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Breeding for Silage Maize for Sustainable Animal husbandry

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ABSTRACT

Maize (Zea mays L.) is not only an important staple crop for millions of people but also an important crop and now emerging as a type of high-energy silage crop. Silage maize continues to be one of the best supplementation options, especially in dry seasons. Breeding for silage also differs from forage hybrids as, for silage, the grain being the richest source of available carbohydrates in the maize plant is an essential breeding goal. Silage maize breeders may need to place greater emphasis on selecting for high whole-plant biomass yield rather than focusing on stalk lodging resistance, grain maturity, barrenness, and high grain yield. Leaf angle and orientation attributes, which account for the suitability of maize plants for high-density plantation, may contribute to enhanced silage productivity. DMY, whole plant digestibility, protein content, and the non-structural carbohydrate content of stover are other important traits to ensure high-quality silage. Cell wall fiber in particular highly influences the nutritional value of forage. Cell wall digestibility and silage traits (cell wall fiber content) have been extensively studied as breeding targets for improving the feeding value of the forage crops.

Keywords: *Silage, Biomass yield, Dry matter, Leaf angle, Lodging, Barrenness, Forage, Stover*

INTRODUCTION

Human population size increases day by day and depends on plants and animals to fulfill their food demands. Livestock provides high-quality foods such as milk, cheese, ghee, and butter etc. For the rural economy, there is a significant role of livestock. The success of dairy farming largely depends upon the health and productivity of the animals. Among various sources of feeding for dairy animals, green fodders are an economic source of nutrition. Green fodders are rich and cheapest sources of carbohydrates, protein, vitamins and minerals for dairy animals. Regular supply of fodder is essential for the production and economic returns from the dairy farming sector. But the availability of green fodder around the year in Northern India is scarce due to extreme seasonal severity from May to June and November to December. Area under fodder cultivation is decreasing due to the ever-increasing demand for cereal grains for human consumption as well as the preference to grow cash crops instead of fodders. Inadequate supply of fodder as one of the reasons for poor livestock productivity (2, 17). Silage is a supplement to the fodder deficient conditions. It is a major source of forage for dairies and feedlots to ensure a high performance of animals and to support sustainable animal production all over the World (11).

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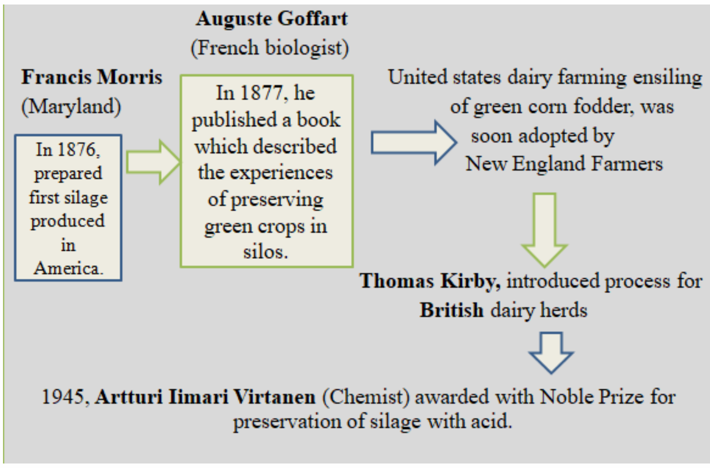
HISTORY



IMPORTANCE OF SILAGE

The purpose of silage-making is to preserve forage through natural fermentation by achieving anaerobic conditions.

1. Relative nutrient yield- Silage yields greatest quantities of energy and protein.

2. Reduced field losses- Losses from ear dropping and grain shattering that occur during corn silage harvest are lower than those occurring during grain harvest.

3. Efficient use of labor- Silage system is more mechanized and less labor-intensive (4).

4. Supplement to fodder- It eases the serious feed shortage experienced in the dry season.

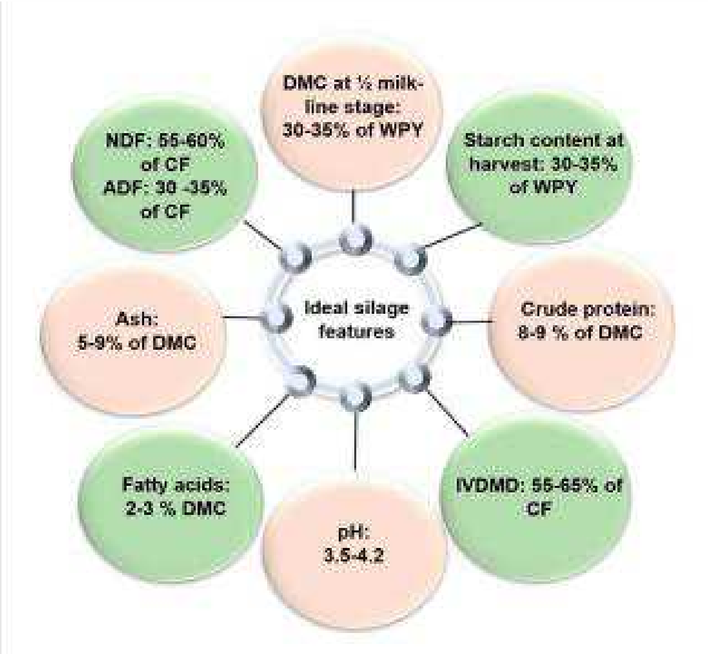
5. Efficient use of land- Better use of land with two or three crops annually.

6. Economic benefits- Advantages can be taken of the higher milk price during periods of feed shortage (3).

IDEAL CONDITIONS FOR SILAGE

Avoid bad weather at the time of harvest. Select a crop that is to be ensiled when it has 30-35% dry matter. pH should be 3-4 for a continuation of fermentation process (29).

- No fungal or mold growth.
- Golden brown color.
- Pleasant fruity odor/acceptable aroma.
- Ammoniacal N levels should not exceed 9%–15% of the total-N as ammonia imparts flavor and aroma to plants.
- Free-flowing and non-sticky texture.
- Mildly acidic taste with an optimum pH of around 4.0–4.5.
- More lactic acid should be present compared to other acids, and butyric acid levels should be very low, around 0.2%–0.5% (15).



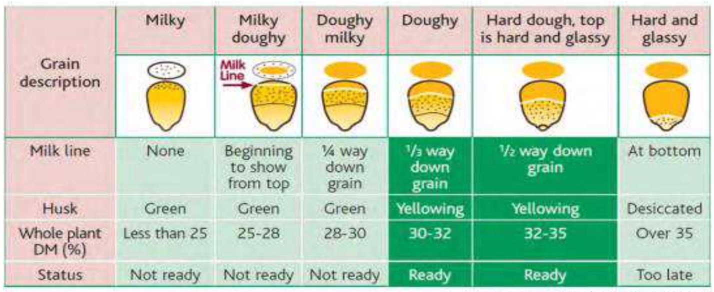
CROPS FOR SILAGE

The fodder crops such as maize, sorghum, oats, pearl millet, and hybrid napier rich in soluble carbohydrates are most suitable for fodder ensiling. Corn silage is an important feed source for dairy cattle and sorghum silage is becoming more common in the beef cattle industry. Corn silage is generally preferred for dairies because it can produce the most energy per acre with less labor required. Meanwhile, sorghum requires less fertilization and maintenance and is generally choice for low-input systems. Nutrient yield of sorghum silage is the same as corn silage but biomass yield is typically lower (5). Sorghum and millets can produce one or more ratoon crops that can be grazed. And normally not used on dairy systems because production tends to be much lower compared to the first crop and is best when cut earlier. Alfalfa is also very common for silage but in Florida, most legumes are not productive enough to justify ensiling (19). Oats silage may be an alternative silage source in cold and dry regions and may provide support to meet silage needs by planting ahead of corn (16).

Table 1. The Optimum time of harvesting for silage crops

S. No	Crop	Stage of harvest	Days after sowing
1.	*Kharif* Maize	Milk stage	70-80
2.	Spring Maize		90-100
3.	Summer Maize		80-90
4.	Sorghum	Boot to milk stage	80-90
5.	Bajra	Flowering	50-60
6.	Oats	Milk stage	90-105

Silage quality depends on dry matter content. Because dry matter content (DMC) is an important criterion for determining the harvest maturity of silage maize. The best physiological maturity stage of maize kernel for silage is the half-milk stage, with optimum moisture of 30%– 35%. At the half-milk line stage, half of the kernel is filled with milky endosperm, which highly enhances the fermentation process; the remaining content is hard starch digested by the ruminant. Low DMC due to early harvest results in low dry matter silage, which may be bulky and, thus, reduces feed intake and animal performance (28).



Grain description	Milky	Milky doughy	Doughy milky	Doughy	Hard dough, top is hard and glassy	Hard and glassy
Milk line	None	Beginning to show from top	¼ way down grain	⅓ way down grain	½ way down grain	At bottom
Husk	Green	Green	Green	Yellowing	Yellowing	Desiccated
Whole plant DM (%)	Less than 25	25-28	28-30	30-32	32-35	Over 35
Status	Not ready	Not ready	Not ready	Ready	Ready	Too late

Source: Kumar *et al* (2019)

Fig. Detection of Optimum Stage of Harvesting for Silage

WHY MAIZE SUITABLE CROP FOR SILAGE?

Maize is a high-energy, low-protein forage commonly used for dairy animals like cows and buffalos due to quick growth high biomass, good palatability, absence of anti-nutritional components. It is also preferred for silage over other crops due to its softness, high starch content and sufficient soluble sugars. It can be consumed by ruminants in large amounts (23). Corn silage has a high-quality fiber content and high energy density as compared to other crops. It is considered as one of the most economical forage producers can grow based on yield and energy value and requires less labor (Since harvested in a single operation) and is generally less costly (per tone DM) (12).

BREEDING APPROACHES FOR IMPROVEMENT OF SILAGE MAIZE QUALITY

CONVENTIONAL BREEDING TECHNIQUES-

Ideotype Breeding

Ideotype for Silage Maize- Ideal plant for *Zea mays* L. breeding will maximally utilize an optimum production environment. The environment should include adequate moisture, favorable temperature throughout the growing season, adequate fertility, high plant densities, narrow row spacing, and early planting dates (21).

The maize plant should produce optimally when grown in such an environment would be characterized by:

1. Stiff-vertically-oriented leaves above the ear- Average of leaf angle between 10^0-15^0 shows significant interaction between corn product and population density. Upright leaf angle allows more penetration of sunlight (13). Vertically-oriented leaves, especially those in upper canopy, allow sunlight to penetrate deeper into the canopy, which can result in more efficient canopy-level light use and whole-plant photosynthesis (9). Liguleless1 (lg1), Liguleless2 (lg2), CLA4, nana plant 2 some of the maize genes which control leaf angle (20).

2. Maximum photosynthetic efficiency- Silage maize depends on both biomass yield and grain yield for the production of good silage quality (33). Photosynthetic efficiency effect the whole plant yield, which may increased by adjusting planting density and application of nitrogen fertilizer (27).

3. Sparse tassel- Tassel branch number is key trait that contributes greatly to grain yield in maize. Tassel with more branches contributes to prolonged pollination time and improved setting rate. However, more tassel branch numbers will consume more energy to produce pollen, thus reducing the nutrients by ear and then effecting corn yield (36). SQUAMOSA PROMOTER BINDING PROTEIN LIKE (SPL), KNOTTED 1 (KN1) plays important role in reduction of tassel branch numbers (14).

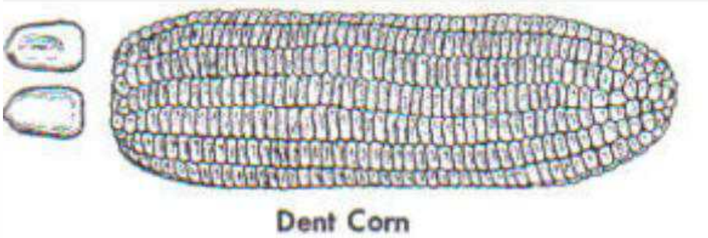
Fig. Different tassel type as Compact, Sparse, Fully Sparse, Curve, and Super Curve

4. Early flowering- Flowering time, an important factor in plant adaptability and genetic improvement for harvesting date, biomass yield, crop rotation scheme, and terminal drought resistance, regulated by various genes as dlf1, encodes leucine zipper protein and ZmSOC1 encodes conserved MADS domain (1). Vgt1 cis-acting regulatory element influences the transcript expression levels of downstream gene ZmRap2.7 which is associated with late flowering (8).

5. Reduced plant height- The primary purpose of reducing plant height in maize will reduce lodging incidence. Tall cultivars require low densities to maximize grain yield per area. Luis and Salvador (1997) designed an experiment and evaluated reduction in plant height through the use of dwarfing genes, but the use of dwarfing genes does not improve the yield of maize plant. DELLA domain proteins are of particular interest for dwarfing genotypes in maize because of the gibberellin-insensitive dwarf phenotype. Dwarf plant 8 (d8) and d9 mutant are responsible for increased production (18).

6. More number of Leaves- The primary goal of silage maize production is to obtain the greatest possible amount of digestible nutrients. Silage quality is affected by dry matter production extremely important digestibility traits (26). The ideotype for silage with a greater number of leaves are suitable for maximum production of dry matter and rumen digestibility. (31) use a leafy gene mutant (lfy1) and observed an increase the total leaf area and particularly the number of leaves above the ear and grater yield potential.

7. Dent-type kernels- The feeding value of forage maize largely depends on the characteristics of starch degradation (6). The endosperm of corn contains >85% of the starch, which acts as a significant substrate for rumen fermentation, leading to the production of substantial amounts of propionic acid, which is a powerful source of energy (32). Dent lines possess more starch degradation than flints due to their floury endosperm and reduced vitreousness. Dent corn has a soft, starchy endosperm with a small, indented area on the crown of the kernel. . Flint corn, on the other hand, has a hard, vitreous endosperm that is more difficult to be ground into flour. The difference in hard starch in these corn lines makes them differential for digestibility in the rumen of cattle. (25) compared the ruminal starch degradability of chopped, unensiled, and ensiled grains. Dent corn had a higher digestibility value than flint corn. However, ensiling the corn increased the ruminal starch degradability by an average of 5.8% for both dent and flint corn. Furthermore, the ensiled dent corn showed superior starch digestibility compared to flint corn.



8. Reduced lignin content- Lignin is the polymer of phenylpropanoids, also called monolignols. Guaiacyl (G), syringyl (S), and p-hydroxyphenyl (H) units constitute most of the maize lignin. Lignin content plays a crucial role in providing structural support, reduces water loss and entry of disease-causing organisms in plant. But in silage maize it shows negative impact on the nutrient availability of the plant fiber, lignin is regarded as a low-quality component of silage. To regulates the amount of digestible fiber; hence, it has a direct and important impact on the forage's digestible energy (DE) value (7). Brown midrib maize is naturally created by single-gene mutations that impact the lignin biosynthetic pathway (the phenylpropanoids pathway), resulting in its lower lignin content, thereby increasing fiber digestibility. As the name implies, the midrib veins of BMR maize leaves have a unique brown tinge. BMR silage corn has many advantages, such as its favorable impact on the ash, NDF, ADF, and CP levels in maize plants (37).

Ideal Genotype for Silage Maize Breeding

S. No.	Inbred Line	Silage Trait
1	I 160	Narrow leaf angle, early maturity, sparse tassel type
2	EML 256	Sparse tassel, early maturity, dent type kernel (Starch)
3	I 164	Narrow leaf angle, sparse tassel
4	VL 1077	Yellow (nutrient) and dent kernel (starch)
5	I 172	Plant height and sparse tassel
6	LM 11	Narrow leaf angle, sparse tassel
7	PML 912	Early maturity

Recurrent Selection- Exotic populations of the late maturity group are more adaptive to various agroclimatic conditions and the hybrids obtained by such populations follow the tendencies of early maturation and a vegetative period that is a few days shorter than the parental forms (34). (24) use the recurrent selection for the creation of early flowering in late maize synthetic population that resulted progeny with a period of days until silking averagely shorter with 5 days.

Heterosis Breeding- Heterosis is common biological phenomena in nature. It substantially contributes to the biomass yield and grain yield of plants. (22) produced 45 hybrids by crossing African tall x GWC-0319 and African tall x GWC-0321 using line x tester mating design. And observed crosses of African tall x GWC-0321 showed heterobeltiosis for forage yield and crude protein content.

Mutation Breeding- The brown mid rib mutations are among the earliest described in maize. Plants containing a brown midrib mutation exhibit a reddish brown pigmentation of the leaf midrib starting when there are four to six leaves. These mutations are known to alter lignin composition and digestibility of plants. (35) used two independent bm3 mutations have resulted from structural changes in the COMT gene, which encodes the enzyme O-methyltransferase involved in lignin biosynthesis. Observed that bm3-1 allele has arisen from an insertional event producing COMT mRNA aletred in both size and amount. The second bm3 allele, bm3-2 resulted from deletion of part of COMT gene. These results clearly demonstrate that mutations at the COMT gene give a brown midrib3 phenotype.

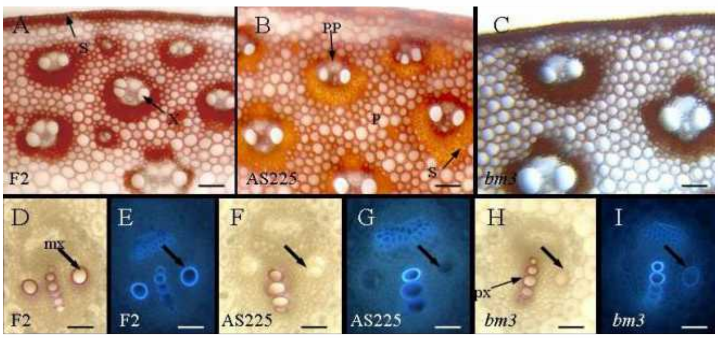


Fig: Differences in coloration of lignified tissues between F2, AS225 and F2bm3 lines in the presence of Maüle reagent (AC) are visible.

MODERN BREEDING TECHNIQUES

Unlike traditional plant breeding, which involves the crossing of hundreds or thousands of genes, plant biotechnology allows for the transfer of only one or a few desirable genes. Genomic selection (GS) is one breeding methodology that helps select superior plants as parents for the next selection cycle using estimated breeding values. whole-genome sequencing application, maize DNA markers have proven to be tools for various analyses ranging from phylogenetic analysis to positional cloning of genes. In biotechnology applications, maize markers have been used to characterize germplasm, perform DNA fingerprinting, map quantitative trait loci, perform MAS, and identify candidate genes. Modern biotechnological tools such as CRISPR/Cas 9, RNAi, TALENs, and ZFNs can be used for site-directed mutagenesis to either knock out genes or perform base editing.

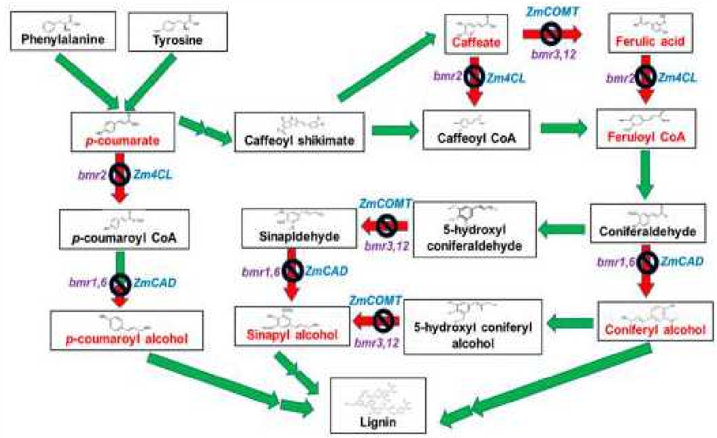


Fig. Genes related to lignin biosynthesis knock out using Genome Editing Tools

This more precise science allows plant breeders to develop crops with specific beneficial traits and without undesirable traits. Through traditional breeding methods, genes have been transferred from one individual to another to produce individuals which exhibit particular desirable traits. These crossings are usually between individuals of the same, or closely related, species. The gene pool available for use, in traditional crossing, is thus limited to those genes present in individuals which can be induced to breed using natural crossing methods.

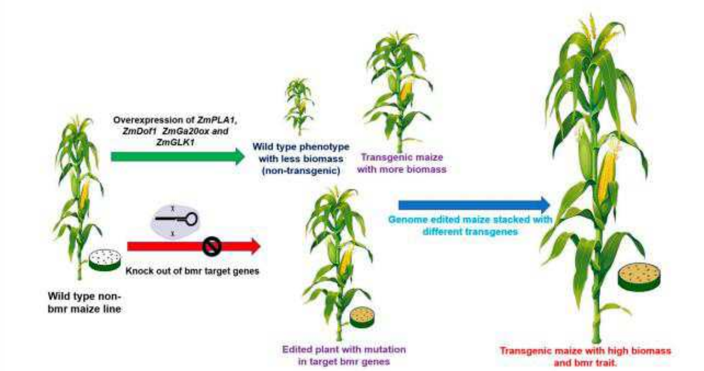


Fig. GE and Transgenic technology for development of high biomass and bmr trait for silage maize

COMMERCIAL VARIETIES FOR SILAGE MAIZE

- H6213
- H628
- H629
- H614
- KH 600-23A
- Silage Master- High biomass
- J 1006
- PMH 10
- DKC 9108
- S 180- Early harvest, dent-type seed, suitable for all locations
- Korean- Fatty acid
- 7474- Sweet, juicy, early harvest

CONCLUSION

Silage plays a critical role in livestock nutrition as it serves as a preserved source of easily digestible nutrients in diets for high-producing livestock, ensuring optimal rumen function. Additionally, it serves as a supplementary feed during winter and drought periods. With the rising global demand for silage driven by the growing world population, the increasing size of livestock farms, and the need to secure global food security, it is essential to foster multidisciplinary collaborations between experts in plant breeding, mechanical engineering, chemistry, biochemistry, microbiology, and animal nutrition to develop innovative solutions to improve the efficiency, quality, and safety of silage production, ultimately benefiting farmers, consumers, and industry. The proposed ideotype and described quality parameters in this study can be used as a useful resource for breeding silage maize.

FUTURE PROSPECTS

Production of Silage maize increases in India especially in Punjab during recent years. It acts as a substitute of fodder during dry period conditions of weather. Because at that time there is a shortage of fodder as well as also a rich source of nutrients. No need of providing supplement feeds to animals. Due to all of the above, assumed that the marketing of silage maize increases till 2030.

CONFLICT OF INTEREST

No conflict of interest by author side.

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