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REVIEW ARTICLE

Overview of Maize-Based Value-Added Foods in Ethiopia: Traditional Uses, Product Development, Industrial Applications, Storage, and Safety

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ABSTRACT

Maize holds significant importance in Ethiopia as a staple food crop, offering availability, affordability, and versatility for nutrient-dense food products. The purpose of this review was to assess maize utilization in traditional foods, its industrial application, and safety issues related to storage in Ethiopia. A systematic literature review approach was utilized to collect the number of articles published between 2012 and 2021 from databases like Google Scholar, Scopus, and DOAJ using specific search terms related to maize and Ethiopian foods. Accordingly, traditional foods like bread, injera, kitta, kurkufa, besso, fosose, and porridge, as well as drinks like tella, areki, borde, and cheka, emphasize the cultural significance of maize in the country's culinary practices. Additionally, the nutrient profile, product making potential, and aflatoxin levels for improved and released maize varieties were also evaluated. Furthermore, composite flour based on maize can enhance protein, energy and sensory attributes of complementary porridge, gruels, soup, cookies, and extruded food products in Ethiopia. A number of food processing enterprises produce value-added maize-based foods such as corn flakes, maize-soya blends, and instant maize flour, which diversifies the country's maize product market and creates economic opportunities. In Ethiopia, common storage structures for maize include gotta, gotera, sacks, underground pits, polypropylene bags and metal silos. Mycotoxins, notably, aflatoxin is harmful secondary metabolites of fungi isolated from maize stored in different storage materials, pose safety risks; that can cause health problems and financial losses. Overall, maize holds promise for food security and malnutrition relief in Ethiopia.

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1. INTRODUCTION

Maize serves as a crucial staple food crop in numerous developing nations including Ethiopia (Badu-Apraku *et al*., 2017; Jaleta *et al*., 2018). According to national agricultural data, maize is a dietary staple for about 90% of Ethiopians (CSA, 2020). Beyond its prominence as a dietary staple, maize has been skillfully incorporated into a wide array of traditional foods and beverages deeply rooted in the diverse culture of many Ethiopians' (Tadesse *et al*., 2020). The widespread adoption and integration of maize into the Ethiopian food system can be attributed to its adaptability to diverse agro-ecological conditions, high yield potential, and versatility in food processing (Yadesa and Diro, 2023). The major types of maize for human diets in Ethiopia are common maize, quality protein maize, and Provitamin A rich maize. Tryptophan and lysine, two essential amino acids that are lacking in normal types of maize, are present in sufficient amounts in quality protein maize (Alamerew, 2008; Abiose Sumbo and Victor, 2014). Lysine and tryptophan content of quality protein maize exceeds that of the common maize by 70-100% (Sofi *et al*., 2009).

Protein energy malnutrition and micronutrient deficiency are persistent among vulnerable population groups like school aged children, pregnant, lactating women, and the elderly in Ethiopia (Herrador *et al*., 2014; Rodamo *et al*., 2018; Zewdie *et al*., 2021). The main reasons for these chronic nutrition problems might be the limited knowledge of diet diversification, inadequate consumption of balanced diet and low awareness on nutrition education (Nair *et al*., 2016). Quality protein maize has paramount role to reduce protein energy malnutrition, alleviate hunger, and improve livelihoods (Vivek *et al*, 2008). Fortification and enrichment of maize flour with oils, vitamins, and minerals rich legumes, fruits, vegetables, roots, and tubers are promising approaches to improve micronutrient intake and mitigate protein energy malnutrition. There are regional differences in the kinds of food and methods for preparing food from maize in Ethiopia. For instance, maize is the main ingredient in the cuisines known locally as *kurkufa, fosose, and genfo* in the southern Ethiopia. Traditionally, fermented and non-fermented products such as Bread, *kitta, injera*, local drinks like *tella, areki, shameta, borde,* and other foods are made from maize and consumed by people in the state of Oromiya and other neighboring regions. Maize is one of the main ingredients used in the production of *borde, tella, and areke*, according to Tafare (2015). Maize also has wide industrial applications and plenty of value-added products can be processed from it in Ethiopia. Instant maize flour, maize - soya blend, corn flakes, are among value added maize products produced by Fikir food processing, Dina food processing, and family flour factory in Ethiopia.

This review was aimed to assess the maize utilization in the traditional foods, beverages, complementary foods, its industrial application, research on maize-based foods, storage and safety in Ethiopia.

2. METHODOLOGY

This review article was prepared by employing a systematic literature review approach. Several literature searches were performed to obtain relevant articles published between 2012 and 2021 in the recognized data bases such as Google scholar, African journal online (AJOL), Scopus and Directory of open access journals (DOAJ). Terms that were used in the search engine included injera, unleavened flat bread, complementary foods, snack foods and traditional beverages related to maize in Ethiopia. All articles that reported traditional foods, beverages, injera, Kitta (unleavened flat bread), porridge, gruels, instant complementary food, and complementary flour prepared using maize based ingredients, published in English in peer reviewed journals were included. A total of 47 papers were collected and 24 of them were included in this study based on set inclusion criteria. Qualitative studies, short communication, and commentaries with inadequate information on maize value addition were excluded from this review. Some reports outside 2012 to 2021 were included for preparation of this manuscript to show general facts and over all importance of maize. Additional Published works, reports from international organizations, and proceedings on maize based value addition were also searched from Google and utilized in the preparation of this manuscript. Furthermore, nutritional significance, storage, and safety on maize and maize based value-added foods were highlighted in this manuscript.

3. NUTRITIONAL VALUE AND HEALTH BENEFITS OF MAIZE

Maize is good source of energy, carbohydrates, fiber, quality protein, antioxidants, some vitamins, and minerals. It contained about 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100g as compared to rice and wheat, but has lower protein content (Nuss *et al*., 2010). It is also a valuable source of B vitamins, essential minerals, and dietary fiber (FAOSTAT, 2021). Maize accounts for 40% of the cereal production in Sub-Saharan Africa, where more than 80% is consumed as food. It contributes at least 30% of the total calorie intake for the population, with individual consumption ranging from 52 to 450 g/person/day. In Latin America, maize consumption varies from 50 to 267 g/person/day (Poole et al., 2020; Prasanna et al., 2021). Certain vitamins, such as the B-complex, A, and C, which are derived from foods made from maize, are good for heart health, brain function, skin health, and immune system stimulation (Rouf Shah *et al*., 2016; Sarwar *et al*., 2022). Naturally, the numerous carotenoids present in maize, such as beta-carotene (provitamin A), zeaxanthin, lutein, and cryptoxanthin, have been demonstrated to offer a variety of health benefits, ranging from reducing oxidative stress to preserving normal vision (Masisi *et al*., 2015).

Maize is a highly valued source of oil for human consumption because it lowers blood cholesterol levels. Essential fatty acids, particularly linoleic acid found in corn oil, are vital for blood pressure maintenance, blood cholesterol regulation, and the prevention of cardiovascular illnesses (Sokola-Wysoczańska *etal.*, 2018). Moreover, the presence of resistant starch, sometimes referred to as high-amylose, in maize has been linked to positive impacts on human health. The small intestine is unable to fully digest and absorb resistant starch found in maize. However, consumption of resistant starch can alter the microbial populations by increasing levels of beneficial bacteria and reducing harmful microorganisms exerting positive impact on gut health. It can also enhance the excretion of cholesterol in the stool, preserve colon health, lower the risk of diabetes, boost fermentation and the large intestine's production of short-chain fatty acids, and reduce the risk of obesity-related conditions, atherosclerosis, and cancer (Ashwar *et al*., 2016). Eating maize can influence the metabolism of cholesterol and reduce body fat buildup, hence reducing the risk of obesity, diabetes, hyper lipidemia , and atherosclerosis (Bello et al., 2021; Wang et al., 2024).

Maize is also well-known for being a substantial source of a number of phytochemical compounds, including phytosterols, phenolic compounds, and carotenoids. Such phytochemicals are essential for preventing chronic illnesses and may have antioxidant qualities (Nawaz, 2018; Siyuan *et al*., 2018). Consuming products derived from fermented foods including maize may help prevent and treat illnesses such as intestinal infections, oxidative stress, diabetes, hypertension, hyper lipidemia, and numerous cognitive impairments (Diez-Ozaeta and Astiazaran, 2022). In 2018, seven maize varieties collected from Bako and Melkassa Agricultural Research Centers were evaluated for their nutrient composition (Table 1). According to the finding, the proximate composition of maize varieties in % ranged from 9.42 - 11.45, 1.37 - 1.74, 5.13 - 7.22, 9.69 - 15.30, 1.62 - 3.45, 62.13 - 69.99 for moisture, total ash, crude fat, protein, fiber, carbohydrate, respectively. The energy value of maize ranged from 365.93 to 385.82 Kcal/100g. In addition, the mineral contents like iron (Fe), zinc (Zn) and calcium (Ca) of maize in mg/100g were ranged from 2.34 - 3.73, 2.31 - 2.93 and 31.25 - 48.1, respectively. The minimum total carotenoids in the yellow maize varieties were 11.43 (Melkassa 7) and the maximum was 27.62 µg/g (Melkassa 1Q). No carotenoid was detected in the white maize variety like Bako hybrid 660 (Demeke, 2018). As shown in Table 1, the highest protein content was found in BHQPY 545 maize variety while the lowest protein content was recorded in Melkassa-2 maize variety. The highest calcium content was found in Melkassa-6 maize variety while the lowest calcium content was recorded in CML 165 maize inbred line.

Another study, which focused on the evaluation of the proximate compositions and essential amino acid, tryptophan content of 37 Ethiopian maize varieties revealed that ash, moisture, fat, protein, crude fiber and total carbohydrates contents of 37 maize varieties were in a range of 0.90% – 1.53%, 8.52% – 12.86%, 4.01% – 5.99%, 7.48% – 11.60%, 1.39% – 2.05%, 67.64% – 74.88%, respectively. Tryptophan levels in different QPM varieties ranged from 0.04 to 0.11% in grains of five QPM varieties (BHQPY545, BHQPY548, MHQ 138, Melkasa-6) implying all fulfil the tryptophan content threshold of quality protein maize (Girmay *et al*., 2019).

4. MAIZE BASED FOODS AND BEVERAGES

4.1. Traditional foods

In Ethiopia, the history of traditional foods and beverages dates back to the early days of crop domestication and agricultural innovation. It is associated with celebrations such as holidays, festivals, social gatherings, funerals, honoring guests, and special occasions (Anteneh *et al*., 2011). The integration of maize into the traditional food culture of Ethiopia has led to the development of a diverse repertoire of indigenous maize-based recipes and preparations (Hall and Sharples, 2008). There were some achievements in developing and improving Ethiopian traditional maize-based foods. The most common maize based Ethiopian traditional foods are Injera, Genfo (porridge), Kita, other maize products (**Table 2**).

Injera: It is a traditional fermented flatbread that served as the widely consumed dish among most Ethiopians (Tadesse, 2020). Yasin, (2021) conducted a study to evaluate the effect of proportion and fermentation on the textural and visual qualities of injera prepared from a blend of quality protein maize and teff flours. It was found that a composite flour of Melkassa 6Q to teff (Magna) in a ratio of 60:40, fermented for 72 hours, showed the highest number of eyes and the lowest texture in the injera. According to Abraha and Abay (2017) injera prepared from 50:50 ratio of 545 BHQPY and *Cimama* teff variety showed similar sensorial acceptability with that of 100% teff injera.

Kitta: It describes a range of unleavened breads made from maize and other cereals and baked on a flat griddle and widely consumed as family food in southern Ethiopia (Bassore and Desalegn, 2017). These breads can be filled with different ingredients, including spicy meat or beans, or they can be left plain (Abebe *et al*., 2007). A variety of composite flours, including amaranth and maize can be used in the production *kitta* (Bassore and Desalegn, 2017). Similarly, micro-nutrient rich and acceptable *kitta* was prepared maize and orange-fleshed sweet potatoes composite flour (Tadesse *et al*., 2015). ***Kurkufa and fosose***: *Kurkufa* is a traditional food made with cooked kale and maize flour and topped with tomatoes, onions, and garlic (yetneberk *et al*., 2000). It is a product that resembles porridge but has better nutritional composition derived from added ingredients. It is widely known and consumed in the southern Ethiopia. The other traditional maize based food product is locally called *fosose* that can be prepared by mixing boiled haricot bean and maize flour and cooked by adding it into sauce prepared from onion, garlic, oil or butter in metal pan. Haricot bean garlic, onion, tomatoes supplements protein fat, minerals and vitamins that improves the overall nutritional status of the product.

Table 1. Proximate composition and some mineral contents of maize grown in Ethiopia

Varieties	Moisture (%)	Ash value (%)	Crude protein (%)	Crude fat (%)	Crude fiber (%)	Carbohydrate (%)	Energy (kcal/100g)	Calcium (Ca) (mg/100g)	Iron (Fe) (mg/100g)	Zinc (Zn) (mg/100g)
CML 161	11.31	1.40	12.03	5.13	2.22	67.91	365.93	34.39	3.70	2.50
Melkasa-1q	9.42	1.53	13.11	7.22	1.62	67.10	385.82	30.86	2.34	2.46
BHQMY 545	10.62	1.74	15.30	6.71	3.45	62.13	370.27	34.92	2.46	2.48
CML 165	9.93	1.62	9.69	6.14	2.63	69.99	373.98	21.98	3.73	2.31
Melkassa-7	9.91	1.63	11.92	4.98	2.46	69.10	368.90	36.32	3.27	2.93
Gibe Awash	11.01	1.46	10.27	6.05	2.26	68.95	371.33	48.10	3.18	2.92
BH 660	11.45	1.37	12.32	5.33	1.82	67.71	368.09	31.25	2.39	2.52
Melkassa -2	9.68	1.58	9.23	5.87	3.73	73.64	384.31	3 4.54	3.60	2.94
Melkassa-6	9.47	1.49	10.22	5.32	2.30	80.67	411.4	63.05	2.93	2.87

***Source :** Demeka, 2018 ; Asrat Yasin, 2019 ; Feyera et al., 2020*

4.2. Traditional beverages

In addition to the diverse range of maize-based foods, the Ethiopian culinary tradition also features a variety of traditional maize-based beverages that hold cultural significance and served in various social functions. These include, ***tella*,** a traditional fermented Ethiopian cereal-based drink, that utilizes maize, wheat, barley, sorghum and millets as a key ingredients. A small amount of sprouted cereal flour and hops are added for flavor and taste during tella preparation. It is often consumed during social gatherings, religious ceremonies, and cultural events. Furthermore, the fermentation processes involved in the production of beverages like tella can lead to the formation of beneficial compounds, such as probiotics, which can contribute to digestive health and overall well-being. The maize and other cereals utilized as a major component in the production of tella are attributed to variation in alcohol levels, proteins, unique taste, and other sensory acceptability of prepared *tella*. ***Areki****:* The fermented products can be distilled to produce *Areki*, a concentrated alcoholic beverage using traditional distillation process (Mulaw *et al*., 2020). In Ethiopia, it is a popular alcoholic beverage that is consumed in both urban and rural settings. ***Borde***: It is a traditional, non-alcoholic beverage made from fermented maize and other cereals that is well-liked in southern and western parts of Ethiopia having short shelf life (Blandino et., 2003; Nemo and Bacha, 2021). *Borde* is thought to improve lactation, and after giving birth, lactating mothers are advised to consume large amounts of borde in areas where borde producing is popular.

Cheka: It is a traditional fermented beverage made from cereals that is mostly enjoyed in Darashe, Konso, Alle, and their surrounding areas in southwest Ethiopia (Worku *et al*., 2015). Grain ingredients like barley, wheat, finger millet, sorghum, maize, and certain vegetable additions are commonly used to make it. Maize can be used as a major ingredient by the Konso community in the production of *cheka* for home consumption and commercial purposes.

Table 2. Traditional foods formulated from maize based flour

Products	Formulation	Key objectives and findings	References
Kitta	*Kitta* (flatbread) was prepared using a blend of maize and orange-fleshed sweet potato (OFSP) flours in ratios of 75:25, 70:30, and 65:35, alongside a 100% control sample from maize.	Address limited provitamin A contents present in maize flour, replacing up to 35% of maize flour with OFSP flour resulted in acceptable kitta (flat br ead). Moreover, an increased β-carotene content was observed as the proportion of OFSP in the blend was increased.	Teferra et al. (2015)
Kitta	Amaranth flour (10-20%) obtained from soaked, steamed, and untreated grains was incorporated into maize flour (80-90%) to formulate kitta.	Incorporating pre-treated amaranth flour up to 20% with maize is recommended, as it was well-received by consumers and also enhanced the nutritional value of the product.	Bassore & Desalegn, (2017).
Kitta	Flatbread was formulated using blends of kocho, broad bean, and QPM flours at various ratios: 50:35:15, 50:30:20, 50:25:25 and 50:20:30 respectively. A control flatbread was prepared using 100% kocho.	The findings indicate that blending kocho with broad bean and QPM enhances the nutritional value of flatbread without compromising its sensory quality. A recommended blend for flatbread making is 50% kocho, 25% broad bean, and 25% QPM flour mixture.	Serka *et al.* (2019)
Kitta	*Kitta* was developed using a composite flour of germinated maize and stinging nettle (Urtica simensis) leaf powder in ratios of 90:10, 85:15, 80:20, and 75:25, alongside a 100% control sample.	Supplementing maize flour with up to 15% nettle flour resulted in sensory acceptable *kitta*. Furthermore, treatments such as soaking nettle leaves with ethanol shock are recommended to enhance the recovery of nutrients.	Diddana et al. (2021)
Traditional bread (*diffo debo*)	Bread was formulated using common maize (85-95%) and Quality Protein Maize (85-95%), blended with soybean (5-15%) and cassava flours (5-15%).	Nutritionally enhanced *diffo debo*, maintaining quality, can be achieved by incorporating up to 15% soybean flour and substituting 10% of wheat flour with cassava flour.	Mesfin and Shimelis (2013)
Traditional bread	Bread was formulated using germinated maize variety of BH-660 (65-82.2%),	The optimum blend, achieving acceptable sensory evaluation, consisted	Abera et al. (2014)

Products	Formulation	Key objectives and findings	References
	soybean (10-30%), and moringa leaf powder (5-10%) in varying proportions.	of 75.7% maize flour, 17.5% soybean flour, and 6.8% moringa leaf powder.	
Injera	Teff (50-100%), sorghum (0-50%), and maize (Melkassa-6Q) (0-50%) flours were combined using a simplex lattice coded design to create acceptable injera.	Fermented products rich in probiotic and amino acid profile. Nutritionally and sensorially acceptable injera was prepared using an optimized ratio with the proportion consists of 55.4% teff, 37.3% sorghum, and 7.3% maize flour.	Legesse, (2015)

4.3. Complementary foods

In addition to breast milk, complementary foods are provided to older infants and young children after six months of age to meet their calorie, protein, and micronutrient requirements (Bhandari and Chowdhury, 2016). According to the 2019 International Classification of Functioning, Disability and Health (ICF) and Ethiopian Public Health Institute (EPHI), 21% of Ethiopian children were underweight, 7% were wasting, and over 37% were stunted. Stunting, underweight, wasting, micronutrient deficiencies, overweight, obesity, and other diet-related non-communicable diseases can all be managed with an adequate intake of complementary foods (White *et al*., 2017).

Combinations of maize, legumes, fruits, vegetables, roots, and tubers were used to formulate cost effective, wholesome, and culturally acceptable complementary porridge, gruels, soup, and instant flour in Ethiopia. Composite flour made up of 36% germinated quality protein maize, 36% germinated chickpea, 18% orange fleshed sweet potato, and 10% red teff flour was utilized in the production of complementary porridge with good protein, fat, zinc, and iron content as well as decreased viscosity (Desalegn *et al*., 2015). Enhanced protein and sensory acceptable complementary porridge was formulated from varying proportions of broad bean, barley and maize (Kebebu *et al*., 2013).

Nutritious and sensory acceptable complementary porridge made from maize-based composite flour has been reported in several investigations (Table 3). The complementary porridge prepared from *anchote*, carrot, and soybean in addition to maize showed high protein, mineral, and β-carotene composition (Tsigereda, 2016). Complementary gruel made by combining soybeans with maize exhibited increased protein, nutrient density, and energy value (Buta and Emire, 2015). Furthermore, a protein-rich complementary food was developed using composite flour composed of maize, roasted peas, and malted barley (Fikiru *et al*., 2017). Additionally, a micronutrient and protein-rich complementary food was developed by combining taro and soybeans with maize flour (Melesse, 2018). The incorporation of peas and *anchote* in the production of maize-based complementary food contributed to an increase in protein and energy content (Gemeda, 2020). Similarly, a protein and micronutrient-rich complementary porridge was made from fermented maize, haricot beans, and cooking banana flour (Feyera, 2019).

Table 3. Complementary foods formulated from maize flour in Ethiopia

Products	Formulation	Major findings	References
Complementary food	Complementary food was formulated using flour derived from untreated, soaked, and germinated QPM and chickpea grains, combined with Orange-Fleshed Sweet Potato and red teff flour.	Addition of germinated chickpeas and maize to formulated blends significantly enhanced the protein content of the maize based complementary flour over other blends. Protein content ranged from 10.42 for soaked QPM 36g+soaked chickpea 36g+red teff 10g+OFSP 18g based complementary flour to 12.70 g/100g for germinated QPM 36g+germinated chickpea 36g+red teff 10g+OFSP 18g based complementary flour. Beta-carotene composition of complementary flour increased from 291.63+1.91µg/100g to 565.09+4.41 µg/100g for complementary flour composed of germinated QPM 43gm+germinated chickpea 29g+red teff 10g+OFSP 18g flour, and complementary flour consists of raw QPM 43g+raw	Berhanu, (2013)

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Products	Formulation	Major findings	References
		chickpea 29g+red teff 10g+OFSP 18g flour, respectively. Study demonstrated that the use of locally available and affordable ingredients to enhance the nutritional quality of complementary foods. In addition, the best result was achieved with a blend consisting of 36% germinated QPM, 36% germinated chickpea, 18% OFSP, and 10% red teff flour. This combination resulted in complementary porridge with increased protein, fat, zinc, and iron content, along with reduced viscosity.	
Complimentary food	Porridge was developed from 10% broad bean, 63% barley and 27% maize flour; 20% broad bean, 56% barley and 24% maize flour; 30% broad bean, 49% barley and 21% maize flour as well as barley-maize (70:30) as a control.	The study showed that broad bean containing maize porridge had a higher protein content and sensorially porridge having 10% broad bean flour was the most preferred.	Kebebu et al. (2013)
Complementary food	Complementary porridge was prepared using composite flours of 48hr germinated maize, pumpkin pulp, and pumpkin seeds in ratios of 80:10:10, 60:20:20, and 40:30:30, alongside a control sample made with 100% ungerminated maize.	The ratio of 40% germinated maize, 30% pumpkin pulp, and 30% pumpkin seeds showed significantly increased levels of zinc, vitamin A, energy, protein, fat, and fiber, with acceptable sensory qualities.	Tona Zema et al. (2015)
Complimentary foods	Complimentary food was formulated from QPM (BHQPY-545) (45-85%), anchote (10-20%), carrot (5-15%) and soybean (0-20%) flour blends using D-optimal mixture design.	Based on nutrient, calorie, mineral, β-carotene and sensory results, optimized proportions were found from 55% QPM, 10% anchote, 15% carrot and 20% soybean flour blends.	Kebede (2016)
Complementary food	Complementary porridge was formulated using a blend of malted barley flour (4-12%), de-branned maize flour (55-90%), and roasted pea flour (20-35%) using a D-optimal mixture design.	The study's finding concluded that a nutritionally and Sensorially acceptable complementary food achieved by blending maize, pea, and malted barley flours within the ranges of 55.0-68.5% maize, 27.5-35.0% pea, and 4-10% malted barley.	Fikiru et al. (2017)
Complementary food	Complementary food was developed using optimization methods, combining pre-gelatinized taro flour (40-50%), maize (30-40%), and soybean (20-30%) flour.	The optimized formulation for complementary food showed that a blend containing 50% taro flour, 30% maize flour, and 20% soybean flour achieved the best results.	Melese (2018)
Complementary food	A blend of maize (BH-66) (45-61%), pea (23-31%), and anchote	A blend of 53.90% maize, 31.0% pea, and 15.10% anchote flours resulted a good	Gemede (2020)

Products	Formulation	Major findings	References
	(14-28%) flours was formulated using a Mixture design to develop complementary diets.	and acceptable complementary food. The formulation is also recommended as a suitable to alleviate protein energy malnutrition and it can be used as a substitute for the expensive commercial complementary food.	
Complementary food	Complementary food was formulated using flours of maize, pigeon pea, and sun-dried moringa leaf at various ratios.	Nutritionally enhanced and sensorially acceptable complementary food was obtained using 85% maize, 10% moringa, and 5% pigeon pea flours. Increasing the proportion of moringa above 10% resulted in decreased sensory acceptability.	Badebo and Eyesa, (2021)
Complementary food	Complementary porridge was developed using fermented maize (Melkassa-2) and haricot bean's, fermented for 0, 24, and 36hrs, combined with cooking banana with the mixing proportion of 65:20:15, 60:30:10, 50:35:15, and 30:60:10 (maize: haricot beans: cooking banana). Additionally, a control sample was prepared using 100% maize flour.	Nutritionally and sensorially acceptable porridge was achieved by using a composite flour consisting of 60% maize and 30% haricot bean flours (fermented for 24 hours), then mixed with 10% cooking banana flour.	Milkesa (2021)
Weaning food	Weaning gruel suitable for the age group of 6 to 18 months was developed from a blend of QPM (BHQPY-545) and soybean flours. The flours were fermented for 0hr, 24hr, and 48hr using natural and controlled fermentation methods, with particle size distributions of <500µm and <250µm.	Sensorially acceptable product with higher energy and nutrient density was obtained using a formulation of 82% QPM and 18% soybean, fermented for 24 hours with flour particle sizes less than 250µm. Less viscous gruel was also found with improved dietary qualities.	Buta and Emire (2015)

4.4. Snack foods

Maize plays a vital role in household consumption, both in rural and urban areas of Ethiopia. In rural areas, maize dominates consumption baskets, providing an average of 436 calories per capita, whereas in urban areas typically receive only 107 calories per capita from maize-based foods (Demeke, 2012). Many studies have made significant efforts to promote the use of composite flour in various snack food formulations (Noorfarahzilah *et al.*, 2014; Oduro-Obeng and Plahar, 2017). This involves partially substituting maize with a combination of other cereals like teff, rice, sorghum, wheat, and barley, as well as incorporating pulses, roots, tubers and other ingredients (Reddy *et al.*, 2014).

People of all ages consume snack food on a large scale worldwide. Snack food is high in carbohydrates, fats and calories, but low in protein, fiber, vitamins and minerals. There are a number of ready-to-eat snack foods like bread, cookies, biscuits, and extruded products that are made only from maize and its composite flour (Table 4). Some protein -rich maize-based formulated snack foods in Ethiopia were, extruded product made from maize, defatted soya bean and chickpea (Taye, 2013). Another protein enhanced extruded snack food was prepared by incorporating lentil into maize flour (Taye, 2013). Protein and energy dense maize based composite bread was also prepared using soybean and cassava as composite flour (Mesfin and Shimelis , 2013). ; Similarly, protein and micronutrient rich composite bread was developed from germinated maize, soybean and moringa leaf powder based composite flour(Abera *et al.* 2014). Supplementation of broad bean and kocho to quality protein maize was utilized in the production of improved protein and energy content of flat bread (Serka *et al.*, 2019).

Table 4. Cookies and extruded product formulated from maize flour

Product	Formulation	Major findings	References
Cookies	Cookies were developed using a blend of wheat flour (60-100%), QPM flour	The study concluded that cookies made from a blend of 10% dried carrot powder,	Tesfaye and Zegeye (2010)

Product	Formulation	Major findings	References
	(5-20%), and dried carrot powder (5-20%). The baking temperature was evaluated at 150°C, 175°C, and 200°C, with a baking time of 10 minutes.	10% QPM flour, and 80% wheat flour, baked at 175°C, resulted in superior quality compared to cookies made from other formulations.	
Extruded product	A protein-enriched ready-to-eat (RTE) extruded product was developed by blending 589g/kg maize flour (BH-660), 291g/kg defatted soy-flour, and 120g/kg chickpea flour under various processing conditions. These conditions included different moisture levels (17% and 20%), barrel temperatures (120°C, 130°C, and 140°C), and screw speeds (150 rpm, 200 rpm, and 250 rpm).	According to sensory evaluation results, the extrudate produced with a moisture content of 17%, a temperature of 140°C, and a screw speed of 200 rpm was rated as the most preferred product.	Abyneh (2013)
Extruded product	Expanded food (extruded snacks) product was formulated from lentil (10%, 30% and 50%) and corn (BH-660) flour (50%, 70% and 90%) mixes.	A blend of 47.8% lentil flour, 52.2% corn flour on dry weight basis processed at 15.82% moisture content and a barrel temperature of 181.97°C was selected as the best formulation to yield a protein rich extruded product with desirable physical and functional attributes	Tadesse (2014)

4.5. Industrial maize-based food products in Ethiopia

Maize can be used as raw materials in the processed food, pharmaceutical, confectionery and other related industries (Sofi *et al*., 2009; Poole *et al*., 2021). In Ethiopia, some of the major industrial maize products include maize flour, corn oil, infant foods, corn starch, and corn flakes (Alemu *et al*., 2014). These products make a considerable contribution to the local economy, food security, serving both domestic and export markets (Table 5). Maize (*Zea mays L.*) is the third most prominent cereal crops widely grown throughout the world after wheat and rice. It serves as an important source of food and nutritional security for millions of people, particularly in the developing regions of Sub-Saharan Africa and Latin America (Shiferaw *et al*., 2011). Most of the maize produced in developed world is used for animal feed and as a raw material for processed food, pharmaceutical, confectionery and related industries (Sofi et al., 2009).

Maize is a more versatile and multifunctional crop when compared to other cereal crops. It serves a variety of purposes, including as an industrial and energy crop in wealthy economies and as a food security measure in underdeveloped economies (Poole et al., 2021). In Ethiopia, maize is expanding beyond its role as a staple food to become a significant industrial commodity. Some of the primary industrial maize products produced in Addis Ababa and its surrounding areas include maize flour, corn oil, corn starch, and corn flakes (**Table 5**). These products make a considerable contribution to the local economy, serving both domestic and export markets. Currently, there are only a few maize flour producers in Ethiopia, and their annual production is significantly lower than the demand for maize flour in the country.

Table 5. Industrial based food products from maize in Ethiopia

Products	Factory name	Location	Production capacity
Maize flour	Gelan Gets Food Processing Plant	Gelan town, Oromiya	1200 quintals/day
Corn flour	Zesso flour	Furi, Shegger city, Oromiya	12,000 tons/month
Maize flour	Enat flour	Addis Ababa	1000 quintals/day
Maize flour	Dina food processing	East Shewa, Awash Melkassa, Oromiya	2000 quintals/day
Corn-soya blend	Faffa Food Complex, GUTS Agro-Industry	Addis Ababa	5,000 and 10,000 tons
Corn flakes	Ethio-Maize Products and Agro-Industry		
Corn oil	Guder Agro-Industry PLC	Addis Ababa	

Source: Face to face interview with factory general manager

4.6. Maize storage and safety

Farmers can store excess maize for an extended time in safe storage methods. The preservation of nutritional composition and prevention of microbial contamination in maize are achieved by appropriate storage conditions and structures (Worku *et al*., 2022). Ethiopian farmers used a variety of methods for storing maize, including gotta, gotera, sacks, polypropylene bags, underground pits, and metal silos (Worku *et al*., 2019). Despite of the various storage structures, the storage conditions practiced by farmers are at room temperature that might varied from one location to another. The secondary metabolites of fungus called mycotoxins are the main safety issue in maize and are harmful to humans, animals and result in both illness and financial losses (Awuchi *et al*., 2021). Aflatoxin, fumonisin, deoxynivalenol, and ochra-toxin are the major mycotoxin capable of contaminating maize and maize based food products (Bullerman, 2014). Mycotoxin contamination contributes to hunger and malnutrition by directly reducing food availability (Udomkun *et al*., 2017). According to Logrieco *et al*. (2018), mycotoxin contamination has a detrimental effect on small-holder farmers' income and health as well as regional, global trade and economy. The East African community has established maximum tolerable values for total aflatoxin (10ng/g) and total fumonisin (2 μg/g) in maize grains (EAC, 2013). In addition, the European Commission (2006a) set a maximum permissible level of deoxynivalenol (0.75 μg/g) and ochra toxin (5 ng/g) in food products.

According to Worku *et al*. (2019), the mean concentrations of aflatoxin, fumonisin, deoxynivalenol, and ochratoxin in a sample of maize taken from five possible potential maize growing districts in Ethiopia, namely: Mer-Awi, Wenberma, Halaba, Chelia, and Toke Kutaye were 14.7±11.6 ng/g, 0.68±0.94 μg/g, 0.65±0.46 μg/g, and 8.2±30.6 ng/g, respectively. These mycotoxin were detected in collected maize samples stored in *gotta*, *gotera* and polypropylene bags for six to 7 months of storage. Maize and maize based food products are mostly affected by aflatoxin and ochratoxin, which have been found to be present above the maximum limit of tolerance. In a separate study, aflatoxins B1 and G1 were detected in nine maize samples from a total of 43 maize samples collected from Bako, Ambo and Melkassa areas. The maize samples were stored in *gotera*, and polypropylene bags before collected for the study. The highest levels of aflatoxin G1 and aflatoxin B1 were detected in maize samples collected from Bako at 4.14 μg/kg and 1.28 μg/kg respectively, while in maize samples collected from Ambo, the highest level of aflatoxin B1 and G1 was found to be 1.24 μg/kg and 0.52μ g/kg, respectively (Alemayehu and Demirew, 2022).

CONCLUSIONS

Maize is a staple food crop with great promise for affordability, availability, and versatility when combined with other crops to provide a variety of nutrient-dense food products. It can be used as an ingredient in the production of cultural foods such as porridge, fosose, and unleavened bread, as well as industrial inputs for the production of corn flakes, snack foods, instant maize flour, and corn soya blend flour. Maize also has the potential to improve micronutrient intake and mitigate protein-energy malnutrition by complementing pulses, root and tubers, fruits, vegetables, and oil crops. The BHQPY 545 maize variety had the highest protein content, while the Melkassa-6 maize variety had the highest calcium content and energy levels. Mycotoxins (Aflatoxin and Ochratoxin) are potential safety issues in maize and maize-based food products.

6. FUTURE RESEARCH DIRECTION

Future food and nutrition research direction on maize should focus on the key areas including; Screening of maize varieties with high pro vitamin A, high zinc kernel and amino acids for nutrient fortification. In addition, high starch content for the starch-extracting industry as well as maize with superior flour functional, rheological, and pasting properties for bakery, and breakfast snack industries. Similarly, development of nutrient dense and acceptable maize based food products for targeted groups, and evaluation of the structural and compositional aspects of maize flour to determine its behavior during processing and baking require further study. Furthermore, study on the interactions between starch, protein, and other components in maize flour during food processing, mitigation mechanism of safety issue for maize and maize based food products need attention. Strengthen the linkages between food technologists, breeders and food processing companies, and provide access to ensure the availability of lab-scale maize processing machines need future consideration.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

No generated data was used during and for preparation of this manuscript.

AI/LLM USE DISCLOSURE

AI/LLM tools were not used for literature searches, gathering background information, and rephrasing/editing certain sentences for clarity and language improvement. All content was reviewed, verified, and fully approved by the authors, who take complete responsibility for the manuscript.

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