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Chittaranjan Kole, Chandrashekhar P. Joshi, David R. Shonnard

Sugarbeet

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29 Sugarbeet

Pawan Kumar, Anjanabha Bhattacharya, and Rippy Singh
University of Georgia

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29.1 INTRODUCTION

The world population is growing at an alarming rate, and with this growth the demand for energy is also increasing at a rapid pace. It is projected that there will be more than a 50% increase in energy demand in 2025, with most coming from rapidly developing nations. This increased demand cannot be met with finite fossil energy sources like petroleum and coal. Therefore, the present-day energy scenario and concerns for global warming have stimulated the search for an alternative to fossil fuel energy which ought to not only be renewable but also ecofriendly with low emission of greenhouse gases (GHGs). Bioenergy from plants is one such source that has the potential to reduce dependence on fossil fuels.

Ethanol produced from plants can be used as an energy source in its pure state or it can be used by blending with petroleum fuel in engines. It offers several advantages over fossil fuel: it has a high octane number (the higher the number, the more efficient the energy usage) (Balat 2009), low toxicity to humans, low volatility, and low evaporation (Hira and de Oliveira 2009). Bioethanol is being produced from sugar-rich crops such as sugarcane and sugarbeet (Wegner and Hagnefelt 2008). Bioethanol production from sugarbeet is of recent origin. It helps to stabilize falling sugar prices in addition to bridging global energy demands. It is more cost-efficient to convert sugars to ethanol than unlocking complex polysaccharides from plant sources because to date there has been limited success in separating lignin from plant material that prevents access of cellulose (polysaccharides) to trap the source molecules needed as raw material in bioethanol production.

Sugarcane is adapted to tropical regions of the world, whereas sugarbeet is predominately grown in temperate regions; therefore, the two sugar-rich crops occupy different geographical niches. Sugarbeet was identified as a crop of choice for sugar production in the temperate regions in the early nineteenth century, when sugar was largely imported from the tropical and subtropical countries and so was considered to be a luxury item that few could afford. Sugar was used largely as a base in traditional medicine such as homeopathy and was a very expensive product that was only derived from cane sugar. Although sugarbeet contains less sugar (17%; Milford and Watson 1971) than sugarcane (18–22%), and it is a poor transformer of sugars from the photoassimilate, it had advantages because it could be grown in temperate climate and the foliage could be used as a
cattle feed. This prompted the farmers to start cultivating this crop in the western countries, and now it occupies a sizable acreage. Today it meets almost half of the demand for sugar consumption in the developed world.

29.2 SUGARBEET AS A SUGAR CROP
Sugarbeet (Beta vulgaris L.) belongs to family Chenopodiaceae and is an important sugar crop of the world second only next to sugarcane. This is a hardy crop. It is drought and heat tolerant and can grow in saline conditions, although its cultivation is labor-intensive (Streibig et al. 2009). Sugarbeet is a biennial plant predominately grown in temperate regions where beets are planted in spring and harvested in autumn. When grown in warmer regions the beets are planted in autumn and harvested in spring. The recent introduction of tropical sugarbeet has enabled its cultivation in tropical and subtropical regions.

Sugarbeet has been grown for food and fodder (Clarke and Edye 1996) since ancient times, but its value as a sugar crop was realized in the mid-18th century when a method for extracting sugar from the beets was discovered. German chemist Andreas Marggraf discovered that beets contain sucrose, which was similar to that produced from sugarcane. However, an efficient protocol was not developed for another 50 years. In the late eighteenth century, one of Marggraf’s students, Franz Karl Achard, succeeded in developing efficient methodology for producing crystalline sugar from sugarbeet on an industrial scale. It was the research effort of Karl Achard that established sugarbeet as an economic source of sucrose in Europe. Karl Archard is now considered to be the father of the sugarbeet industry (Ensminger and Konlande 1993).

29.3 EXTRACTION OF SUGAR
Sugarbeet is harvested mechanically; a series of blades on harvesters cut off the top leaves and the crown. The roots are then cleaned to remove attached soil before transportation. At the processing plant, sugar content of the crop is determined, which in turn determines a grower’s payment (Dodic et al. 2009). After thorough cleaning, the beets are chopped into slices called “cossettes.” Sugar from beets is removed through a diffusion process. The cossettes are mixed with hot water at approximately 70°C for approximately 90 min. The sugar in the beets passes from the plant cells into the surrounding water by diffusion. This sugar-containing water is referred to as “raw juice,” and the left behind cossettes are called “pulp,” which is high in moisture but low in sugar content. Remnant sugar from the pulp is squeezed out in a screw press to remove as much juice as possible. This juice is used as part of the water in the diffuser, and the pulp is then sent to a drying plant where it can be processed into other value-added products.

The raw juice needs to be cleaned before crystallization. This is done by a process called “carbonation,” where the juice is mixed with milk of lime [calcium hydroxide, Ca(OH)₂] and bubbling carbon dioxide through the mixture. Small clumps of chalk start to form in the juice, and as these clumps form, they collect much of the nonsugar from the mixture (Kenter and Hoffmann 2007). After removal of chalk particles, a clean sugar solution is left behind, which is called “thin juice.” Thin juice is concentrated into “thick juice” by evaporation in a multistage evaporator. This thick juice contains approximately 60% sucrose by weight. Thick juice is then fed into crystallizers to form sugar crystals, and a centrifugation step separates the sugar crystals from the liquid molasses.

29.4 BIOETHANOL PRODUCTION FROM SUGARS
Biofuels produced from sugar and starch-rich crops (e.g., sugarcane, sugarbeet, and corn) are often referred to as first-generation biofuels because these crops were the first candidates for bioethanol production. The sugar extracted from these crops is fermented anaerobically to produce ethanol. The trend of producing ethanol started from Brazil, where sugar production was much higher than
Sugarbeet

the demand and petroleum was costly. Sugar-based bioethanol allowed Brazil to achieve energy self-sufficiency (Gressel 2008).

Sucrose produced by sugarbeet is a disaccharide molecule made up of glucose and fructose. Monosaccharides like glucose and fructose serve as base material for ethanol production. Therefore, the sucrose molecule first needs to be broken down into its component sugars. This is done by enzymatic hydrolysis of sucrose catalyzed by the enzyme invertase, which converts sucrose into glucose and fructose:

\[
\text{C}_{12}\text{H}_{22}\text{O}_{11} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{C}_6\text{H}_{12}\text{O}_6
\]  

(Sucrose) (Glucose) (Fructose) (29.1)

Enzymatic hydrolysis is followed by the fermentation process for the production of bioethanol. Commercial yeast such as \textit{Saccharomyces cerevisiae} converts glucose into ethanol under anaerobic conditions. The recently introduced strain \textit{S. cerevisiae} ATCC 36859 has proven to be an efficient microbe in enhancing ethanol production from sugarbeet molasses (Atiyeh and Duvnjak 2003a).

\[
\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2
\]  

(Glucose) (Ethanol) (29.2)

Many other microbes are also capable of ethanol formation. Many bacteria such as \textit{Enterobacteriaceas, Spirochaeta, and Bacteroides} spp. and yeasts including \textit{S. cerevisiae}, \textit{S. uvarum, Schizosaccharomyces pombe}, and \textit{Klyuyeromyces} sp. metabolize glucose under anaerobic conditions by the Embden–Meyerhof pathway. In this pathway, one molecule of glucose yields two molecules of pyruvate, which are then decarboxylated to acetaldehyde and then reduced to ethanol. The ethanol thus produced is low in concentration (8–12%). A distillation process is used to increase the concentration of ethanol to the required levels. Modified techniques are used in this process to recover a large portion of ethanol and to prevent ethanol emission into the atmosphere or ethanol losses with water (Krylova et al. 2008).

All of the intermediates produced during sugarbeet processing can be used as raw material for ethanol production. All of these have advantages and limitations. Direct use of beet or pulp as raw material is not very efficient (Turquois et al. 1999) because there is a slow release of sugars from the pulp into fermented solution and the long-term storage of beet leads to a loss of sugar due to enzyme action (Berghall 1997). Solids from raw juice contain 85–90% sugars and 10–15% nonsugar; therefore, raw juice can be used as raw material for fermentation after slight pH adjustments. Easy decomposition by microbes and low storability limits the use of raw juice for direct fermentation. However, thin juice is very suitable for ethanol production (Figure 29.1). Molasses, produced during the crystallization process, is a traditional raw material for distilleries, and more than 90% of ethanol is produced from this raw material.

29.5 SUGARBEET IMPROVEMENT

Sugarbeet continues to be a major crop meeting our daily needs for sugar consumption; thus, major genetic studies have been initiated in recent years to improve the quality and productivity. Other objectives include selection for resistance against insects, pests, and diseases. Crop modeling is another area that should be explored to increase productivity. A specific areawise crop model should be developed that will help us to decide on agronomic practices and harvesting schedules. Sugarbeet can be grown as an intercrop between the main crops.

Thus, increasing the productivity of sugarbeet is of paramount importance and for it to become a successful biofuel crop the need of the hour is to identify and exploit genetic potential of the crop through better selection of traits (Doney and Theurer 1984; Kuhn 1998) that contribute to the
physiological characters of importance related to crop productivity. Agronomic performance of
different sugarbeet varieties and germplasm accession at different locations should also be evaluated
to identify varieties adapted to a particular area (Sarwar et al. 2008). Efforts should be given to
create a genetic map of the crop species, which will help in advocating better breeding programs
focused on crop improvement. Sugarbeet improvement could be aided by identifying quantitative
trait loci (QTL) linked to simple sequence repeats (SSRs), random amplified polymorphic DNA
(RAPD), expressed sequence tags (ESTs), or amplified fragment length polymorphism (AFLP)
markers. Schnedier et al. (2001) identified 21 different QTL associated with sugar content, sugar
and beet yield, and amino-nitrogen content in sugarbeet verified at six locations. Further, targeted
induced local lesion in genomes (TILLING) should also be undertaken to identify mutants with
increased productivity, less canopy area, and decreased days to maturity. Other approaches may
include targeted reduction of genes by RNA interference (RNAi) and micro-RNA, which may
increase productivity and reduce diversion of photoassimilates toward noneconomic parts of the
plants [i.e., vegetative parts particularly genes involved in gibberellin (GA) metabolism]. Also,
identification and ectopic expression of transgenes should also be considered. Therefore, cloning
genes responsible for rapid conversion of sugars (dextrose, raffinose, and sucrose) to ethanol (Atiyeh
and Duvnjak 2003b) and then expression of such genes in a plant system will enhance the production
of ethanol.

Smith (2008) reported that manipulation of ADP-glucose pyrophosphorylase, which plays a
role in the sugar signaling pathway, to increase the yields of starch have been met with limited
success. One of the aspects for biofuel production is synchronous maturity of the crops used
for biofuel production. Many chemicals that promote synchronous maturity such as naphthalene
acetic acid (NAA) could be useful. Also, application of gibberelic acid (GA) may result in high
yield. Anti-GA substances such as paclobutrazol can be used to control plant height, or ectopic
expression of GA 2-oxidase will result in dwarf plants (Dijkstra et al. 2008). This will allow for
easy harvest of the produce with low cost on resources and saving time. Compact plants are also
less prone to damage by biotic and abiotic stresses. Several research groups including researchers
from the United Kingdom have concentrated their efforts on controlling stature and flowering in
sugarbeet at Boomsbarn, Rothamsted Research, England (Mutasa-Gottgens et al. 2008). Other

![Flowchart showing stepwise procedure involved in the production of bioethanol from sugar
and starch components of sugarbeet.](image-url)
efforts include transcriptional profiling under stress conditions in sugarbeet, thus increasing our understanding of the crop productivity under different physiological conditions, which could be utilized in crop improvement (Pestsova et al. 2009). Another study by Ozolina et al. (2005) explored the fluctuation of plant hormones and sugar deposition in sugarbeet, thus adding to our existing knowledge base of sugar distribution. Sadaghian et al. (1993) conducted an experiment to identify the genetic basis of number of cells, their length, and GA sensitivity in sugarbeet in relation to bolting, which ultimately determines productivity. Selective photoassimilate partitioning should also be included in the crop improvement regimes. Another strategy could be manipulating the C\textsubscript{3} mechanism of photosynthesis in favor of the C\textsubscript{4} mechanism, which is present in the grass family and at present, can only be grown in tropical regions. Such mechanism should be explored in sugarbeet, thus increasing carbon sequestration. Sévenier et al. (1998) ectopically expressed a gene encoding 1-sucrose::sucrose fructosyl transferase (1-SST) from *Helianthus tuberosus* into sugarbeet that increases fructan (forms of simple sugars) content without subsequently altering plant architecture. This could later be used potentially in biofuel production. Further, manipulating genes for enhanced solar energy capture and conversion of photosynthate to sugars (as mentioned in relation to C\textsubscript{3} and C\textsubscript{4} crops), and genes that provide endurance to plants growing under saline conditions or on land not usable for cultivation should be emphasized particularly when soil salinity problems are growing out of proportion in the modern world (Antizar-Ladislao and Turrion-Gomez 2008). Therefore, production of transgenic plants with the above-mentioned traits would help in developing a more robust plant phenotype that was not always possible through conventional or molecular breeding.

Better extension activity should be adopted to disseminate new technologies and crop varieties to the farming community and better postharvest facility should be ensured.

### 29.6 ALTERNATIVE USES

Sugarbeet is largely used for sugar production and as a root vegetable crop throughout the world. Although it had humble beginnings as a minor crop that was considered a poor man’s food or feed for cattle, today it has gained widespread importance. It is in fact the same species as red garden beets. After the sugar has been extracted, the molasses can be used as a material source for biogas production and as a fertilizer (Okiely 1992). The leftover biomass after extraction of the sugar can be used as cattle feed. The green mass left after harvesting the crop can be ploughed back to the soil, restoring soil fertility and organic matter content. Keeping these points in perspective, sugarbeet cultivation may act as a sort of incentive for the farming community in terms of rural employment and socioeconomic development, soil conservation, agricultural sustainability, and as such in the developing world (Venturi and Venturi 2003).

### 29.7 FURTHER DISCUSSIONS AND CONCLUSIONS

As the demand for alternative biofuel crops intensifies along with the long-standing debate between “food versus fuel” in the modern world, sugarbeet has come a long way to be a part of the solution, being able to provide a green fuel in this era of climate change concerns. What was considered as poor man’s crop or as a cattle feed crop species and largely neglected a few centuries ago could now be a lead crop in sugar production for the liquid fuel industry. With falling sugar prices, sugarbeet can be put to another use—to produce bioethanol instead for traditional uses—thus ensuring good returns to the growers. As conversion of sugar to ethanol still remains the most viable and practical option to produce biofuels, the popularity of sugarbeet in biofuel production is bound to increase. This requires a major restructuring of the sugar industry throughout the world backed by reasonable pricing for the producers. Biofuel plants, which use sugarbeet, should be located in the vicinity of the area of production to decrease the price of production and create ample avenues of employment. Further, the production and supply chain need to be straightened, thus eliminating unnecessary
middlemen to reduce the price per unit. The need of the hour is to identify or develop superior genotypes and to identify genes responsible for enhancing sugar production in this crop species validated at different climatic regimes. We have much better technologies available on the industrial side for the production of the biofuel; thus, crop productivity to supply the raw material seems to be a bottleneck. Large amounts of subsidy have already been provided in biofuel ventures, and there is much scope of innovation based on local conditions, which will lessen our dependence on gasoline-based industries backed by legislature.

REFERENCES


