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REVIEW PAPER

Maize nutritional quality and value addition: a brief overview

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Abstract: Maize is a major cereal crop that is known as the "Queen of Cereals" due to its numerous uses and high productivity potential. Maize is not only one of the most significant cereal crops in India but the world as well. It is crucial for both human and animal nutrition in general and for fulfilling the calorie and protein needs of millions of people in emerging nations. Due to unhealthy life style and habits of the present generation, many health problems have been noticed in the last two decades. Multigrain concepts of nutrition can play a significant role to mitigate these health challenges. As we all know that maize has a lot of fiber, antioxidants, and other vitamins and minerals. Various value-added products prepared from maize have the potential to alleviate nutritional disorders. In view of above, the current article describes the nutritional quality along with the potential and opportunity for countless value-added products made from maize, which are crucial for dietary and economic stability.

Keywords: Maize · Nutritional quality · QPM · Value added products

Introduction

Southern Mexico and Mesoamerica saw the domestication of maize (*Zea mays* L., often known as corn) more than 9,000 years ago (Awika, 2011; Kennett *et al.*, 2020). Despite maize's later domestication and relative isolation until European settlement in the Americas, maize has rapidly spread throughout the world since then and has become the leading global staple cereal in terms of annual production exceeding 1 billion metric tonnes (Garcia-Lara *et al*., 2019). A significant portion of the human diet is made up of the three primary global staple cereals: wheat, rice, and maize, which together account for an estimated 42% of the world's food calories and 37% of the average protein intake (FAO STAT 2021).

The total area of maize (for dry grain) in the world is 197 M hectares, with significant regions in Asia, Latin America, and sub-Saharan Africa (SSA) (FAOStat, 2021). In many nations, particularly in SSA, Latin America, and a few nations in Asia, it is a well-established and significant crop for human consumption, accounting for more than 20% of food calories there (Shiferaw *et al*., 2011). In comparison to wheat and rice, maize is a more adaptable crop with a wider range of uses. It has a variety of roles as an industrial and energy crop in developed economies, where it is largely used as a crop for livestock feed. The demand for maize as feed is increasing along with economic development (including income growth and urbanization), which is driving the consumption of animal-source foods (Table 1).

Throughout the past ten years, there has been a rise in interest in agri-food systems (Brouwer *et al*., 2020; Fanzo *et al*., 2021; HLPE, 2017; IFAD, 2021). This partly reflects worries about How to effectively provide for the recent global food crisis the expanding global population within the parameters of the planet (Willett *et al.*, 2019) and in the setting of global warming (Jones and Yosef, 2015). It has an impact on a heightened curiosity about agri-food system results, whether it is concerning nutrition and food, environmental sustainability, livelihoods, inclusion, and the prospect for resilience to restructure agri-food systems to enhance these. Thus, agri-food systems are crucial for the 17 goals of the

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Table 1. Global cereals production statistics (annual averages for dry grain only)

		1993–95 (TE1995)	2017–19 (TE2019)	2021-2022 (TE2022)	Relative change (%)
Maize	Area (Million ha, M ha)	135	197	206.87	
	Production (Million ton, Mt)	521	1,137	1216.03	118%
	Yield (t/ha)	3.9	5.8	5.88	50%
Rice (Paddy)	Area (M ha)	148	164	165.92	11%
	Production (Mt)	538	757	513.97	41%
	Yield (t/ha)	3.6	4.6	4.63	26%
Wheat	Area (M ha)	218	216	221.74	-1%
	Production (Mt)	545	757	779.21	39%
	Yield (t/ha)	2.5	3.5	3.51	40%
Other cereals	Area (M ha)	191	149	147.8	-22%
	Production (Mt)	315	301	300.5	-4%
	Yield (t/ha)	1.6	2.0	2.12	23%
All cereals	Area (M ha)	692	727	735	5%
	Production (Mt)	1,919	2,952	3142	54%
	Yield (t/ha)	2.8	4.1	4.6	46%

Source: FAO Stat (2021). TE: triennium ending

2030 Agenda for Sustainable Development SDGs (Fanzo), Sustainable Development Goals.

Maize kernel composition and anatomy

In general maize kernel is a good source of proteins, carbohydrates, lipids, and some of the essential minerals and vitamins. Especially the large and small nutrients in the maize kernel importantly contributed to its improved food plus feed quality. Besides, Maize also has highest energy (ME 3350 kcal/kg) among cereal grains. As a result, maize is known as a nutritional cereal (Table 2).

The endosperm, germ, pericarp, and tip cap make up 83%, 11%, 5%, and 1%, respectively, of the maize kernel's four main structural components. Starch makes up the majority of the endosperm, which is encased in a protein matrix. The two primary forms of starch are opaque and hard or vitreous. Starch degradability and in vivo starch digestibility in ruminants are inversely correlated with the former (Gunaratna *et al*., 2010). The maize kernel's embryo, also known as the germ, contains nutrients and enzymes necessary for the growth and development of new maize. Its fat content is also significantly high (around 33.3%). The germ of the kernel has around 80% of the mineral content, but the endosperm only possesses 1%. The three most common minerals are phosphorus (in the form of phytate), potassium, and magnesium, which together account for almost 85% of the mineral composition of kernels. Sulfur, which is mostly found in organic form as a component of methionine and cystine, is the fourth most common element. Moreover, the germ includes anti-oxidants including vitamin E. Except for the tip cap, the endosperm, and germ are surrounded by a high-fiber (8.8% crude) semipermeable barrier called the pericarp. During kernel development and the kernel dry-down period, moisture and nutrients pass through the tip cap. On the tip cap, the black layer, or hilum, serves as a seal. Due to the genetics of the endosperm sink, maternal parent, and environment, maize kernels are amenable to changes that change their nutritional content (Nuss and Tanumihardjo, 2010).

Table 2. Status of macromolecules, nutrients, and minerals in maize (composition per 100 g of edible portion of maize)

Parameter	Quantity	Parameter	Quantity
Carbohydrate	71.88 g	Riboflavin	0.10 mg
Protein	8.84 g	Amino acid	1.78 mg
Fat	4.57 g	Mineral	1.5 g
Fibre	2.15 g	Calcium	10 mg
Ash	2.33 g	Iron	2.3 mg
Moisture	10.23 g	Potassium	286 mg
Phosphorus	348 mg	Thiamine	0.42 mg
Sodium	15.9 mg	Vitamin C	0.12 mg
Sulfur	114 mg	Magnesium	139 mg

Source: Tanumihardjo *et al.* (2020)

The maize varieties can be categorized based on their kernel textures such as dent, flint, waxy, flour, sweet, pop, and pod corn. Except for pod corn, these divisions are based on the quality, quantity, and pattern of endosperm composition, which defines the size of the kernel and is not indicative of natural relationships. As in the cases of floury (fl) versus flint (FI), sugary (su) versus starchy (Su), waxy (wx) versus nonwaxy (Wx), and other single recessive gene modifiers that have been used in breeding special-purpose maize, viz. sweet corn, popcorn, waxy maize, etc.

QPM and nutritional security

The biological value of QPM maize is nearly twice as high as that of normal maize (NM), greater than that of wheat and rice, and matches that of milk for real protein digestibility, which helps to reduce feed demand. In comparison to animal protein, the cost index for the manufacture of each unit of QPM protein is substantially lower (Gupta *et al*., 2009). Consequently, QPM can be used as food for the country's nutritionally undernourished people, especially in tribal and hilly areas where maize is the main crop. Besides this, QPM can be used as a nutritionally superior meal for children, pregnant and lactating mothers, adolescents, and the old age population of the country (Prasanna *et al*., 2001). In the future, India will likely host 50% of the world's hatcheries because QPM also provides low-cost, high-quality feed to support the growth of the chicken industry. QPM thereby ensures that India has access to food and nutrition (Table 3).

QPM has created a new possibility in the field of animal nutrition as well thanks to its well-balanced amino acid composition. Rising earnings and an increase in meat eating have led to a shift in the world's cereal demand that favors maize as a key feed crop. According to predictions, demand for monogastric animals like pork and poultry will rise by 30% globally. The poultry sector is looking for maize due to its higher levels of oil and amino acids (Hellin and Erenstein, 2009). Balanced meals are necessary for people to completely utilize their genetic potential (Ignjatovic-Micic *et al*., 2013). Oil added to nutritionally enriched QPM has the potential to take the place of more expensive dietary sources of fats and proteins. Since oil has a higher calorific value than starch, it is preferred that kernels should have a high oil concentration (Saleh *et al*., 1997; Yin *et al*., 2002). The study showing the dietary replacement of NM by QPM showed a considerable increase in broiler weight gain with much better feed efficiency (Table 4). The need for soybean meal and consequent expense is significantly reduced in broiler diets when QPM is substituted for NM at a rate of 60% (Subsuban *et al.*,1990). The use of QPM in place of normal maize resulted in savings of 2.8% on chicken feed and 3.4% on pig feed, according to calculations for a pig and poultry ration consisting of NM, QPM, sorghum, soybean meal, and synthetic lysine and tryptophan (Pereira *et al.*, 1992). Studies have also proven enhanced growth in pigs when QPM is substituted with normal maize, hence increasing the bio-available protein (Mbuya *et al.*, 2011; Ai and Jane, 2016). As a result, QPM can lower the cost of animal feed by spending less on more expensive sources of high protein.

Value-added products of maize

In India, maize is generally consumed in the form of chapati, popcorn, roasted fresh cob, etc. Different value-added products of maize are classified based on utility.

Table 3. Status of various protein fractions and amino acids in normal maize and QPM kernels of Indian genotypes

Protein / amino acid	Normal maize (%)	QPM (%)
Albumins	3.2	13.2
Globulins	1.5	3.9
Prolamines	47.2	22.8
Glutelins	35.1	50.0
Tryptophan	0.3 or less	0.6 or more
Lysine	1.2-1.5	2.4 or more

Source: Anonymous (2010)

Table 4. Protein quality in different types of maize *vis* other cereals

Cereal	Protein Quality (% casein)	Cereal	Protein Quality (% casein)
Rice	79.3	Sorghum	32.5
Wheat	38.7	Barley	58.0
Normal maize	32.1	Pearl millet	46.4
Opaque-2 maize	96.8	Finger millet	35.7
QPM	82.1	Teff	56.2
Oats	59.0	Rye	64.8

Source: FAO (2022)

Most common value-added products

1. *Corn oil*- The majority of refined maize oil is used in cooking, where its high smoke point makes it an excellent frying oil. It is also used as a biodiesel feedstock. Maize oil can also be used to make soap, paint, inks, textiles, nitroglycerin, and pesticides, as well as to protect metal surfaces from rust.

2. *Corn Syrup*- Corn syrup, a food syrup primarily composed of glucose, is derived from grain starch. Corn syrup is used in cooking to soften the texture, add volume, keep the sugar from crystallizing, and improve flavor.

3. *Corn flakes*- Corn flakes are one of the most nutritious foods and are consumed as breakfast food not only in India but elsewhere in the world. In addition to their delicious flavor, crispy cornflakes are also well-liked for their friable texture, flavorful blend, and, most importantly, their simplicity in preparation. This crucial agro-based food processing sector has a lot of room to grow, especially in regions where maize is grown, to meet the growing demand of urban and industrialized cities.

4. *Pop corn*- Popcorn is a common snack at sporting events and movie theatres. Traditions differ as to whether popcorn is consumed as a salty snack food (as it is in the United States) or as a sweet snack food with caramelized sugar (predominating in Germany). Popcorn is naturally low in calories, fat, sugar, and salt while being abundant in nutritional fiber and antioxidants. Those with dietary limits on their intake of calories, fat, or sodium may find it to be an alluring snack as a result. However, substantial amounts of fat, sugar, and sodium are frequently added for flavor to prepared popcorn, making it fast a very poor choice for persons on restricted diets.

5. *Roasted corn*- When corn is in season, masala butta, or spiced fire-roasted corn on the cob, is a popular street snack in India.

Some other value-added products of maize which are used directly or indirectly in human consumption are listed in Table 5. These products enhance the market value of maize.

Fermented products of maize

Maize can be prepared and consumed in a variety of ways. It's typically ground and pounded. The dish can be cooked, baked, or fried. The whole grain can be boiled, roasted, or fermented. Cooking maize meal with water yields a thick mush or dough. It can be combined with water to make gruel, porridge, or soup. In this section, we demonstrate the variety, significance, and microbiological characteristics of some fermented maize products. Some globally fermented corn products and their nutritive value as shown in the Table 6.

a) Fermented Industrial products- Maize fermented products are mostly utilized for Industrial purposes some as described below.

i) Beverages- Corn starch grits are mostly used for beverages purpose, beer and distilled liquors are the major products with respect to the volume of production and utilization.

ii) Wines- High fructose corn syrup-sweetened "wine

Table 5. Different types of value added product by using QPM

Products	Types
Traditional products	Ladoo, halwa, kheer, chapati, sev, mathi, pakora and cheela
Baked products	Bread, nan khatai and cake
Extruded products	Vermicelli and pasta
Snacks and savoury items	QPM biscuit salted, QPM biscuit sweet, choco maize biscuit, honey maize chikki, maize matthi, namak para, sev, shakarpara, QPM burfi, QPM halwa, suji upma, suji kheer, sevian (sweet), sevian (upma), QPM chatni powder-I, QPM chatni powder-II and QPM chatni powder-III
Convenience foods	Instant idli mix, instant dhokla mix, and porridge mix; sprouted products– sprouted chat, QPM vada, QPMsevian and QPM flour
Specialty foods	High-quality protein mix,low-quality protein mix, quality protein mix for the elderly, QPM honey liquid, and honey maize water (Singh, 2006)

Source: Kawatra and Sehgal (2022)

Table 6. Fermented food products of maize.

Name of the fermented food	Description	Microorganism	Nutritive value	References
Chicha	Salivation and/ or malting	*Saccharomyces cerevisiae, S. Mycoderma vini Lactobacillus, Acetobacter, Aspergillus, Penicillium*	Vitamins B	Steinkraus (1996)
Tesguino	Malting and extraction juice of maize stalk followed by boiling of juice	*S. cerevisiae Lactobacillus Streptococcus, Leuconostoc, Pediococcus, Saccharomyces Candida Cryptococcus, Hansenula*	Rich in vitamins and enzymes & serves as a refreshing alcoholic drink.	Ulloa *et al.* (1987); Wacher-Rodarte (1995)
Umqombothi	Malting	Lactic acid, bacteria and yeast.	Vit B mild alcohol sour aroma	Bleiberg *et al.* (1979); Coetzee (1982)
Busaa (Nigeria, Ghana)	Opaque maize beer	*Pediococcus L. helveticus, L. salivarius* riboflavin *cerevisiae, Candida krusei*	Crude protein, thiamine	Farnworth (2003; Willis (2002)
Atole Hurtado (Mexico)	Steeping and milling of maize grains	Lactic acid and bacteria	Sour nonalcoholic porridge, diacetyl provides sensory properties	Escamilla-Hurta *et al.* (1993)
Pozol	Boiling of kernels	*Leuconostoc mesenteroides Lactobacillus plantarum, L. Confusus, Lactococcus, Trichosporon guillermondii, C. parapsilosis, S. Cerevisiae*	Control of diarrhoea; antagonistic to manypathogen-ic bacteria, yeast and moulds; acidic flavour.	Ulloa *et al.* (1987); Canas-Urbina *et al.* (1993); Nuraida *et al.* (1995)
Mahewu	Based on corn meal	*Streptococcus lactis, delbrueckii, Candida Guilliermondii*	Non-alcoholic sour and beverages	Gadaga *et al.* (1999); Odunfa *et al.* (2001); Steinkraus (1996)
Abati (Paraguy and Argentina)	Based on maize dough	Lactic acid, bacteria and yeast.	Alcoholic beverages	Haard *et al.* (1999)
Cachiri (Brazil)	Based on maize manihot or fruit and produced on clay pots	Lactic acid, bacteria and yeast.	Fermented non-alcoholic beverages	Haard *et al.* (1999)
Agua-agria (Mexico)	Grinding of maize with water	Lactic acid and bacteria	Non-alcoholic beverages	Haard *et al.* (1999)

coolers" and sweet "pop" both have a considerable market demand for wine production.

iii) *Distilled liquors*- Maize corn is the chief source of carbohydrates that helps the production of better quality liquors.

iv) *Fuel alcohol and chemicals*- By fermenting corn, dextrose, or molasses, ethanol, citric acid, glutamic acids, lysine, and food-grade lactic acid can be produced more cheaply. Riboflavin (vitamin B2) and cobalamine (vitamin B12) are two vitamins that are produced through fermentation utilizing dextrose and corn syrup liquor.

v) *Antibiotics*- For the commercial manufacturing of antibiotics, corn syrup, dextrose, corn starch, lactose, and sucrose are the primary carbohydrate sources. The most common antibiotics manufactured are tetracycline, penicillin, neomycin, bacitracin, and streptomycin. Penicillin, bacitracin, and neomycin, in particular, have been used in very large quantities as growth promoters in animal feeds.

vi) *Enzymes*- Because society is becoming increasingly prone to diseases as a result of nutrient deficiencies or excesses, it is classified as one of the vulnerable groups. Of course, they require the attention that the university has turned its attention. The goods created thus far are inexpensive in order to reach the targeted population, which is currently unable to afford the high cost of purchasing nutrient-dense food products. The requirement of customers seeking dietary diversity owing to shifting food habits in the age of globalization and urbanization will unquestionably be met by low-cost healthy food products in a variety of formats.

b) *Fermentations of maize residues to value-added coproducts*

i) *Ethanol*- Mixed sugars made from maize fiber and other biomass sources have the potential to be used as the starting material for the fermentation of a wide range of useful products, such as enzymes, organic acids, biopolymers, carotenoids, amino acids, and vitamins. Ethanol is very interesting. According to estimates, using the corn fiber fraction would result in a 10% increase in ethanol yields (Gulati *et al*., 1996)

ii) *Xylitol*- Xylose could also end up as xylitol. A valuable sugar alternative is xylitol, a sugar alcohol derivative of xylose (Pepper and Olinger, 1998). In terms of sweetness, xylitol is comparable to sucrose, but unlike sucrose, it has anti-cariogenic properties and is metabolized via an insulin-independent mechanism. Xylitol is particularly helpful in mints, sweets, and toothpaste because of its significant negative heat of solution. Xylitol is traditionally made from birch wood chips using a chemical procedure, and it costs around $7 per kilogram31. It has been proposed that a bioconversion procedure might provide a more cost-effective option.

iii) *Pullulan*- Much little study has been reported on the creation of value-added byproducts from maize-based fuel ethanol stillage, despite the fact that bioconversions of corn fiber and other lignocellulosic wastes have received a lot of attention. In order to create corn condensed distiller's solubles (CCDS), which is then combined with maize fiber to create corn gluten feed, the initial or thin sillage (TS) from ethanol distillation the process is concentrated by evaporation (Leathers, 1998).

Moreover, CCDS contains growth agents such as peptides and vitamins, which are well known. Hence, the stillage wastes mimic the ingredients for a fermentation medium. As a result, stillage wastes have been evaluated as production substrates for the valuable bioproducts of pullulan and astaxanthin (Leathers, 2002).

iv) *Astaxanthin*- The carotenoid pigment called astaxanthin is what gives salmon their distinctive color. The pigment is crucial for customer approval and may also have favorable effects on health. Salmon must eat this pigment since they are unable to produce it. Astaxanthin is a costly feed additive for salmon raised on farms. The astaxanthin-rich red yeast *Phaffia rhodozyma* has been commercially developed as an addition to aquaculture feed (Pepper and Olinger 1988).

Conclusion

Maize is used as a direct food source and an indirect feed source for meals derived from animals in a variety of global agri-food systems. It is a flexible, multipurpose crop that is mostly utilized for feed around the world. As maize has such a wide range of nutritional benefits, there are many opportunities to produce products with additional value. In addition to ensuring higher returns for farmers, the commercialization, promotion, and adoption of maize-based value-added products will also provide jobs for upcoming new generations and promote dietary diversity for consumers. Moreover, it guarantees nutritional and food security to India.

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