxins and allergens shows that these hazards are yet to be extensively explored, representing a substantial gap in food safety research pertaining to these grains. Given the increasing incorporation of chemical additives in value-added products, evaluating their potential health implications is critical (Crevel et al., 2014).

3.4. Value addition

3.4.1. Common value-added products from traditional grains

The commonly value-added products identified from the reviewed literature are indicated in Table 3 and these include alcoholic and non-alcoholic beverages, gruel, porridge, sour porridge, flour, and dumplings. Zimbabwe had the highest number of published articles (50%) on value addition of traditional grains, followed by India (21.4%), Nigeria (7.1%), and Nepal (7.1%). The high utilisation of traditional grains in value addition in Zimbabwe can be attributed to the fact that Zimbabwe has a diverse agricultural sector, with a wide range of traditional grains being cultivated (Ndlovu et al., 2020). In addition, traditional grains are an integral part of Zimbabwean culture and hold significant cultural values that are deeply rooted in traditional practices (Nciizah et al., 2021). Some of the studies (14.2%) were conducted in multiple countries in Africa (Botswana, Burkna, Cameroon, Ethiopia, Eritrea, Ghana, Nigeria, South Africa, Somalia, Sudan, Uganda, Zambia, and Zimbabwe). The value-added products in these countries include bread and pancakes, dumplings and couscous, porridge, gruels, opaque and cloudy beers, and non-alcoholic fermented beverages. According to Sawadogo-Lingani et al. (2021), throughout sub-Saharan Africa, sorghum is the grain of choice in the production of popular traditional cloudy and opaque beers. The key ingredient of these beers is sorghum malt. Pearl millet is mainly used to prepare traditional fermented or unfermented porridges, and for brewing traditional beers and wines (Laminu et al., 2011). Pearl millet-based gruels and steamed cakes are prepared for feeding infants and preschool children. Malted pearl millet in combination with legumes is used to prepare weaning foods (Hema et al., 2022). Porridges are the most common and simplest foods prepared from sorghum and millet. Porridges are classified into thick and thin porridges, the difference lying in their solid content and consistency (Taylor & Duodu, 2015, 2019).

3.4.2. Common processing methods in value addition of traditional grains

The processing methods commonly used in the value addition of traditional grains are presented in Figure 4. Fermentation (17%) was the most common of these processing methods, followed by dehulling (8.5%), milling (8.5%) and malting (8.5%). Fermented foods derived from sorghum and millet, such as sour porridge and beverages, are rich in probiotics and bioactive compounds, which offer health benefits like improved digestion and immune support (Bwamu et al., 2022; Gwekwe et al., 2024). Fermentation has been demonstrated to effectively decrease antinutrient levels, particularly phytic acid, through the activation of endogenous phytase enzymes (Rastogi et al., 2022). This process subsequently increases the bioavailability of minerals such as iron and zinc, thus addressing the widespread micronutrient deficiencies prevalent in regions reliant on these grains (Endalew et al., 2024).

Malting, which was one of the second most commonly used processing methods, enhances nutrient digestibility by enzymatically degrading complex carbohydrates and proteins (Hejazi & Orsat, 2016). According to Simran et al. (2024) malting not only makes food tastier and easier to digest but also addresses two important challenges, i.e. reducing antinutrients and improving the availability of essential nutrients. Dehulling, another commonly used processing method, reduces anti-nutritional factors like phytates and tannins, which are concentrated in the bran (Gwekwe et al., 2024; Singh & Rao, 2025). The other identified processing methods include

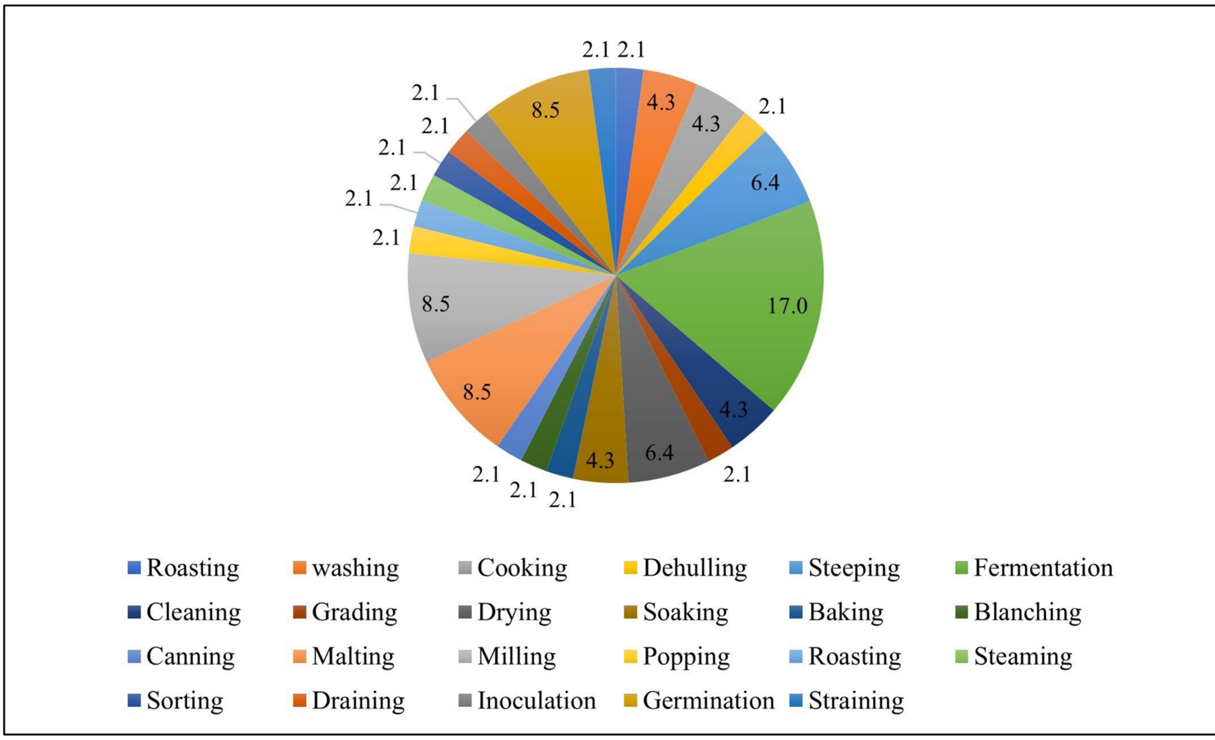

Figure 4. Common processing methods used in value addition of traditional grains in sub-Saharan Africa and South Asia (n = 47).

milling, soaking, roasting, and popping (Table 3) and these also contribute to improving the palatability, usability of grains, and overall acceptance of these grains within various dietary contexts. More so, the traditional processing methods are considered to reduce the phytic acid level in cereals and millet (Sheethal et al., 2022).

The results presented in this section provide insights into various techniques used to enhance the nutritional quality, palatability, and shelf life of sorghum and millets. Despite these many processing methods being used, challenges persist in optimising these processing methods to retain nutrients while addressing food safety issues. For example, while fermentation effectively reduces antinutrients, it necessitates careful monitoring to prevent microbial contamination. Similarly, the malting and extrusion processes must be calibrated to balance nutrient retention with energy efficiency (Ananthanarayan et al., 2022). Future research should aim to refine these methods to enhance the nutritional value, safety, and economic viability of sorghum and millet products.

3.4.3. Food safety value-added products

The results presented in Table 3 show that only one study (Ezekiel et al., 2018) reported microbiological hazards in alcoholic beverages made from sorghum and millet using germination, milling, and fermentation processes. This result points to the need for strict hygiene and fermentation controls to mitigate potential contamination risks during processing. This literature review reveals that there are limited studies on the food safety of value-added products, reflecting a huge research gap that needs to be explored.

4. Conclusion

This review highlights the role of sorghum and millets in addressing food and nutrition security challenges in sub-Saharan Africa and South Asia, particularly in the context of climate change. It provides valuable insights into the nutritional profile, food safety hazards, and common processing methods of traditional grains, sorghum, and millet in sub-Saharan Africa and South Asia. On nutritional profiling, the results revealed that sorghum and millets are rich sources of essential nutrients, including proteins, and dietary fibres, minerals such as iron, zinc, and B vitamins. The review also emphasises the importance of food safety when consuming sorghum and millet. The presence of mycotoxins, particularly aflatoxins, and microbial hazards necessitate enhanced handling, storage, and processing practices to ensure consumer safety. Despite these challenges, the potential for value addition through products like porridge, beverages, and flour remains largely untapped. By bringing together current knowledge on nutritional benefits, processing techniques, and food safety issues, this review provides insights for researchers, policymakers, and industry stakeholders. It stresses the importance of promoting sorghum and millets as climate-resilient crops that can contribute to sustainable food systems. With informed decision-making and innovation, these grains can significantly impact global efforts to achieve food security, improve nutrition, and enhance resilience against climate-induced food crises.

This review highlights key research gaps and opportunities for improving the understanding and utilisation of sorghum and millet grains. Mycotoxin contamination, particularly from aflatoxins, poses a significant food safety concern; however, comprehensive and scalable mitigation strategies remain underexplored. Although traditional processing techniques such as fermentation, malting, and milling are commonly used, their optimisation to maximise nutrient retention, improve bioavailability, and mitigate food safety risks requires further investigation. Future research should prioritise optimising these processing methods to enhance nutrient bioavailability while effectively reducing antinutritional factors and contamination risks. Additionally, there is an urgent need for thorough studies on chemical and allergen hazards across various production systems to ensure food safety and strengthen consumer confidence.

The findings emphasise the nutritional richness of sorghum and millets and their potential as climate-resilient crops for food security in vulnerable regions. However, optimising processing methods and addressing food safety concerns, particularly aflatoxins, is critical to maximising their benefits. Future research should prioritise exploring innovative and scalable methods to enhance nutrient retention and minimise contamination risks.

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Authors' contributions

LM, BMM, LKN, and MM sought the funding; LM, BMM, LKN, MM, IK and MK conceptualised and designed the study; LM, BMM, LKN, MM, IK and MK supervised and reviewed the study. TJM, GC, MgM collected the data and critiqued the MS; TJM wrote the initial draft.

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Data availability statement

Even though adequate data have been provided in the form of tables and figures, all authors declare that if more data are required, then the data will be provided by the corresponding author (lmacheka@muast.ac.zw) on a request basis.

References

Abedin, M. J., Abdullah, A. T. M., Satter, M. A., & Farzana, T. (2022). Physical, functional, nutritional and antioxidant properties of foxtail millet in Bangladesh. *Heliyon*, *8*(10), e11186. https://doi.org/10.1016/j.heliyon.2022.e11186

Adebiyi, J. A., Obadina, A. O., Adebo, O. A., & Kayitesi, E. (2018). Fermented and malted millet products in Africa: Expedition from traditional/ethnic foods to industrial value-added products. *Critical Reviews in Food Science and Nutrition*, *58*(3), 463–474. https://doi.org/10.1080/10408398.2016.1188056

Adeyeye, S. A. O., Ashaolu, T. J., & Idowu-Adebayo, F. (2022). Mycotoxins: Food safety, consumer health and Africa's Food security. *Polycyclic Aromatic Compounds*, *42*(8), 5779–5795. https://doi.org/10.1080/10406638.2021.1957952

Ajiboye, T. O., Iliasu, G. A., Adeleye, A. O., Abdussalam, F. A., Akinpelu, S. A., Ogunbode, S. M., Jimoh, S. O., & Oloyede, O. B. (2014). Nutritional and antioxidant dispositions of sorghum/millet-based beverages indigenous to Nigeria. *Food Science & Nutrition*, *2*(5), 597–604. https://doi.org/10.1002/fsn3.140

Akello, J., Ortega-Beltran, A., Katati, B., Atehnkeng, J., Augusto, J., Mwila, C. M., Mahuku, G., Chikoye, D., & Bandyopadhyay, R. (2021). Prevalence of Aflatoxin- and Fumonisin-Producing fungi associated with cereal crops grown in zimbabwe and their associated risks in a climate change scenario. *Foods*, *10*(2), 287. https://doi.org/10.3390/foods10020287

Akinola, R., Pereira, L. M., Mabhaudhi, T., de Bruin, F.-M., & Rusch, L. (2020). A review of indigenous food crops in Africa and the implications for more sustainable and healthy food systems. *Sustainability*, *12*(8), 3493. Article 8. https://doi.org/10.3390/su12083493

Akplo, T., Faye, A., Obour, A., Stewart, Z., Min, D., & Prasad, P. V. V. (2023). Dual-purpose crops for grain and fodder to improve nutrition security in semi-arid sub-Saharan Africa: A review. *Food and Energy Security*, *12*(5), e492. https://doi.org/10.1002/fes3.492

Ananthanarayan, L., Kumar, V., Panghal, A., Singh, B., Waghmare, R., Gat, Y., & Kaur, N. (2022). Use of microalgal biomass as functional ingredient for preparation of cereal based extrudates: impact of processing on amino acid concentrations and colour degradation kinetics. *Brazilian Journal of Pharmaceutical Sciences*, *58*, e18665. https://doi.org/10.1590/s2175-97902020000118665

Anitha, S., Rajendran, A., Botha, R., Baruah, C., Mer, P., Sebastian, J., Upadhyay, S., & Kane-Potaka, J. (2024). Variation in the nutrient content of different genotypes and varieties of millets, studied globally: A systematic review. *Frontiers in Sustainable Food Systems*, *8*, 1324046. https://doi.org/10.3389/fsufs.2024.1324046

Apraku, A., Moyo, P., & Akpan, W. (2019). Coping with climate change in Africa: An analysis of local interpretations in Eastern Cape, SA. *Development Southern Africa*, *36*(3), 295–308. https://doi.org/10.1080/0376835X.2018.1482199

Asante, I. S., Aidoo, M., Prah, S., Asante, B. O., & Sackey, C. K. (2024). Managing aflatoxin contamination threats in groundnut (*Arachis hypogaea* L.) production in Ghana: The role of adoption of management strategies. *Journal of Stored Products Research*, *107*, 102335. https://doi.org/10.1016/j.jspr.2024.102335

Astoreca, A. L., Emateguy, L. G., & Alconada, T. M. (2019). Fungal contamination and mycotoxins associated with sorghum crop: Its relevance today. *European Journal of Plant Pathology*, *155*(2), 381–392. https://doi.org/10.1007/s10658-019-01797-w

Astoreca, A., Vaamonde, G., Dalcero, A., Marin, S., & Ramos, A. (2014). Abiotic factors and their interactions influence on the co-production of aflatoxin B1 and cyclopiazonic acid by *Aspergillus flavus* isolated from corn. *Food Microbiology*, *38*, 276–283. https://doi.org/10.1016/j.fm.2013.07.012

Ayelign, A., & De Saeger, S. (2020). Mycotoxins in Ethiopia: Current status, implications to food safety and mitigation strategies. *Food Control*, *113*, 107163. https://doi.org/10.1016/j.foodcont.2020.107163

Bhuiyan, M. A., Galdes, N., Cuschieri, S., & Hu, P. (2024). A comparative systematic review of risk factors, prevalence, and challenges contributing to non-communicable diseases in South Asia, Africa, and Caribbeans. *Journal of Health, Population and Nutrition*, *43*(1), 140. https://doi.org/10.1186/s41043-024-00607-2

Branca, G., & Perelli, C. (2020). 'Clearing the air': Common drivers of climate-smart smallholder food production in Eastern and Southern Africa. *Journal of Cleaner Production*, *270*, 121900. https://doi.org/10.1016/j.jclepro.2020.121900

Breslauer, R., Nalbandian, E., Reinman, T., Rezaey, M., Ganjyal, G. M., & Murphy, K. M. (2023). Buckwheat production and value-added processing: A review of potential Western Washington cropping and food system applications. *Sustainability*, *15*(20), 14758. https://doi.org/10.3390/su152014758

Bwamu, K. E., Nkirote, K. C., Kahiu, N. E., & Edgar, K. D. (2022). Optimization of fermentation and malting process of sorghum beverage and effects on nutritional quality. *African Journal of Food Science*, *16*(10), 252–260. https://doi.org/10.5897/AJFS2022.2211

Chandra Manna, M., Rahman, M. M., Naidu, R., Sahu, A., Bhattacharjya, S., Wanjari, R. H., Patra, A. K., Chaudhari, S. K., Majumdar., & Khanna, S. S. (2018). Chapter three - bio-waste management in subtropical soils of India: Future Challenges and Opportunities in Agriculture. In D. L. Sparks (Ed.), *Advances in Agronomy* (Vol. 152, pp. 87–148). Academic Press. https://doi.org/10.1016/bs.agron.2018.07.002

Chavan, U., J, K., Shinde, M., & Patil, J. (2016). Preparation and nutritional quality of sorghum chakali. *International Journal of Recent Scientific Research*, *7*, 8404–8411.

Chavan, U., Patil, J., & Shinde, M. (2016). Nutritional and roti quality of sorghum genotypes. *Indonesian Journal of Agricultural Science*, *10*(2), 80–87. https://doi.org/10.21082/ijas.v10n2.2009.80-87

Chinyama, J., Masamha, B., & Nyamadzawo, G, (2023). Formulating finger millet (Eleusine coracana L) and cowpea (Vigna unguiculata) food blend for enhanced micronutrients for children below 5 years. *African Journal of Food, Agriculture, Nutrition and Development*, *23*(04), 23238–23262. https://doi.org/10.18697/ajfand.119.20610

Chitindingu, K., Benhura, M. A. N., & Muchuweti, M. (2011). Food shortage in Zimbabwe: Can wild cereal grains be an alternative source of nutrition? *Journal of Advances in Chemistry*, *7*(2), 1300–1307. https://doi.org/10.24297/jac.v7i2.2358

Chiweshe, M., Edziwa, X., & Chikoore, M. R. (2012). *Developing a high protein-energy cereal blend using locally produced small grain cereals and legumes*.

Crevel, R. W. R., Baumert, J. L., Baka, A., Houben, G. F., Knulst, A. C., Kruizinga, A. G., Luccioli, S., Taylor, S. L., & Madsen, C. B. (2014). Development and evolution of risk assessment for food allergens. *Food and Chemical Toxicology: An International Journal Published for the British Industrial Biological Research Association*, *67*, 262–276. https://doi.org/10.1016/j.fct.2014.01.032

Dey, S., Saxena, A., Kumar, Y., Maity, T., & Tarafdar, A. (2022). Understanding the antinutritional factors and bioactive compounds of kodo millet (Paspalum scrobiculatum) and little millet (Panicum sumatrense). *Journal of Food Quality*, *2022*(1), 1–19. https://doi.org/10.1155/2022/1578448

Dixit-Bajpai, P., & Ravichandran, R. (2024). The potential of millet grains: A comprehensive review of nutritional value, processing technologies, and future prospects for food security and health promotion. *Journal of Food Technology & Nutrition Sciences*, *6*, 1–8.

Dube, T., Mlilo, C., Moyo, P., Ncube, C., & Phiri, K. (2018). *Will Adaptation Carry the Future? Questioning the Long-term Capacity of Smallholder Farmers' Adaptation Strategies against Climate Change in Gwanda District, Zimbabwe*. http://ir.lsu.ac.zw/handle/123456789/460

Endalew, H. W., Atlabachew, M., Karavoltsos, S., Sakellari, A., Aslam, M. F., Allen, L., Griffiths, H., Zoumpoulakis, P., Kanellou, A., Yehuala, T. F., Abera, M. K., Tenagashaw, M. W., & Cherie, H. A. (2024). Effect of fermentation on nutrient composition, antinutrients, and mineral bioaccessibility of finger millet based *Injera*: A traditional Ethiopian food. *Food Research International (Ottawa, Ont.)*, *190*, 114635. https://doi.org/10.1016/j.foodres.2024.114635

Ezekiel, C. N., Ayeni, K. I., Misihairabgwi, J. M., Somorin, Y. M., Chibuzor-Onyema, I. E., Oyedele, O. A., Abia, W. A., Sulyok, M., Shephard, G. S., & Krska, R. (2018). Traditionally processed beverages in Africa: A review of the mycotoxin occurrence patterns and exposure assessment. *Comprehensive Reviews in Food Science and Food Safety*, *17*(2), 334–351. https://doi.org/10.1111/1541-4337.12329

Gabaza, M., Shumoy, H., Louwagie, L., Muchuweti, M., Vandamme, P., Du Laing, G., & Raes, K. (2018). Traditional fermentation and cooking of finger millet: Implications on mineral binders and subsequent bioaccessibility. *Journal of Food Composition and Analysis*, *68*, 87–94. https://doi.org/10.1016/j.jfca.2017.05.011

Gabaza, M., Shumoy, H., Muchuweti, M., Vandamme, P., & Raes, K. (2018). Iron and zinc bioaccessibility of fermented maize, sorghum and millets from five locations in Zimbabwe. *Food Research International* , *103*, 361–370. https://doi.org/10.1016/j.foodres.2017.10.047

Galani, Y. J. H., Orfila, C., & Gong, Y. Y. (2022). A review of micronutrient deficiencies and analysis of maize contribution to nutrient requirements of women and children in Eastern and Southern Africa. *Critical Reviews in Food Science and Nutrition*, *62*(6), 1568–1591. https://doi.org/10.1080/10408398.2020.1844636

Gong, A., Song, M., & Zhang, J. (2024). Current strategies in controlling Aspergillus flavus and aflatoxins in grains during Storage: A review. *Sustainability*, *16*(8), 3171. https://doi.org/10.3390/su16083171

Gwekwe, B. N., Chopera, P., Matsungo, T. M., Chidewe, C., Mukanganyama, S., Nyakudya, E., Mtambanengwe, F., Mapfumo, P., & Nyanga, L. K. (2024). Effect of dehulling, fermentation, and roasting on the nutrient and anti-nutrient content of sorghum and pearl millet flour. *International Journal on Food, Agriculture and Natural Resources*, *5*(1), 1–7. https://doi.org/10.46676/ij-fanres.v5i1.221

Hassan, Z. M., Sebola, N. A., & Mabelebele, M. (2021). The nutritional use of millet grain for food and feed: A review. *Agriculture & Food Security*, *10*(1), 16. https://doi.org/10.1186/s40066-020-00282-6

Hema, V., Ramaprabha, M., Saraswathi, R., Chakkaravarthy, P. N., & Sinija, V. R. (2022). Millet Food Products. In C. Anandharamakrishnan, A. Rawson, & C. K. Sunil (Eds.), *Handbook of Millets—Processing, Quality, and Nutrition Status.* (pp. 265–299). Springer Nature. https://doi.org/10.1007/978-981-16-7224-8_12

Hendek Ertop, M., & Bektaş, M. (2018). Enhancement of bioavailable micronutrients and reduction of antinutrients in foods with some processes. *Food and Health*, *4*(3), 159–165. https://doi.org/10.3153/FH18016

Hejazi, S. N., & Orsat, V. (2016). Malting process optimization for protein digestibility enhancement in finger millet grain. *Journal of Food Science and Technology*, *53*(4), 1929–1938. https://doi.org/10.1007/s13197-016-2188-x

Hossain, M. S., Islam, M. N., Rahman, M. M., Mostofa, M. G., & Khan, M. A. R. (2022). Sorghum: A prospective crop for climatic vulnerability, food and nutritional security. *Journal of Agriculture and Food Research*, *8*, 100300. https://doi.org/10.1016/j.jafr.2022.100300

Jimoh, W. L. O., & Abdullahi, M. S. (2017). Proximate analysis of selected sorghum cultivars. *Bayero Journal of Pure and Applied Sciences*, *10*(1), 285. https://doi.org/10.4314/bajopas.v10i1

Jiri, O., Mafongoya, P. L., & Chivenge, P, (2017). Climate smart crops for food and nutritional security for semi-arid zones of Zimbabwe. *African Journal of Food, Agriculture, Nutrition and Development*, *17*(03), 12280–12294. https://doi.org/10.18697/ajfand.79.16285

Kaela, C. R., Lilly, M., Rheeder, J. P., Misihairabgwi, J. M., & Alberts, J. F. (2023). Mycological and multiple mycotoxin surveillance of sorghum and pearl millet produced by smallholder farmers in Namibia. *Current Microbiology*, *80*(5), 164. https://doi.org/10.1007/s00284-023-03263-7

Kebede, H., Liu, X., Jin, J., & Xing, F. (2020). Current status of major mycotoxins contamination in food and feed in Africa. *Food Control*, *110*, 106975. https://doi.org/10.1016/j.foodcont.2019.106975

Kulamarva, A. G., Sosle, V. R., & Raghavan, G. S. V. (2009). Nutritional and rheological properties of Sorghum. *International Journal of Food Properties*, *12*(1), 55–69. https://doi.org/10.1080/10942910802252148

Kumar, A., Pathak, H., Bhadauria, S., & Sudan, J. (2021). Aflatoxin contamination in food crops: Causes, detection, and management: A review. *Food Production, Processing and Nutrition*, *3*(1), 17. https://doi.org/10.1186/s43014-021-00064-y

Kumar, A., Tomer, V., Kaur, A., Kumar, V., & Gupta, K. (2018). Millets: A solution to agrarian and nutritional challenges. *Agriculture & Food Security*, *7*(1), 31. https://doi.org/10.1186/s40066-018-0183-3

Kumar, R. R., Singh, S. P., Rai, G. K., Krishnan, V., Berwal, M. K., Goswami, S., T, V., Mishra, G. P., Satyavathi, C. T., Singh, B., & Praveen, S. (2022). Iron and zinc at a cross-road: A trade-off between micronutrients and anti-nutritional factors in pearl millet flour for enhancing the bioavailability. *Journal of Food Composition and Analysis*, *111*, 104591. https://doi.org/10.1016/j.jfca.2022.104591

Kutman, U. B. (2023). Mineral nutrition and crop quality (Chapter 9). In Z. Rengel, I. Cakmak, P. J. White (Eds.), *Marschner's Mineral Nutrition of Plants.* (pp. 419–444). Elsevier.

Laminu, H. H., Modu, S., & Numan, A. I. (2011). *Production, in vitro protein digestibility, phytate content and acceptability of weaning foods prepared from pearl millet (Pennisetum typhoideum) and cowpea (Vigna unguiculata)*.

Manandhar, A., Milindi, P., & Shah, A. (2018). An overview of the post-harvest grain storage practices of smallholder farmers in developing countries. *Agriculture*, *8*(4), 57. https://doi.org/10.3390/agriculture8040057

Mapfeka, R. F., Mandumbu, R., Zengeza, T., Kamota, A., Masamha, B., Marongwe, F. D., Mutsamba-Magwaza, E. F., Nyakudya, E., & Nyamadzawo, G. (2019). Post-harvest cereal structures and climate change resilience in rural Zimbabwe: A review. *International Journal of Postharvest Technology and Innovation*, *6*(4), 257–275. https://doi.org/10.1504/IJPTI.2019.106460

Matumba, L., Monjerezi, M., Khonga, E. B., & Lakudzala, D. D. (2011). Aflatoxins in sorghum, sorghum malt and traditional opaque beer in southern Malawi. *Food Control*, *22*(2), 266–268. https://doi.org/10.1016/j.foodcont.2010.07.008

Matumba, L., Sulyok, M., Njoroge, S. M. C., Njumbe Ediage, E., Van Poucke, C., De Saeger, S., & Krska, R. (2015). Uncommon occurrence ratios of aflatoxin B1, B 2, G 1, and G 2 in maize and groundnuts from Malawi. *Mycotoxin Research*, *31*(1), 57–62. https://doi.org/10.1007/s12550-014-0209-z

Maurya, R., Boini, T., Misro, L., Radhakrishnan, T., Sreedharan, A. P., & Gaidhani, D. (2023). Comprehensive review on millets: Nutritional values, effect of food processing and dietary aspects. *Journal of Drug Research in Ayurvedic Sciences*, *8*(Suppl 1), S82–S98. https://doi.org/10.4103/jdras.jdras_123_23

Medina, A., Schmidt-Heydt, M., Rodríguez, A., Parra, R., Geisen, R., & Magan, N. (2015). Impacts of environmental stress on growth, secondary metabolite biosynthetic gene clusters and metabolite production of xerotolerant/xerophilic fungi. *Current Genetics*, *61*(3), 325–334. https://doi.org/10.1007/s00294-014-0455-9

Misra, A. K. (2014). Climate change and challenges of water and food security. *International Journal of Sustainable Built Environment*, *3*(1), 153–165. https://doi.org/10.1016/j.ijsbe.2014.04.006

Mohapatra, D., Patel, A. S., Kar, A., Deshpande, S. S., & Tripathi, M. K. (2019). Effect of different processing conditions on proximate composition, anti-oxidants, anti-nutrients and amino acid profile of grain sorghum. *Food Chemistry*, *271*, 129–135. https://doi.org/10.1016/j.foodchem.2018.07.196

Mugochi, T., Mutukumira, T., & Zvauya, R. (2001). Comparison of sensory characteristics of traditional Zimbabwean non-alcoholic cereal beverages, *masvusvu* and *mangisi* with *mahewu*, a commercial cereal product. *Ecology of Food and Nutrition*, *40*(4), 299–309. https://doi.org/10.1080/03670244.2001.9991655

Mukarumbwa, P., & Mushunje, A. (Eds.) (2010). *Potential of Sorghum and Finger Millet to Enhance Household Food Security in Zimbabwe's Semi-arid Regions: A Review*. https://doi.org/10.22004/ag.econ.96430

Musundire, R., Dhlakama, R. B., & Serere, J. H. (2021). Physico-chemical and sensory quality evaluation of an extruded nutrient-dense termite (Macrotermes natalensis) and millet (Eleusine coracana) instant porridge. *International Journal of Tropical Insect Science*, *41*(3), 2059–2070. https://doi.org/10.1007/s42690-021-00488-6

Nciizah, T., Nciizah, E., Mubekaphi, C., & Nciizah, A. (2021). Role of small grains in adapting to climate change: Zvishavane District, Zimbabwe. In W. Leal Filho, N. Oguge, D. Ayal, L. Adeleke, I. da Silva (Eds.), *African Handbook of Climate Change Adaptation* (pp. 1–19). https://doi.org/10.1007/978-3-030-42091-8_254-1

Ndlovu, E., Prinsloo, B., & Le Roux, T. (2020). Impact of climate change and variability on traditional farming systems: Farmers' perceptions from south-west, semi-arid Zimbabwe. *Jamba* , *12*(1), 742. https://doi.org/10.4102/jamba.v12i1.742

Ndlovu, S., Mpofu, M., & Moyo, P. (2020). Debunking the effectiveness of in-kind transfers in alleviating urban household food insecurity in Bulawayo, Zimbabwe. *Development Southern Africa*, *37*(1), 55–69. https://doi.org/10.1080/0376835X.2019.1584031

Ngetich, F. K., Mairura, F. S., Musafiri, C. M., Kiboi, M. N., & Shisanya, C. A. (2022). Smallholders' coping strategies in response to climate variability in semi-arid agro-ecozones of Upper Eastern Kenya. *Social Sciences & Humanities Open*, *6*(1), 100319. https://doi.org/10.1016/j.ssaho.2022.100319

Nhara, R. B., Pisa, C., Chigede, N., Gwazani, R., Muteveri, M., Murimoga, L., Ruzengwe, F. M., Nhara, R. B., Pisa, C., Chigede, N., Gwazani, R., Muteveri, M., Murimoga, L., &

Ruzengwe, F. M. (2024). *Processing of Millets (10), 55-71*. IntechOpen. https://doi.org/10.5772/intechopen.1005457

Phiri, K., Dube, T., Moyo, P., Ncube, C., & Ndlovu, S. (2019). Small grains 'resistance'? Making sense of Zimbabwean smallholder farmers' cropping choices and patterns within a climate change context. *Cogent Social Sciences*, *5*(1), 1622485. https://doi.org/10.1080/23311886.2019.1622485

Rao, P. P., Birthal, P. S., Reddy, B. V. S., Rai, K. N., & Ramesh, S. (2006). Diagnostics of Sorghum and Pearl Millet grains-based nutrition in India. *International Sorghum and Millets Newsletter*, *47*, 93–96.

Rastogi, Y. R., Thakur, R., Thakur, P., Mittal, A., Chakrabarti, S., Siwal, S. S., Thakur, V. K., Saini, R. V., & Saini, A. K. (2022). Food fermentation – Significance to public health and sustainability challenges of modern diet and food systems. *International Journal of Food Microbiology*, *371*, 109666. https://doi.org/10.1016/j.ijfoodmicro.2022.109666

Regmi, B., Kunwar, S., Acharya, T., & Gyawali, P. (2023). Potential of underutilized grain crops in the Western Mountains of Nepal for food and nutrient security. *Agriculture*, *13*(7), 1360. https://doi.org/10.3390/agriculture13071360

Sawadogo-Lingani, H., Owusu-Kwarteng, J., Glover, R., Diawara, B., Jakobsen, M., & Jespersen, L. (2021). Sustainable production of African traditional beers with focus on dolo, a West African sorghum-based alcoholic beverage. *Frontiers in Sustainable Food Systems*, *5*, 672410. https://doi.org/10.3389/fsufs.2021.672410

Seetha, A., Munthali, W., Msere, H. W., Swai, E., Muzanila, Y., Sichone, E., Tsusaka, T. W., Rathore, A., & Okori, P. (2017a). Occurrence of aflatoxins and its management in diverse cropping systems of central Tanzania. *Mycotoxin Research*, *33*(4), 323–331. https://doi.org/10.1007/s12550-017-0286-x

Sheethal, H. V., Baruah, C., Subhash, K., Ananthan, R., & Longvah, T. (2022). Insights of nutritional and anti-nutritional retention in traditionally processed millets. *Frontiers in Sustainable Food Systems*, *5*, 735356. https://doi.org/10.3389/fsufs.2021.735356

Shegro, A., Shargie, N. G., van Biljon, A., & Labuschagne, M. T. (2012). Diversity in starch, protein and mineral composition of sorghum landrace accessions from Ethiopia. *Journal of Crop Science and Biotechnology*, *15*(4), 275–280. https://doi.org/10.1007/s12892-012-0008-z

Silas, C., Nyasha, S., & Tapiwa, K. A. (2021). *Exploring Constraints and Opportunities for Sorghum Production in Dry Regions of Zimbabwe*. https://journals.nasspublishing.com/index.php/NJAS/article/download/327/450 https://doi.org/10.36956/njas.v3i2.327

Simran, Chaudhary, S., Avinashe, H., Dubey, N., . (2024). Nutritional advantages and opportunities for its processing of Finger Millet (Eleusine coracana L.): A comprehensive review. *Journal of Advances in Biology & Biotechnology*, *27*(7), 605–617 https://doi.org/10.9734/jabb/2024/v27i71021

Singh, S. M., & Rao, P. S. (2025). Impact dehulling of browntop millet: Its physical and nutritional characterization. *Journal of Cereal Science*, *121*, 104078. https://doi.org/10.1016/j.jcs.2024.104078

Šmídová, Z., & Rysová, J. (2022). Gluten-free bread and bakery products technology. *Foods (Basel, Switzerland)*, *11*(3), 480. https://doi.org/10.3390/foods11030480

Sreenivasa, M. Y., Dass, R. S., Raj, A. P. C., & Janardhana, G. R. (2008). PCR method for the detection of genus fusarium and fumonisin-producing isolates from freshly harvested sorghum grains grown in Karnataka, India. *Journal of Food Safety*, *28*(2), 236–247. https://doi.org/10.1111/j.1745-4565.2008.00117.x

Subramanyam, A., Balaguravaiah, D., & Y. R, T. (2003). *Influence of weather, dryspells and management practices on aflatoxin contamination in groundnut*. https://agris.fao.org/search/en/providers/122648/records/647480af2d3f560f80b16eef

Tamilselvan, T., & Kushwaha, A. (2020). Effect of traditional processing methods on the nutritional composition of sorghum (Sorghum bicolour L. Moench) flour. *European Journal of Nutrition & Food Safety*, *12*(7), 69–77. https://doi.org/10.9734/ejnfs/2020/v12i730252

Tanwar, R., Panghal, A., Chaudhary, G., Kumari, A., & Chhikara, N. (2023). Nutritional, phytochemical and functional potential of sorghum: A review. *Food Chemistry Advances*, *3*, 100501. https://doi.org/10.1016/j.focha.2023.100501

Taylor, J. R. N., & Duodu, K. G. (2015). Effects of processing sorghum and millets on their phenolic phytochemicals and the implications of this to the health-enhancing properties of sorghum and millet food and beverage products. *Journal of the Science of Food and Agriculture*, *95*(2), 225–237. https://doi.org/10.1002/jsfa.6713

Taylor, J. R., & Duodu, K. G. (2019). Traditional sorghum and millet food and beverage products and their technologies. In John R. N. Taylor, & Kwaku G. Duodu (Eds.), *Sorghum and Millets* (pp. 259–292). Elsevier. https://doi.org/10.1016/B978-0-12-811527-5.00009-5

Tibagonzeka, J. E., Akumu, G., Kiyimba, F., Atukwase, A., Wambete, J., Bbemba, J., & Muyonga, J. H. (2018). Post-harvest handling practices and losses for legumes and starchy staples in Uganda. *Agricultural Sciences*, *09*(01), 141–156. https://doi.org/10.4236/as.2018.91011

Tripathi, G., Jitendrakumar, P. H., Borah, A., Nath, D., Das, H., Bansal, S., Singh, N., & Singh, B. V. (2023). A review on nutritional and health benefits of millets. *International Journal of Plant & Soil Science*, *35*(19), 1736–1743. https://doi.org/10.9734/ijpss/2023/v35i193722

Utono, I, . (2013). Assessment of grain loss due to insect pest during storage for small-scale farmers of Kebbi. *IOSR Journal of Agriculture and Veterinary Science*, *3*(5), 38–50. https://doi.org/10.9790/2380-0353850

White, J. M., Drummond, E., Bijalwan, V., Singhkumarwong, A., Betigeri, A., & Blankenship, J. (2023). Micronutrient gaps during the complementary feeding period in seven countries in Southeast Asia: A comprehensive nutrient gap assessment. *Maternal & Child Nutrition*, *19 Suppl 2*(Suppl 2)2, e13577. https://doi.org/10.1111/mcn.13577

Dicko, M. H., Gruppen, H., Traoré, A. S., Voragen, A. G., & van Berkel, W. J. (2006). *Sorghum grain as human food in Africa: Relevance of content of starch and amylase activities. African Journal of Biotechnology*, *5*(5), 384–395. https://www.ajol.info/index.php/ajb/article/view/137858

Xu, F., Baker, R., c., Whitaker, T. b., Luo, H., Zhao, Y., Stevenson, A., Boesch, C. j., & Zhang, G. (2022). Review of good agricultural practices for smallholder maize farmers to minimise aflatoxin contamination. *World Mycotoxin Journal*, *15*(2), 171–186. https://doi.org/10.3920/WMJ2021.2685

Zeffa, D. M., Nogueira, A. F., Buratto, J. S., de Oliveira, R. B. R., Neto, J. d S., & Moda-Cirino, V. (2021). Genetic variability of mineral content in different grain structures of bean cultivars from Mesoamerican and Andean gene pools. *Plants* , *10*(6), 1246. https://doi.org/10.3390/plants10061246

ZimVAC. (2020). Zimbabwe Rural Livelihood Assessment Report. Retrieved from Harare:http://fnc.org.zw/wp-content/uploads/2020/10/Zimbabwe-Vulnerability-Assessment-Committee-2020-Rural-Livelihoods-Assessment-Report.pdf