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Maize and Its Use in Human Food

POPA Călin [1,2], Roxana CĂLUGĂR[2*], Florin RUSSU[2], Andrei VARGA[2], Leon MUNTEAN[1]
[1]University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca,
Faculty of Agriculture, Department of Crop Science,
3-5 Calea Mănăştur, 400372, Cluj-Napoca, Romania
[2]Agricultural Research and Development Station Turda
27 Agriculturii, 401100, Turda, Cluj, Romania
*Correspondence: roxana.calugar@scdaturda.ro

Abstract: Maize is an important source of nutrition that also plays an important role in preventing chronic diseases. Maize is used in both human and animal feed. To improve the biochemical content, remarkable results have been obtained in terms of improving the content with starch (amylose and amylopectin), proteins (lysine, tryptophan, carotenoids), sugars or oil. The inbred lines from the Agricultural Research and Development Station Turda germplasm collection, with an increased content in the previously mentioned components, are used in maize breeding programs, both for the improvement of the inbred lines uses as the parental genotypes, through the use of backcrossing, and for the creation of new hybrids, superior from a qualitative point of view.

Keywords: carotenoid, human food, maize, protein.

Introduction

At the world level, maize occupies the second place in terms of area, being surpassed by wheat but from the point of view of the total production obtained, maize is ahead of wheat (FAOSTAT, 2023). According to the same source, between 2019 and 2021, worldwide between 194-205 million hectares were cultivated with maize with total productions of about 1.2 billion tons obtained. Through the large areas it occupies, but especially through the productions it achieves, humanity is largely dependent on maize, in providing food (Cristea, 2004).

Due to the chemical composition of all its constituent parts, maize, in addition to its nutritional importance for humans, is also a staple food for animal feed and a valuable raw material for industry. The importance of maize also results from the fact that it is a food rich in substances with nutritional value, especially energy of 355 kcal per 100 g of flour with 15% moisture, compared to 352 kcal for wheat flour, 348 kcal for rye flour and 346 kcal for hulled barley (Cristea, 2004). Also, maize has a good digestibility, the kcal losses in the digestion process being only 8.28%.

Regarding the nutritional importance of maize kernels, numerous authors (Nuss and Tanumihardjo, 2010; Wildman et al., 2010; Shah et al., 2016) claim that they are an important source of carbohydrates, proteins, fats, as well as minerals (phosphorus, sodium, sulphur, potassium, magnesium, selenium and copper) and vitamins (E, K, B1, B2, B3, B5, B6), but lack in some others. In countries facing problems related to population anemia and other problems due to food shortages, the content of maize is enhanced with iron, carotenoids and other minerals (Ranum et al., 2014; Zurak et al., 2021).

Maize can also be considered a good source of biochemically active substances such as carotenoids, phenolic compounds and phytosterols, providing benefits for human health and reducing the occurrence of major chronic diseases (Lopez-Martinez et al., 2009; Yongfeng and Jaylin, 2016; Sheng et al., 2018). According to Liu (2004), bioactive chemical compounds naturally present in plants are phytochemicals that provide benefits to human health with the potential to reduce the risk of major chronic diseases. Important sources of various major phytochemicals such as carotenoids, phenolic compounds and phytosterols are found in maize (Jiang and Wang, 2005; Kopsell et al., 2009; Lopez-Martinez et al., 2009).

In the modern era, the forms of maize used for certain destinations have been diversified. In human nutrition, it is sometimes used directly, without special processing, but in most cases it is industrialized. For most countries in Latin America, Africa and Asia, maize is a basic food product being consumed, in the boiled form, directly from the cob or boiled kernels or it is used in the preparation of various types of traditional foods (Yongfeng and Jaylin, 2016). For consumption in the form of boiled cobs or preserved kernels, the genotypes from the *saccharata* convariety are preferred, in which the taste qualities are conditioned by the existence of one or more recessive genes: *sugary1* (*su1*), *shrunken2* (*sh2*), *sugary enhancer1* (*se1*) (Haș et al., 2004).

By wet or dry grinding of maize kernels, products are obtained that may or may not undergo further changes, being used to produce cereals that can be consumed for breakfast or in the form of various snacks, tortillas and many other food products (Nuss and Tanumihardjo, 2010). Another way, in which it is used in human nutrition, is in the form of popcorn, for which, the kernells from the *everta* variety are used.

In Romania, one of the most common uses in human nutrition is in the form of polenta; for this use, the preferred flour is obtained from maize of the *indurata* convariety and preferably with the orange colour of the kernels.

Obtaining maize hybrids with a special purpose for human consumption requires, first of all, the identification of germplasm sources that correspond to the objectives pursued. In this regard, we will further describe some of the gene sources used at the Agricultural Research and Development Station (ARDS) Turda to obtain special purpose maize hybrids.

1. Starch content in maize

Starch consists of a mix of amylose and amylopectin and is the most abundant storage carbohydrate in maize kernel. The amylose and amylopectin content confers unique properties in food processing and industrial application. Starch in normal corn endosperm is about 25% amylose and 75% amylopectin (Nelson and Pan, 1995). The ratio of amylose to amylopectin plays an important role in the structure and quality of food and processing products. The amylose content determines the firmness of the starch, whereas the amylopectin is responsible for the formation of crystalline granules and thickening of paste (Whitt et al., 2002; Li et al., 2018)

Out of all types of starch, corn starch is a valuable ingredient in food production, over 80% of the world starch market (Scrob et al., 2014). The progress regarding the production of starch from cereals is remarkable important, because these types of starch comprise 55-75% of the intake daily human food and is the main source of food for domestic animals (Pan, 2000; Șchiop et al., 2011).

1.1 Increase in amylose content in maize

In general, high-amylose hybrids have a rather small food market, being typically used in the chip, fruit jam and chewing gum industries.

Human consumption of high-amylose maize helps alter microbial populations, lower cholesterol and increase fecal excretion, increase fermentation and production of short-chain fatty acids in the large intestine, reducing diarrheal symptoms, which altogether reduce the risk of rectal cancer, atherosclerosis, and obesity-related complications (Murphy et al., 2008).

Other researchers also mention that the consumption of high-amylose maize influences cholesterol metabolism, decreases body fat storage, reducing the risk of atherosclerosis, hyperlipidemia, diabetes and obesity (Higgins, 2004).

Amylose content can be increased by using *amylose extender* (*ae*) mutant endosperm content.

In the maize germplasm collection from ARDS Turda, there are also amylose-extender inbred lines that can be used in breeding programs as sources to increase amylose in maize genotypes.

1.2 Increase in amylopectin content in maize

In maize with high amylopectin content, the endosperm is dull and has a waxy appearance. For this reason it was called waxy, and the recessive gene was given the symbol *wx*.

Waxy maize is generally regarded as relatively easy to wet mill compared with normal corn, giving a high yield of starch composed of nearly 100% amylopectin and low in residual protein content (Kent et al., 2019).

The improvement of maize rich in amylopectin is quite easy and is done by transferring the *waxy* (*wx*) gene, through backcross. Maize genotypes rich in amylopectin are used in the milk and cheese industry, as stabilizers for ice cream, in the paper and textile industry (Cristea, 2004).

At ARDS Turda, several waxy inbred lines have been completed in Turda, currently four inbred lines are kept in the collection as sources for the wx gene: A 508 Wx, T 350 Wx, T 152 Wx and W 629 Wx[1].

2. Protein content in maize

In the maize breeding programs, a special place is occupied by the activity in the direction of improving the protein content (on average >10%) of the grains as well as in the direction of improving the protein quality. Through selection works for about 60 years, in Bur White varieties that had an average 10.9% protein, it was possible to increase the protein content to 22.84%, but also its decrease to 4.96% (Cristea, 2004).

High protein content can be transferred to valuable inbred lines by backcrossing with different sources, followed by chemical analysis of each backcross generation.

If increasing the total amount of grain protein is not difficult and has been practically achieved, improving the protein quality is particularly difficult. It is also difficult to combine the high protein content with their superior quality.

2.1 Increase of lysine and tryptophan content in maize

The problem that dominated the last part of the 20th century, in improving the quality of maize, was obtaining genotypes that combine total protein content, with a reduced proportion of zein and an increased amount of lysine and tryptophan. In general, hybrids of normal maize contains 35-65 % zein or low-quality protein (Luo and Wang, 2016; Malhotra and Alghuthaymi, 2022).

The discoveries made at Purdue University in Illinois created the premises for solving this problem; Mertz et al. (1964) and Nelson et al. (1965) showed that the effects of the *opaque2* (*o2)* and *fluory2 (fl2)* mutants are manifested by the increase in the content of essential amino acids (lysine and tryptophan) and the considerable decrease in the content of zein. Both the more intensively used *o2* and *fl2* genes and the mutants whose qualities were discovered later have some common characteristics: lower zein fraction, floury endosperm, low kernel weight, dull kernel colour, an increased sensitivity to cryptogamic diseases of cereals and cobs (Vasal, 2000).

Maize hybrids rich in essential amino acids initially had quite a big impact on some agricultural areas, including in Romania, but the production was lower by 10-20%, the high humidity of the grains at harvest due to the slow loss of water from the grains, the psychological effect of the less attractive colour of the kernels, the high percentage of broken grains during mechanized harvesting and the vulnerability to some specific diseases made the cultivated areas quite small.

In the germplasm collection from ARDS Turda there are currently 19 inbred lines of the *opaque* type, genotypes that can be used in breeding programs to increase the content of essential amino acids. Four maize hybrids with higher lysine content were registered at ARDS Turda: Lizin 250, Lizin 125, Betuflor si Betulisa.

2.2 Increase of carotenoid content in maize

Carotenoids are pigments exhibiting yellow, orange, red or purple colours (Demmig-Adams et al., 1996; Strzałka, 2003; Maoka, 2020) and are present in photosynthetic bacteria, some fungi, algae, plants and animals. Carotenoids are divided into two groups: carotenes (α-carotene, β-carotene, β,ψ-carotene (γ-carotene), lycopene) and xanthophylls (β-cryptoxanthin, lutein, zeaxanthin, astaxanthin, fucoxanthin, peridinin). β-carotene, α-carotene, lycopene, β-cryptoxanthin, lutein, and zeaxanthin have been found to be the major components and make up more than 90% of the total carotenoids (Khachik et al., 1992; Khachik et al., 1998; Maoka, 2020). Some of these have provitamin A activity, which plays an important role in the human immune system, growth, reproduction, and vision (Saenz et al., 2021). β-Carotene is an orange pigment that in the body can be converted into provitamin A. This vitamin is essential for vision, immune function and cell growth (Huang, 2018).

Lutein and zeaxanthin are also very importamnt due to their antioxidant properties, and accumulation in the retinal macula being involved in vision process (Demming-Adams et al., 2013); may help reduce the risk of certain types of cancer (breast and lung), and have a potential contribution to the prevention of heart disease and stroke (Ribaya-Mercado et al., 2004), UV-induced skin damage, coronary heart disease (Gammone et al., 2017), vision related problems (Cooper, 2004; Muntean, 2020).

In maize, major α-branch carotenoids are lutein, α-cryptoxanthin, and α-carotene, while major β-branch carotenoids are zeaxanthin, β-cryptoxanthin, and β-carotene.

Due to the importance of carotenoids in the human diet, there are various biofortification programs for the carotenoid content of maize worldwide, and there is a varied genetic basis for improving this content (Harjes et al., 2008; Ortiz-Monasterio et al., 2007; Menkir et al., 2008; Menkir et al., 2017; Băcilă et al., 2022; Calugar et al., 2022; Šimić et al., 2023).

In an extensive study that included 2746 inbred lines from Romania, 748 genotypes belonging to the ARDS Turda germplasm collection were analysed, and a series of lines possessing the favorableness genes for increased carotenoid content, crtRB1 and/or *lcy*E were identified (Băcilă et al., 2022).

3. Sugar content in maize

Sweet corn (*Zea mays* L. *saccharata*) is one of the most popular vegetable in several countries: USA, Canada, different Asian countries. The sweet corn crop has gained more and more popularity in the last decades due to its nutritional qualities and the possibilities of diversifying the diet in countries with an advanced social standard (Haș, 2000).

In North, Central America and in some South American countries, sweet corn was one of the basic foods (Tracy, 2000). In Europe, sweet corn entered the market after the Second World War, being already a fairly important crop in Spain, Italy, and France. In the countries of Eastern Europe, sweet corn practically accompanied the introduction into crop of the hybrids with normal grains.

Sweet corn intended for fresh consumption, in frozen or canned form, is a product appreciated by consumers and being very popular in many countries (El-Hamed et al., 2011).

Sweet corn is one of the most important food and economic crops in the United States. Sweet corn eaten fresh, canned or frozen, ranks among the top ten vegetables in terms of value and per capita consumption.

Sweet corn is the third most abundantly consumed vegetable in the United States after tomato (*Solanum lycopersicum* L.) and potato (*Solanum tuberosum* L.). In USA, in the period 2020-2022, sweet corn was the vegetable cultivated on the largest area (over 143,703 hectares), followed by tomatoes (USDA, 2023). The same sources indicate that in terms of total production, in 2021, the first three horticultural crops were tomatoes, onions and sweet corn, combined totalling 53% of the total production of vegetables.

Sweet corn differs qualitatively from regular maize by the proportion of carbohydrates in the endosperm at a certain phenophase (up to about the 30-35th day after pollination) in favour of mono- and disaccharides as a result of the action or interaction of some recessive genes (*su1, sh2, se*). The transfer of the recessive gene can be achieved by backcrossing.

Sweet corn can be classified on the basis of gene composition in the endosperm into five types: normal, sugary enhanced, super sweet, synergistic, and augmented shrunken. Normal sweet corn contains an allelic mutation in the sugar gene, *sugary1* (*su1*), which increases sugar content, but it is converted into starch quite quickly. In the sugary enhaced corn, the *sugary engaced (se)* gene works in addition to the *su1*, and have higher sugar content, is more tender and has extended shelf life, compared to the normal sweet corn varieties. Supersweet corn carries a *shrunken2 (sh2)* genes, and the sugar is converted into starch very slowly, so the sweetness is maintained longer. The synergistic sweet corn have *su1, sh2* and one or two copies of *se*, resulting in very high sugar content and tender kernels, and the augmented shrunken genotypes have *su1*, two copies of *se* and two copies of *sh2*, resulting in tender super sweet kernels (Singh et al., 2014; Ruanjaichon et al., 2021).

In the maize inbred line collection from ARDS Turda, 35 sweet corn lines are maintained and 4 hybrids were also registered, one of which (Deliciul verii) is still currently cultivated in Romania.

4. Oil content in maize

In addition to the main biochemical components of maize kernels, they also contain fats, which generally accumulate in the germs. Maize oil is considered superior quality for human consumption, and the lack of edible vegetable oils has led to the initiation of programs aimed at increasing the oil content of maize kernels (Pajic, 2007). After long selection cycles, the oil content of the Burr White variety was increased from 4.7% to approximately 20%. There have been various programs to improve the oil content of corn kernels, both for use in human food and for animal feed.

Maize germs contain 45–50% oil, which is used in salads, cooking and is obtained through the wet grinding process (Orthoefer et al., 2003). Maize oil contains: 14% saturated fatty acids, 30% monounsaturated fatty acids and 56% polyunsaturated fatty acids.

The refined maize oil contains between 54–60% linoleic acid, 25–31% oleic acid, 11–13% palmitic acid, 2–3% stearic acid and 1%

linolenic acid (CRA, 2006). In the human diet, there are two main forms of vitamin E: alpha (α) and gamma (γ) tocopherols. Maize oil is one of the richest sources of these tocopherols, especially γ-tocopherol (Sen et al., 2006).

Conclusions

The consumption of maize and its derivatives has a beneficial effect on human health, the importance of this crop being of particular importance for humanity.

Maize breeding programs must take into account the improvement of the content in various components, depending on the needs of the market, whether it is starch, proteins, sugars or oil.

Maize can be a basic food in the prevention of diseases caused especially by food shortages, thus the biofortification of this plant must be given special attention.

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