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REVIEW PAPER

Nutritional and medicinal importance of maize in human health

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Abstract: Maize (*Zea mays* L.) has worldwide importance due to its nutritional and medicinal value. It is an excellent source of carbohydrates, dietary fibers, polyunsaturated fatty acids, vitamins, minerals, and natural antioxidants which play significant roles in different physiological processes for maintaining good health and preventing chronic diseases in humans. Decoction of the maize silk, roots, leaves, and cob are used for bladder problems, nausea, vomiting, and stomach complaints. Resistant starch from maize reduces the risk of cecal cancer and atherosclerosis. Its consumption in the diet is beneficial in the reduction of chronic-degenerative diseases such as cancer, diabetes, obesity, and cardiovascular and metabolic problems. The rate of genetic gain for further improvement in nutrient content in maize is being accelerated with the rapid advances made in understanding the genetic control of many macro-and micro-nutrients in maize grains with the increased availability and accessibility of new technologies, especially in developing countries of the world.

Keywords: Diseases · Food · Health · Maize · Nutrition · Phytochemicals

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Introduction

Globally, Maize (*Zea mays* L.) is known as the 'Queen of Cereals' because of its highest genetic yield potential among all the cereals. *Zea* is an ancient Greek word that means 'sustaining life' and *mays* is a word from the Taino language meaning 'life-giver' (Milind and Isha, 2013). Various other synonyms like corn, *zea*, *makka*, *makai*, *makkacholam*, *makkaya*, *makkajanna*, bhutta, *majs*, *mais*, *anaaj*, *jagung*, *barajovar*, etc. are used to recognize this plant in different regions of the world. Botanically, it belongs to Kingdom-Plantae, Subkingdom-Tracheobionta, Superdivision-Spermatophyta, Division-Magnoliophyta, Class- Liliopside (Monocotyledon), Order-Poales, Family-Poaceae (Gramineae), Subfamily- Panicoideae, Tribe-Andropogoneae Genus- *Zea*, and species- *mays*. The *mays spp.* divided into eight groups on the basis of the nature of the endosperm of kernels i.e. popcorn (*Z. mays* var. *everta*), dent corn (*Z. mays var. indentata*), sweet corn (*Z. mays var. saccharata*), flint corn (*Z. mays var. indurate*), flour corn (*Z. mays var. amylacea*), baby corn (*Z. mays var*. *huehuetenangensis*), pod corn (*Z. mays tunicate*), waxy corn (*Z. mays ceratin*) (Iltis and Doebley, 1980).

Maize is native to South America but extensively cultivated in various other countries throughout the world for food and fodder. The global consumption pattern of maize is: feed-61%, food-17%, and industry-22%. Currently, nearly 1147.7 million MT of maize is being produced together by over 170 countries from an area of 193.7 million ha with average productivity of 5.75 t/ha (FAOSTAT, 2020). The United States of America is the largest producer of maize accounting for nearly 40% of the total world's maize production. The other major maize-producing countries are China, Brazil, Argentina, Indonesia, France, South Africa, Mexico, India, Canada, Australia, New Zealand, Pakistan, Nigeria, Japan, Malaysia, Thailand, Taiwan, Philippines, Colombia, Singapore, Netherlands, Romania, Uruguay, Czech Republic, Egypt, Zimbabwe, and Kenya. India produced 31.51 million tonnes in an area of 9.86 million hectares during 2020–21 (DES, 2021). In India, the major maize-growing states, *viz*., Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, West Bengal, Rajasthan, Bihar, Andhra Pradesh, Uttar Pradesh, Telangana, Gujarat, Punjab and Odisha, jointly account for over 95% of the national maize production. The acreage, production and productivity of different states of India is presented in Figures 1, 2 & 3 which are based on the data of DES, 2021. Together with rice and wheat, maize provides at least 30% of the dietary calories of over 4.5 billion people in 94 countries and by 2050, maize demand in developing countries will double.

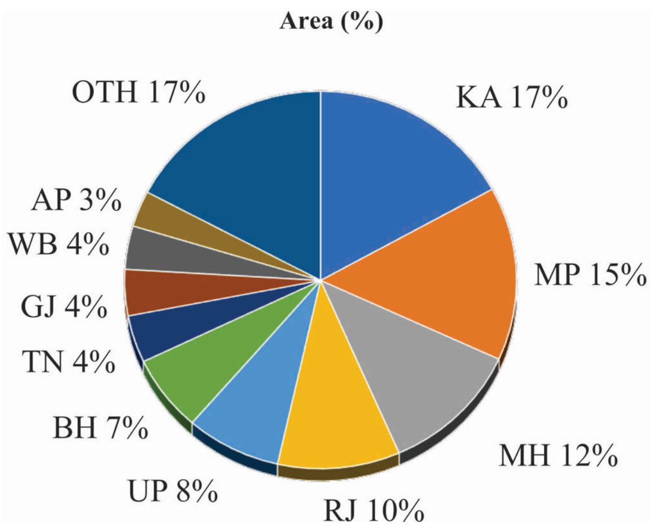

Figure 1. Percentage area under maize in different states of India

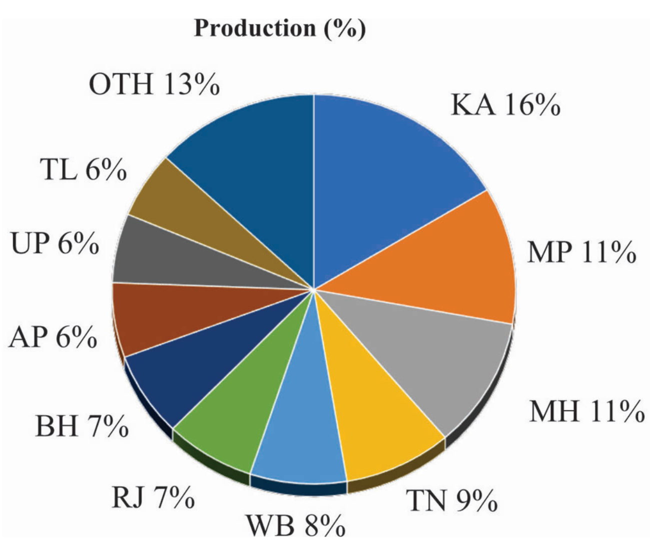

Figure 2. Contribution (%) of different states in maize production in India

In the 21st century, the challenge is not only to produce enough to feed the growing world population, but also providing to all nutritionally balanced diets for good health. Thus, this review aims to discuss the nutritional and medicinal importance of maize in disease prevention and maintaining good health through the intake of it in the diet.

Nutraceutical properties of maize

Maize has a high nutritional value in the human diet as it is an excellent source of vitamins, minerals, protein, carbohydrates, dietary fibers, polyunsaturated fatty acids, and natural antioxidants with a nutraceutical function. Thus, maize has been acknowledged as a functional food. Maize contains near about 65% carbohydrate, 12% fiber, 9% protein, and 4% lipid (Longvah *et al.* 2017). Due to the presence of a high amount of carbohydrates. The complex carbohydrates in maize are digested at a slow rate by the stomach, so provide a good balance of energy levels. It contains all the nine essential amino acids and five conditionally essential amino acids that are required for a human body to perform various functions (Table 1). Maize is also enriched with vitamins and minerals (Tables 2 & 3) which are very essential for different physiological processes in the human body. However, its chemical constituents vary due to differences in genotypes, and environmental factors such as weather and climate, types of soil, agronomical practices, and also depend on the type of corn such as yellow, white, and purple corn. The resistant starch in maize is a type of non-digestible fiber, as it is highly resistant to the activity of digestive enzymes. In maize, the resistant starch seems to be directly related to the percentage of amylose content. In normal corn, the presence of 34% of amylose is related to 0.8% of resistant starch, while in high-amylose corn starch, the recorded presence of 83% amylose results in 39% resistant starch (Jin *et al.*, 2016; Jongfeng and Jay-Lin, 2016). However, the resistant starch can be metabolized by the microbiota of the large intestine through the fermentation process (Higgins, 2004). Both the starch and the resistant starch contained in maize kernels have relevance due to their possible function as regulators of body weight, thus a possible natural alternative for the treatment of obesity and hemorrhoids. (Keenan *et al*., 2006).

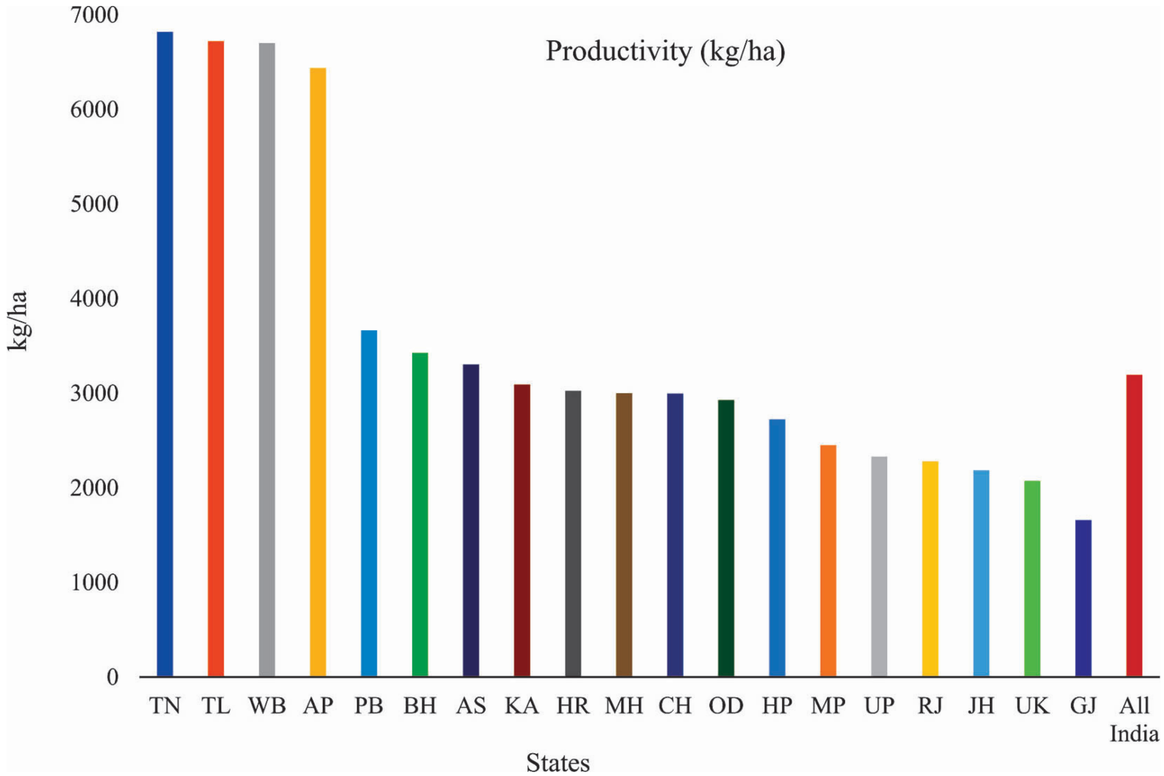

Figure 3. Productivity of maize in different states of India
TN- Tamil Nadu, TL- Telangana, WB- West Bengal, AP- Andhra Pradesh, PB- Punjab, BH- Bihar, AS- Assam, KA- Karnataka, HR- Haryana, MH- Maharashtra, CH- Chhattisgarh, OD- Odisha, HP- Himachal Pradesh, MP- Madhya Pradesh, UP- Uttar Pradesh, RJ- Rajasthan, JH- Jharkhand, UK- Uttarakhand, GJ- Gujrat, OTH- Other

In the endosperm of corn kernels, protein is the second most abundant component having 8–10% of the total weight after the starch (Hannah *et. al*., 1993). The kernel proteins have been classified into four groups in relation to their solubility i.e. albumins (water-soluble proteins), globulins (proteins soluble in saline solutions), prolamins or zeins (proteins soluble in alcoholic solutions), and glutelins (unable to be solubilized in water/saline/ alcoholic. The albumins and globulins are located mainly in the germ, while the prolamins and glutelins can be found predominantly in the endosperm. In relation to their concentration, proteins are distributed unevenly in the maize kernel, where, 40% of the proteins are concentrated in zeins, followed by the glutelins (30%), whereas, globulins and albumins together constitute less than 5%. Of these, approximately 60% of the proteins are concentrated in the endosperm and are prolamins, with á-zein being the most abundant, reaching up to 75% of the total prolamins (Momany *et al.*, 2006). Maize proteins are hydrolyzed by the activity of gastrointestinal enzymes such as pepsin, trypsin, and chymotrypsin. Studies have shown that the bioactive peptides in maize have many beneficial effects on health, mainly as antihypertensive, anticholesterolemic, antioxidant, anti-inflammatory, anticarcinogenic, antimicrobial, and others, due to their immunomodulatory properties.

The corn kernel oil, popularly known as corn oil is a concentrated source of energy that provides essential fatty acids, vitamin E, and a rich source of polyunsaturated fatty acids (PUFA), which help in regulating blood cholesterol and lower elevated blood pressure (Dupont *et al*., 1990). Animal and human studies showed that at least 97% of the oil is digested and absorbed (Chen *et al*., 1987). Carrillo *et al.* (2017) reported that corn oil shows a good content of omega 6 and 9 fatty acids (FA), where, omega 6 contributes 52.7% of the FA content. It is comprised of 40–68% of linoleic acid, 20–32% of oleic acid, and 8–14% of saturated fatty acids, mainly palmitic acid. Moreover, corn oil is a good source of tocopherols with ã-tocopherol (Moreau, 2011). Corn oil was also shown to reduce elevated blood pressure. Corn oil diets have shown blood pressure lowering of about 12% in men and 5% in women with pre-existing hypertension (Iacono and Dougherty, 1993).

Table 1. Essential amino acid profile of maize (dry)

Amino acids	Nutritive value*
Essential amino acids	
Histidine	2.70 ± 0.21
Isoleucine	3.67 ± 0.22
Leucine	12.24 ± 0.57
Lysine	2.64 ± 0.18
Methionine	2.10 ± 0.17
Phenylalanine	5.14 ± 0.29
Threonine	3.23 ± 0.29
Tryptophan	0.57 ± 0.12
Valine	5.41 ± 0.71
Conditionally essential amino acids	
Arginine	4.20 ± 0.24
Cysteine	1.55 ± 0.14
Tyrosine	3.71 ± 0.18
Glycine	3.27 ± 0.15
Proline	7.88 ± 0.71

*All the values are presented as per 100 g of edible portion. (Longvah *et al*., 2017)

Table 2. Vitamin content in maize (dry)

Vitamins	Scientific name	Nutritive value*
Vitamin-A	Retinol	59.2± 17.1 µg
Vitamin-B1	Thiamine	0.33 ± 0.032 mg
Vitamin-B2	Riboflavin	0.09 ± 0.009 mg
Vitamin-B3	Niacin	2.69 ± 0.06 mg
Vitamin-B5	Pantothenic Acid	0.34 ± 0.03 mg
Vitamin-B6	Pyridoxine	0.34 ± 0.017 mg
Vitamin- B7	Biotin	0.49 ± 0.05 µg
Vitamin-B9	Folic Acid	25.8 ± 1.44 µg
Vitamin-C	Ascorbic acid	4.26 ± 0.55 mg
Vitamin-D	Ergocalciferol	33.6 ± 2.82 µg
Vitamin-E	α-Tocopherol	0.36 ± 0.03 mg
Vitamin-K	Phylloquinones	2.50 ± 0.76 µg

*All the values are presented as per 100 g of edible portion (Longvah *et al*., 2017)

Medicinal importance of maize in human health

From ancient times, maize has been used to pacify *kapha*, *pitta*, anorexia, general debilities, emaciation, and hemorrhoids (Kumar and Jhariya, 2013). A kapha diet consisting of barley, maize, millet rye, and buckwheat is favored superior over a diet of oats, rice, and wheat in balancing and managing *kapha dosha*. In recent years, its consumption has been linked to the reduction of chronic-degenerative diseases such as cancer, diabetes, obesity, cardiovascular and metabolic problems, neurodegenerative problems, etc.

Table 3. Mineral content of maize

Minerals	Nutritive value*
Phosphorus (P)	299.6 ± 57.8
Potassium (K)	324.8 ± 33.9
Calcium (Ca)	48.3 ± 12.3
Magnesium (Mg)	107.9 ± 9.4
Sodium (Na)	59.2 ± 4.1
Iron (Fe)	4.8 ± 1.9
Copper (Cu)	1.3 ± 0.2
Manganese (Mn)	1.0 ± 0.2
Zinc (Zn)	4.6 ± 1.2

*All the values are presented as per 100 g of edible portion (Bressani *et al.*, 1989)

Table 4. Major phytochemical compounds in maize

Compounds	Concentration (mg/100 g)	References
(1) Carotenoids		
(a) Carotene	2.20	Watson and Ramstad (1987)
b) Xanthophylls		
(i) Lutein	1.50	Moros *et al.* (2002)
(ii) Zeaxanthin	0.57	
(2) Phenolic compounds		
(a) Ferulic acid (FA)	174	Zhao *et al*. (2005)
(b) Anthocyanins	141.7	Salinas-Moreno *et al.* (1999)
(3) Phytosterols		
(a) Sitosterol	9.91	Locatelli and Berardo (2014)
(b) Stigmasterol	1.52	
(c) Campesterol	3.40	

The phytochemicals in maize grains demonstrate a significant beneficial contribution to reducing the risk of many diseases due to their potent antioxidant activities (Liu, 2007; Madhujith and Shahidi, 2007). Major phytochemical compounds in maize and their concentration are given in Table 4. Maize grains, especially the yellow variety contain large quantities of carotenoid pigments and have a vital significance in the diet of human beings. These carotenoid pigments are also beneficial in preventing cancer (Michaud *et al.*, 2000). Alpha (α) and beta (β) carotene possess provitamin-A activity. A high concentration of β-carotene has been observed to act as a pro-antioxidant and induces apoptosis of colon cancer cells, leukemia cells, melanoma cancer cells, and gastric cancer cells, thus rendering a potent chemopreventive effect (Palozza *et al.*, 2001, 2003; Jang *et. al*., 2009). Xanthophylls i.e. lutein and zeaxanthin protect humans against phototoxic damage and are useful for healthy vision and play a role in age-related macular degeneration and age-related cataract formation. The lutein supplements in the diet for a specific period showed a significant enhancement in macular pigment optical density and notable protection of the macula from light damage (Landrum *et. al*., 1997). Lutein also acts as cancer chemopreventive/suppressing agent (Moreno *et al.*, 2007). Lutein supplementation in a food dose-dependent manner increases tumor latency and inhibits mammary tumor growth, enhances lymphocyte proliferation, lowers the incidence of the palpable tumor, and significantly protects cells against oxidant-induced damages (Chew *et al.*, 1996). Ferulic acid (FA) found in maize has potent antioxidant properties and protects the cell membranes against oxidation. The various benefits of FA derived from maize include anticancer, anti-inflammatory, reducing bone loss, anti-diabetic, and hepatoprotective effects (Kawabata *et al*., 2000; Ou *et al*., 2003; Rukkumani *et al*., 2004). Anthocyanins in maize have been well known for their health-promoting benefits such as anti-carcinogenic, anti-atherogenic, lipid-lowering, anti-diabetic, anti-hypertensive, anti-microbial, and anti-inflammatory properties. Due to their potent antioxidant properties, they are able to decrease capillary permeability and fragility, immune system stimulation, and inhibit platelet aggregation (Ghosh and Konishi, 2007, Shindo *et al*., 2007). Hagiwara *et al.* (2001) have been carried out to demonstrate the anti-neoplastic effects of maize anthocyanins, finding that it prevents carcinogenesis due to exposure to 2-amino-1-methyl-6-phenylimidazo pyridine (a free radical belonging to the nitrosamines group). Long *et al*. (2013) demonstrated the chemopreventive properties of purple corn in the *in-vitro* models of prostate cancer. Urias-Lugo *et al.* (2015) reported on the anti-cancer properties of the phenolic and anthocyanins compounds in maize and they are useful in breast, liver, colon, and prostate cancer. Maysin can be used for the treatment of prostate cancer in humans who are resistant to chemotherapy. The non-amylaceous peptide polysaccharide of corn was isolated and characterized, and after a series of tests, it showed anticancer properties by blocking metastasis mediated by galectin-3 (Jayaram *et al*., 2015). It has also been shown that the bioactive peptides of maize exert antitumor activity through the key mechanisms such as (a) the induction of apoptosis mediated through specific proteases or caspases; the strategies to overcome tumor resistance to apoptotic pathways include the activation of pro-apoptotic receptors, the restoration of the *p53* activity, the modulation of caspases, and the inhibition of the proteasome; (b) by blocking the intermediate generation of tumors by regulating cellular mechanisms associated with cell proliferation and survival, or biosynthetic pathways that control cell growth; and (c) regulation of immune system functions, increasing the expression of antigens associated with the tumor (antigenicity) in cancer cells, activating the tumor cells for them to release warning signals that stimulate the immune response (immunogenicity), or increasing the predisposition of the tumor cells to be recognized and neutralized by the immune system by means of autophagy and apoptosis (Díaz-Gómez *et al*., 2017). Resistant starch in maize, also called as high-amylose maize helps in altering microbial populations and enhance fecal output. It increases fermentation and short-chain fatty acid production in the large intestine and reduces symptoms of diarrhea, which altogether reduce the risk of cecal cancer (Wang *et al.*, 2002; Murphy *et al.*, 2008).

Diabetes, the most severe chronic metabolic disease with a great impact on the health of the world population is one of the fastest growing global health emergencies of the 21st century and has reached alarming levels. According to the International Diabetes Federation, approximately 537 million adults (20–79 years) have been reported with diabetes worldwide during the year 2021 and is expected to increase to 643 million by 2030 and 783 million by 2045. More than 1.2 million children and adolescents (0–19 years) are living with type-1 diabetes. One in six live births is affected by diabetes during pregnancy. Almost one in every two adults living with diabetes is undiagnosed. Diabetes already caused near about 6.7 million deaths (IDF, 2021). Several studies have shown that the consumption of maize improves insulin sensitivity along with a reduction of glucose concentration and a change in blood lipid profile due to the consumption of resistant starch in humans (Keenan *et al*., 2015; Zhou *et al*., 2015). Its consumption influences cholesterol metabolism and lowers body fat storage, therefore, reducing the risk of atherosclerosis, hyperlipidemia, diabetes, and obesity (Higgins, 2004). Resistant starch has also been suggested to be potentially beneficial for improving insulin sensitivity in both animal and human subjects (Johnston *et al.,* 2010). Diabetic nephropathy is one of the main complications of diabetes and is mainly caused by chronic renal failure, which is growing in prevalence. The consumption of feruloylated oligosaccharides from maize bran has been shown to be effective in the regulation of serum insulin levels (Huang *et al*., 2018). In addition, the maize extract rich in anthocyanins have been used as a therapeutic agent focused on the regulation of the abnormal angiogenesis that occurs in diabetic nephropathy, which can lead to renal failure. This is mediated by the decrease in receptor-2 activity for vascular endothelial growth factor after consumption of purple corn, tested in diabetic mice (Kang *et al*., 2013). Huang *et al*. (2015) reported that purple corn extract can have anti-diabetic effects through the protection of the β cells of the pancreas, favoring the secretion of insulin and the activation of the AMPK pathway in diabetic mice i.e. increased phosphorylation by AmpC-activated kinase protein (AmpK), decreases the activity of phosphoenolpyruvate carboxykinase (PEPCK), decreases the transcriptional activity of genes for glucose 6-phosphatase in the liver, and increases the expression of the glucose transporter 4 (GLUT4) in skeletal muscle.

The polyphenols in maize, particularly flavonoids, can also modulate the neuronal signaling cascade activated by aging, acting on the ERK/CREB pathway involved in synaptic plasticity and long-term potentiation, improving learning and memory capacity in humans (Han *et al*., 2007). In the ear and seeds of maize, cyanidin-3-glucoside, pelargonidin-3-glucoside, peonidin-3-glucoside, and its malonated counterparts can be found. Many biological activities have been attributed to these phytochemicals, so it is considered that maize and its byproducts that contain them have an intrinsic capacity to prevent cognitive deterioration and memory decline and are useful in the management of Alzheimer's disease (Choi *et al*., 2012). Maize is believed to have potential anti-HIV activity due to the presence of the *Galanthus nivalis* agglutinin (GNA) lectin. The GNA-lectins are special proteins that can bind to carbohydrates or carbohydrate receptors found on cell membranes. In some micro-organisms including the HIV virus, the binding of lectins onto sugars is believed to inhibit the activity of the virus (Shah *et al.,* 2016).

Present and future prospective

The kernels of yellow maize cultivars commonly grown by farmers contain less than 2 µg/g of provitamin A (PVA) which is insufficient to meet the recommended daily requirement in a diet. To increase the concentrations of PVA carotenoids in maize considerable efforts have been made by researchers through modern breeding technologies (Pixley *et al*., 2013; Andersson *et al*., 2017; Giuliano, 2017; Menkir *et al*., 2017). The biofortified yellow maize rich in beta-carotene might be recommended as an efficient food source to combat Vitamin A deficiency (VAD) in those countries where VAD is a public health problem. Biofortification of maize kernels with high Zn has been undertaken at CIMMYT and IITA for more bioavailability of Zn (Bänziger and Long, 2000; Ortiz-Monasterio *et al.*, 2007; Menkir *et al*., 2008; Hindu *et al*., 2018), The phytic acid in maize adversely affects the Zn content. Due to a lack of Phytase enzyme, the phytic acid is not digested in the gut of humans, poultry, and swine and is expelled directly to the environment through excreta, posing a serious pollution concern due to the continuous expulsion of high phosphorus load into the nearby water bodies (Jorquera *et al*., 2008). Hence, bringing down the phytate in maize might be an important strategy for Zn biofortification.

Lysine and tryptophan are two essential amino acids and these are deficits in maize grain thus, posing the problem of lysine and tryptophan deficiency human diseases like cognitive disorder, kwashiorkor disease, reduced appetite, impaired skeleton development, delayed growth, and aberrant behavior are associated with. These amino acids are also important for curing pellagra disease. Researchers have identified several mutants in maize especially *opaque-2* which are responsible for higher lysine and tryptophan contents. Concerted efforts of researchers spanning over the period of four decades to develop quality protein maize (QPM) which is nutritionally superior maize with high lysine and tryptophan. The *opaque-2* genetic system, endosperm modifier genetic system, and associated gene systems-based approaches are followed in maize for the improvement of quality protein (Maqbool *et al*., 2021). Recently, researchers reported promising result in the development of edible Rabies vaccines in maize, which is safer, cheaper, effective, and does not need to be refrigerated (Loza-Rubio *et al.*, 2008; Das *et al*., 2021).

The anaphylaxis symptoms i.e. sudden drop in blood pressure, difficulty in breathing, tightness in the chest, dizziness, and unconsciousness developed in some persons due to the presence of allergic compounds (9 kd protein and 16 kd protein) in maize. Again, if someone eats corn in large quantities, then it can cause bloating & flatulence due to the presence of a high percentage of starch. Although the milling of the maize kernel into flour and subsequent cooking may increase the accessibility of maize food, further research is needed to develop suitable varieties to solve these problems.

Conclusion

Maize is one of the best nutritive foods for the human diet due to its excellent source of carbohydrates, fiber, protein, vitamins, minerals, and antioxidants such as different types of polyphenols. Thus, based on its health benefits, it is suggested to make it part of our daily diet. The rapid advances that have been made in understanding the genetic control of many macro-and micro-nutrients in maize grains, coupled with the availability of new technologies will accelerate the rate of genetic gain for further improvement in nutrient content in maize. In a developing country like India, the maize crop has great potential to eradicate poverty as well as malnutrition. Modern breeding and biotechnology approaches, Interdisciplinary research, and more effective integration and collaboration of national and international research efforts can enhance the nutritional status as well as productivity of maize.

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