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Review paper

Advancements in breeding for high oil content in maize (Zea mays. L)

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Abstract

Maize is one of the world's most important food crops, supplying>5% deity energy. Due to its wider adaptability, high yield potential, maize is widely utilized as food and animals world worldwide. It enriched with caloric starch and the high energy in its oil. The kernel oil content in commercial high-oil maize hybrids averages ～8%, far lower than that in developed high-oil maize lines (as high as 20%). The maize seed/kernel consisted of endosperm (82%) and the germ (embryo and scutellum) (12%). The germ region makes up 80–84% of kernel oil, with the aleurone and endosperm making up 12% and 5%, respectively. High-oil maize may serve as a valuable forage maize germplasm for breeding. Maize oil is also considered as high-quality oil for human health due to the high proportion of polyun-saturated fatty acids. Selection for high oil increases the proportion of germ and further content of germ oil. The problems that over-shadow the successful production of high-oil corn are low grain yield potential, physiological cost of oil synthesis, low seed vigor, low kernel weight, shorter seed longevity, and poor germination of high-oil corn lines. It is necessary to make efforts to generate nested populations or use marker-assisted recurrent selection (MARS) to accumulate the advantageous quantitative trait loci (QTLs) in the pa-rental lines. The oil content of maize inbreeds and hybrids could be further improved with the use of transgenes, genomics, and metabolic engineering tech-nologies in new insight for the development of high oil maize breeding and strategies.

Keywords: *High Oil Maize; Hybridization; Quantitative Trait Loci; Selection.*

1. Introduction

Maize is the family of Poaceae and the genus Zea which is a group of annual and perennial grasses. It is an annual plant and most commonly cultivated plant height ranges from one meter up to three meters long. It is one of the world's important food crop, which supplies >5% dietary energy. The wider adaptability and high yield potential of maize and its utility as food and extensively being used in animal feeding, either as grain or whole plant forage crop signifies the importance of maize [1]. Maize is widely used as an important renewable resource for industrial materials, biodiesel production, and dietary consumption by humans and animals all over the world. Maize grain have been improved for a longtime mainly due to its starch is rich in caloric and oil is high in energy content [2].

Estimates of world population for 2050 are in the order of 9 billion people resulting in an increased demand for food and feed. Additional weighty drivers of demand for food and feed grains over the next four needs an extra amount (over and above that required for food and feed) of between 163 Mt and 363 Mt y^{-1} will be needed for 2050, need of an additional increase in global demand for cereal grains of between 9% and 19% at that time. Meeting these demands for cereals would require global harvests to increase at annual compound rates of 1.16% y^{-1} (lower bio fuel requirement estimate) or 1.31% y^{-1} (upper bio fuel requirement estimate) from now until 2050 [2].

There are two types of fatty acids: monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA), which are both found in large quantities in sunflower, corn, and soybean oils. The high energy and polyunsaturated fatty acids in maize oil make it a highly quality edible oil that is healthy for humans. Maize can also be used as biomass energy, which can bring considerable income to industrial produc-tion. Therefore, with the increase in oil content in maize kernels, the additional value of maize varieties will certainly increase.

Corn which consists over 6% of oil is referred as high oil corn. The yield of maize has been greatly increased by plant breeding. Increment in maize yield and improvement in quality with a variety of structures and composition area developed by breeders. The amount and quality of carbohydrates, proteins, and oil in the kernel were changed by taking use of genetic variety. The great economical and nutritional value of the maize kernel is mainly due to its high starch (75 % seed weight) and protein (10% seed weight), mainly found in the form of zeins (storage proteins) and oil (4.6 %).

The intensive use of the maize kernel is due not only to its high starch content but also to the oil stored in the embryo. Oil, in fact, is the most valuable crop product from industrial processing of maize grain, and is known as a source of high quality oil for humans [3]. Therefore, in this review the breeding strategy of different breeding techniques that could be utilized and past research scenario in improving maize oil content accessed.

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2. Maize breeding for high oil yield

Three main storage components make up the normal maize kernel: 70–75% starch, 8–10% protein, and 4-5% oil. The majority of vegetable oil is utilized for direct human consumption, but its non-food applications are expanding quickly, particularly in Europe where it serves as the main feedstock for the creation of biodiesel. Maize oil is highly prized for use in both human and animal meals. With more oil in the maize kernel, there is an increase in metabolisable energy and better protein quality, which benefits animal growth rate, feed efficiency, and productivity. Many studies have shown that kernel oil content is positively correlated with kernel protein content (KPC), and negatively correlated with kernel starch content (KSC). High oil maize (HOM) as a value added special crop is negatively affected by significant decreases in starch concentration with increased oil concentration in grain [4].
Studies that continue to uncover advantages related to oil quality or composition are contributing to the rising need for vegetable oil production. When compared to saturated and polyunsaturated fatty acids, oleic acid, a monounsaturated fatty acid has been shown to have significant health and cooking benefits. Increasing the amount of seed oil and its oleic-acid content would be a significant step in meeting the demands of this market; which is major goals for plant breeding and biotechnology.
Maize oil is a good vegetable oil since it is high in polyunsaturated fatty acids and low in linolenic acid [4]. More than 98% of the oil content of maize oil is made up of five fatty acids: stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), and palmitic (C16:0). The quantitative trait of maize's kernel oil content is complicated. Higher oil, protein, lysine, and other limiting amino acid levels are found in the kernels of HOM [5]. The foundational and most often used technique for enhancing desired qualities in crops is conventional breeding. This happens as a result of using traditional phenotypic selection to gather advantageous alleles, as the literature has demonstrated. In the past, HOM germplasm was created from regular maize through careful selection of open-pollinated varieties (OPV). Hopkins began the Illinois selection experiment in 1896, and much research has been done on the chemical makeup of kernels since then [6].

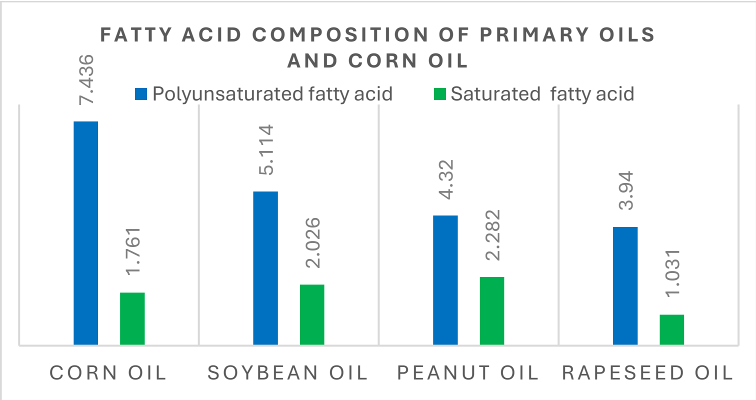

Fig. 1: Fatty Acid Composition of Primary Oils and Corn Oil.

2.1. Maize oil composition and key oil content determinants

The composition of the maize kernel varies according to cultivation techniques, the variety, and soil type, the season, and other elements. Corn oil was first made in a commercial setting in 1889. Corn-kernel oil having pale yellow in color is recognized as a vegetable oil. Refined corn oil has no flavor or aroma and odor are absent from refined corn oil. It can be used both as a cooking oil and in the production of hydrogenated oil. High-oil corn is defined as having an oil content more than 6%. Maize seed/kernel consisted of 82% endosperm, 12% germ, embryo and scutellum. The germ area contains 80–84% of the entire kernel oil, which is then followed by the aleurone (12%) and the endosperm (5%). Maize oil which represents 99% are mainly a mixture of five fatty acid viz oleic (18:1), palmitic (16:0), stearic (18:0), linoleic (18:2), and linolenic (18:3) acids [4].
Maize oil is generally regarded as a beneficial human vegetable oil since it is full of polyunsaturated fatty acids and vitamin E [4]. High-oil maize was reported as a desirable supplement for animal feed due to the high level of metabolizable energy in maize oil and the high protein quality of high-oil maize [7]; [4]. However, the production and breeding of high-oil maize must also take into account grain yield. IHO (Illinois High Oil) and ILO (Illinois Low Oil) are the high oil germplasms now used to identify QTL for grain chemical composition ([8]; [9]). Based on inheritance studies, maize kernel oil content is a quantitatively inherited variable with high heritability, additive effects that dominate non-additive effects (dominance and epistasis), little to no genotype by environment interaction, and the Xenia effect [9].

Table 1: Chemical Composition of Maize Hybrid Grain and Germ

Quality parameters	Composition (%)	Quality parameters	Composition (%)
Germ fat	48.61-54.21	fat	5.80-8.20
Germ	8.39-11.08	starch	69.07-70.54
Kernel fat	5.80-8.20	cellulose	2.20-4.20
Protein*	13.78-16.47	protein	10.40-12.40
Cellulose*	13.45-18.10	palmitic*	9.67-11.30
Ash*	1.78-2.40	stearic*	2.46-3.26
Linoleic*	46.95-54.36	oleic*	30.08-36.75

*Represents maize germ obtained by laboratory wet milling process; [10].

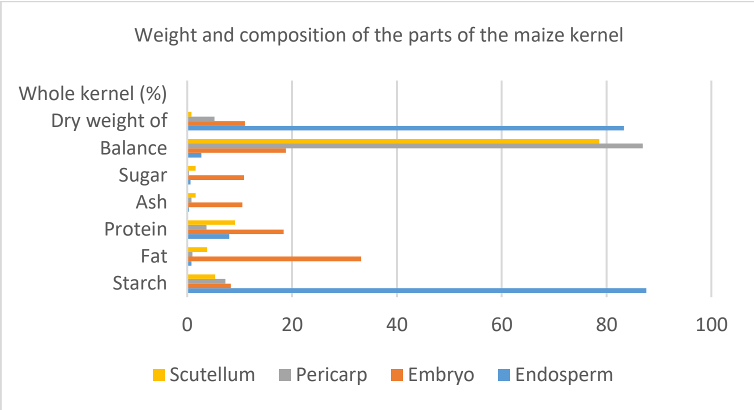

Fig. 2: Weight and Nutritional Composition of Maize Kernel. Source: [10].

3. Breeding strategies and technique to increase the oil content of maize

There is an abundance of knowledge and research on the genetic variation of maize grain's oil content, but the experiment started in 1896 at the University of Illinois in Urbana, USA, is said to have the broadest scope [11]. Several researchers observed from long-term selection trials a significant rise in maize kernel oil in response to selection, with a significant gain in projected selection response per cycle [12], [13]. The complex quantitative feature of maize oil content is regulated by several genes. Therefore, increasing the quantity and quality of maize kernel oil content is a key goal for breeding. Using marker-assisted selection or genetic engineering, it will be possible to improve oil quantity and quality by better understanding the genetic basis of oil synthesis and accumulation [14]. Artificially selected high-oil maize is a value-added crop because its kernels are advantageous as sources of animal feed for more caloric energy and higher-quality protein. Efforts directed toward increasing oil content of maize kernels through breeding have been successful, but unfortunately high-oil lines have significantly reduced yield [6], compared to starch, synthesis of oil is an energy-consuming process. Since high-oil corn hybrids often yield 5–10% less than regular corn, efforts are being done to increase oil content without reducing yield potential. The yield gap between high-oil corn and regular corn hybrids has been reduced as a result of ongoing genetic selection improving the agronomic performance and yield of these hybrids. Recurrent selection was used to begin the breeding program for high oil maize, and after 27 selection cycles, the improved population's oil concentration reached 21.2% [15].

Recently, there has been a lot of interest in applying the top cross strategy to produce high-oil maize from hybrids. Two varieties of corn are planted as part of the system. One type is an elite hybrid used as the "grain parent," accounting for 90 to 92% of the seed. The "pollinator" is a high-oil elite inbred that is the remainder. The elite commercial hybrid grain parent detassels during pollination. These pollinator plants secrete pollen that has genes that make kernels generate larger-than-average embryos or germs (the Xenia effect). The grain generated by fertilization with these pollinators has improved oil and protein quality since the majority of the oil and important amino acids are in the germ. The amount of grain output that pollinator plants provide is quite minimal. This technique was employed by [16] to create high-oil grain that they called TC Blend®. High-oil traits would not be developed if male sterile hybrids in the mixture were fertilised by pollen from normal or low-oil maize hybrids and justified top-crosses outperform single crossings in terms of seed production and seed set.

High-oil maize was created by breeders by recurrent selection to boost energy density for animal feed. Examples of these populations include the Illinois high-oil (IHO) population and the Alexho single-kernel (ASK) synthetic population. Commercial high-oil maize hybrids have not been issued, despite the fact that seed oil content in these populations has increased to as much as 22%, primarily due to a considerable decrease in grain production and other unfavorable agronomic features linked to high-oil germplasm.

3.1. QTL application as breeding strategy for high oil maize molecular breeding

The difference in grain oil content between high-oil maize and regular maize is its most notable feature. In the breeding and production of high-oil maize, grain yield is also crucial. Quantitative trait loci (QTL) mapping for grain yield features using the F2:3 population derived from the hybrid between B73 and a high oil maize inbred line BY804 [15]. The current high oil germplasms utilized to identify QTL for grain chemical composition are Illinois High or Illinois Low Oil [8]. In their study, two elite dent maize inbred lines were crossed with a high oil maize inbred line (GY220) (derived from an Alexander high oil maize background) to produce two related F2:3 populations.

Numerous studies have revealed genetic variation for whole plant digestibility, a key goal in silage maize breeding programs, which is positively correlated with water-soluble carbohydrates (WSC) and negatively correlated with acid detergent fiber (ADF) and neutral detergent fiber (NDF) [17]. Increased cell wall digestibility should lead to improved dry matter digestion [18]. QTL analysis was performed on the kernel chemical component (KCC) of maize in the IHO (Illinois High Oil), ILO (Illinois Low Oil), ILP (Illinois Low Protein), and BHO (Beijing High Oil) populations. The results showed that a variety of genetic variables regulate these features and that additive effects primarily govern the kernel chemical component [19].

The discovery that enhance introgression of favorable alleles from high oil maize into high yielding lines using marker-assisted backcrossing is reported. It composed five QTL for fatty acid composition and oil concentration in three genomic regions [20]. The strongest QTL for oil concentration, oil1-1, located on chromosome 1, was stable over different generations [21]. Beijing High Oil (BHO) was developed from Zhongzong No. 2, a typical maize synthetic produced through 12 inbred lines of the Lancast heterotic group. After 18 selection cycles, its oil content rose from 4.71 to 15.55% [22]. These materials provide a distinctive asset providing a chance to investigate the genetic basis of high oil content in maize.

Recent research suggests that the quantitative trait of maize seed oil content is regulated by more than 40 QTLs [12]. A few major QTLs with significant additive effects may be crucial in influencing the composition of fatty acids and raising the oil content of used germplasm. The compositions of fatty acids and oil concentration were also influenced by a greater number of minor QTL and a specific number of epistatic QTL, both of which had additive interactions [12]. This indicates the complexity of trait inheritance among normal and hybrid maize variety. The oil concentration of the embryo and percentage of the seed that the embryo occupies determine the seed's oil content. Using a BC2 (second backcross generation) population derived from a cross between a high-oil inbred line, ASKC28IB1 (ASK cycle 28 inbred 1), and a normal-oil inbred line, PH09B, a high-oil QTL found on chromosome 6 (qHO6) was found to be a key oil QTL that controlled both seed oil content and embryo oil concentration, but not embryo size or seed weight. It explained 11% and 9.5%, respectively, of the variation in seed oil content and embryo oil concentration.

Only one high-oil QTL (qHO6) has been improved and cloned so far using marker-based selection. By combining two regular corn inbreeds, 8984 and 8622, with one high-oil maize inbreed, GY220, two related RIL populations were created. China Agricultural University, a member of the Lancaster heterotic group, chose and offered GY220, which was produced from the cycle 27 Alexander high oil maize population. The two normal dent corn inbreeds, which belonged to the Chinese Reid heterotic group, were created in their laboratory. 282 and 263 lines, respectively, made up the RIL populations from 8984 6GY220 and 8622 6GY220, which are referred to as population 1 (Pop.1) and population 2 (Pop.2) [23] showing a single cross with a high oil line was used to create a RIL population.

To avoid the reduction in grain yield, a maize breeding program for kernel oil content should be created. Designing a good breeding program requires an understanding of the quantitative genetic variation for maize's oil content. The most significant option for the development of high-oil maize is the development of divergent high-oil parental lines and their application in hybrid development. By repeating selection generation after generation, coupled with inter-mating of the selected individuals or families, favorable alleles for high oil content can be built up. Although doing so will help to continuously raise the genetic ceiling, the procedure is sluggish and time-consuming. It is necessary to make efforts to generate nested populations or use marker-assisted recurrent selection (MARS) to accumulate the advantageous QTLs in the parental lines.

4. Conclusion

High-quality maize oil is preferable for human consumption and animal feed due to its lower saturated fatty acids concentration; stability of its fatty acid content during storage and cooking. In quality aspects maize oil is also thought to be superior to the majority of other edible oils. High-oil corn genotypes have been reported to contain more oil (6-7%) as compared to normal maize kernel oil (3-4%). It was revealed that a sizable number of genes and QTLs regulate the concentration of oil and yield performance of high oil lines. The creation of high-yielding genotypes with increased oil content in germ as well as unsaturated fatty acid and favorable ratio of saturated to unsaturated fatty acid could be enhanced more from a combination of conventional breeding techniques, marker-assisted selection, and transgenic procedures. Therefore, development of high oil parental lines and their use in hybrid development should be employed as breeding strategy and improvement of high oil maize.

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