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Review

Sugar Beet Cultivation in the Tropics and Subtropics: Challenges and Opportunities

Muhammad Tayyab [1,2], Abdul Wakeel [1,*], Muhammad Umair Mubarak [3], Arkadiusz Artyszak [4,*], Sajid Ali [5], Erdogan Esref Hakki [6], Khalid Mahmood [7], Baiquan Song [8] and Muhammad Ishfaq [9]

1 Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, Faisalabad 38040, Pakistan
2 Institute of Plant Nutrition and Soil Science, Kiel University, 24118 Kiel, Germany
3 Agronomy Department, Commercial Division, Engro Fertilizers Limited, Hyderabad 71000, Pakistan
4 Institute of Agriculture, Warsaw University of Life Sciences-SGGW, 02-776 Warsaw, Poland
5 Department of Agronomy, University of the Punjab, Lahore 54590, Pakistan
6 Soil Science and Plant Nutrition Department, Faculty of Agriculture, Selcuk University, Konya 42250, Turkey
7 Rothamsted Research, West Common, Harpenden AL2 5JQ, UK
8 National Sugar Crops Improvement Center, College of Advanced Agriculture and Ecological Environment, Heilongjiang University, Harbin 150080, China
9 College of Resources and Environmental Sciences, National Academy of Agriculture Green Development, Key Laboratory of Plant-Soil Interactions, Ministry of Education, China Agricultural University, Beijing 100193, China
* Correspondence: abdulwakeel77@gmail.com (A.W.); arkadiusz_artyszak@sggw.edu.pl (A.A.)

Abstract: Sugar beet, an important sugar crop, is particularly cultivated in humid regions to produce beet sugar, fulfilling about 25% of the world's sugar requirement, supplementing cane sugar. However, sugar beet is not well adopted in the farming system of the tropics and subtropics, which is largely due to the historically well-established production technology of sugarcane and the lower awareness among local growers of sugar beet cultivation. Thus, the poor understanding of pest and disease management and the lack of processing units for sugar beet partially hinder farmers in the large-scale adaptation of sugar beet in the tropics and subtropics. Recent climatic developments have drawn attention to sugar beet cultivation in those regions, considering the low water demand and about half the growing duration (5–6 months) in contrast to sugarcane, sparing agricultural land for an extra crop. Nevertheless, a considerable knowledge gap exists for sugar beet when closely compared to sugarcane in tropical and subtropical growth conditions. Here, we examined the leverage of existing published articles regarding the significance and potential of sugar beet production in the tropics and subtropics, covering its pros and cons in comparison to sugarcane. The challenges for sugar beet production have also been identified, and possible mitigation strategies are suggested. Our assessment reveals that sugar beet can be a promising sugar crop in tropical and subtropical regions, considering the lower water requirements and higher salt resistance.

Keywords: sugar beet; tropics; adaptation challenges; management practices; sugar recovery; industrial quality

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1. Introduction

Sugar beet (*Beta vulgaris* L.) belongs to the Chenopodiaceae family, having a high concentration of sucrose, and it is used for the production of sugar [1,2]. The sugar extracted from sugarcane, and sugar beet is used as a sweetener in our domestic food and as an ingredient in the food industry for sweet-flavored substances. Sugar is mainly referred to as sucrose and, to some extent, as glucose and fructose [3].

Sugar beet was considered a productive and good rotational crop in Mediterranean regions, and its growth also started in the northern coastal areas [4]. Sugar extraction was started from fodder beet containing a high sugar content in the 18th century; it was a great achievement in the agriculture field in northern Europe. The sugar beet industry was established in Germany as a consequence of sufficient experimental work and flourished during the Napoleonic Wars when sugarcane was replaced by sugar beet as an alternative for sugar production. Its adaptation was especially progressed in France due to France's better policies. The average sugar beet yield of 50–60 t ha^{-1} has been recorded during 2003–2004 when experiments were conducted in 16 countries at 55 different locations [5]. Sugar beet contains a sugar content of 16%, while sugarcane contains a sugar content of 8–10%. Twenty percent of the world's sugar production has been obtained from sugar beet [6].

Extraction of the raw juice, purification of the thin juice, evaporation, and then crystallization are the main steps for processing sugar beet in the sugar industry. Raw juice is the main product extracted from the cossettes, a strip or slice of sugar beet. After evaporation, the juice becomes thick and contains 60% of dissolved solids [7].

It is also used for the production of energy such as ethanol, bioethanol, molasses, cattle feed, pulp, and pectin. Being a short-duration (5–6 months) crop in comparison with that of sugarcane (long duration, i.e., 12–14 months) sugar beet can be considered a better crop. The sucrose content in sugar beet is higher, 14–20%, compared to 10–12% in sugarcane. In addition, inputs such as the water and fertilizer requirements for the cultivation of beet crops are 30–40%, much lower compared to those in sugarcane cultivation, and beet crops have the capability of adaption in a wide range of climatic conditions [8]. There is a dire need to increase sugar production by cultivating sugar beet on saline–sodic soils without reducing the sugar quality. To date, little literature is available to help us better understand the cultivation and large-scale adaptation of sugar beet on these poor quality soils to fulfill the sugar requirement of the rising population. Thus, the main objective of this review is to increase sugar production with a low input cost, particularly in hostile soils and under unfavorable growth conditions. This review presents a comprehensive story of the challenges in and opportunities for the large-scale cultivation of sugar beet in tropical and subtropical regions.

2. Major Sugar Crops Worldwide

Various crop products are used for the extraction of sugar but sugarcane and sugar beet are the most widely used. Sugar palms and sweet sorghum are also used for sugar production. Maize is another important crop that is used for the production of high-fructose syrup in food industries [9]. However, some other plants are also used for the extraction of sugar owing to their sweet sap, including palms, maples, sorghum, mahua or mowrah tree, manna, and stevia [10].

In South and Southeast Asia, palms have been grown for centuries; these contain a sweet sap, which is then converted into a solid mass called jaggery (locally gur) after the sap is boilked. Palmyra (*Borassus flabellifer*), the coconut palm (*Cocos nucifera*), the jaggery palm or toddy fishtail (*Caryota urens*), the nipa palm (*Nipa fruticans*), and the wild date palm (*Phoenix sylvestris*) are a few examples [11].

Several plants from the maple family are also used for sugar and syrup production. Maple syrup was already being produced in North America before the settlement of Europeans. It was an important source of sugar in Canada and North America until it was overtaken by cane and beet sugar. Sorghum was considered another source of sugar during the first half of the eighteenth century in the United States. However, it could not compete with sugarcane and sugar beet starting from about 1880. Despite this, sorghum syrup is still produced on a small scale [12].

Trees from the *Madhuca* or *Bassica* (Sapotaceae) family contain sweet and fleshy edible flowers. In the third to seventh century A.D., *M. indica* and *M.* or *B. latifolia* were considered a source of sugar. The *Esculenta* or *lecanora* (Sphaerothallia) species of the same genus were classified as a sugar source. Two shrubs, *Alhagi maurorum* and *A. pseudalhagi*, secrete a sweet exudate, which can be collected after drying by shaking their bushes. *Tamarix gallica* produces a root-exudate honeylike structure called manna [13].

Stevia (*Stevia rebaudiana*), a wild shrub of the compositae family, contains sweet diterpene glycoside, a complex mixture of sugar, in its leaves. Stevioside, a complex sweet mixture, is extracted from its leaves, which is 250 to 300 times sweeter than sucrose and used in America and Asia for sugar purposes [14].

3. Sugar Beet Cultivation in the Tropics and Subtropics

Sugar beet is a temperate-region crop, so it is believed that beet cannot be grown in warm regions such as India. However, the development of new varieties that perform better in such warm regions has changed people's perception of sugar beet, and now beet growing has begun in tropical and subtropical regions. There are some challenges in the cultivation of sugar beet in these areas, such as water scarcity and salinity, but sugar beet has the potential to be cultivated under saline conditions [15]. Sugarcane cultivation in tropical and subtropical regions is decreasing owing to high-delta crops [16]. Tropical sugar beet has been promoted in India, and its cultivation would be a good step for other tropical countries such as the United States, Brazil, China, Australia, Kenya, and South Africa [17].

An experiment that was conducted at Pune Research Station, India, by Syngenta, a private agriculture firm, to cultivate sugar beet for sugar production as an alternative crop to sugarcane, has proven the adaptability of sugar beet in this region and provided support for its successful growth in other tropical countries such as Pakistan, Bolivia, Sudan, Kenya, and Malawi. The optimum beet size of 0.5–2 kg with a 15–20% sucrose content was recorded in these regions [18]. The concentration of sugar in sugar beet is influenced by sugar beet cultivars and agro-climatic conditions. In temperate regions, most of the sugar beet is cultivated on a commercial scale. The major sugar beet producers in the world are France, Germany, Turkey, the USA, the Russian Federation, Poland, Ukraine, China, and Italy [19].

Sugar beet cultivation has been started on a commercial scale in Khyber Pakhtoon Khawah (KPK), Pakistan, and its cultivation has also been introduced in Punjab, but, in Sindh and Baluchistan, it is cultivated on a small scale. Some exotic varieties of sugar beet have been tested for the adaptability of these cultivars in a wide range of areas in Pakistan at the National Agriculture Research Center (NARC), Islamabad. Due to water-scarcity challenges, there is a great need to grow such types of varieties which have lower water requirements. In the Punjab province of Pakistan, various types of sugar beet cultivars are being tested in different agro-climatic regions to evaluate their germination, yield, and sugar recovery [20]. Similarly, experiments on sugar beet have been conducted for nutrient management and adaptation in the Peshawar valley of Pakistan [21].

Sugar beet is cultivated in Bangladesh as a vegetable crop. The varieties of beet were selected for this tropical region against heat and disease tolerance during field trials in India. The yield of beet was recorded as 68 t to 106 t ha^{-1} with an average sugar content of 20% in these areas [22,23]. Kave-poly and Kave terma are the beet cultivars that showed a better yield and sugar content, respectively, in Bannu and Dera Ismail Khan (KPK). The germination, yield, and sugar recovery of beet showed different trends when an experiment was conducted under various conditions in Punjab, Pakistan [24]. The cultivation of sugar beet has been started in more than 56 countries worldwide. The global sugar-beet-cultivated area was 4.565 M ha, producing a total yield of beet of 229.201 M t in 2018. The top ten beet-producing countries in the world world are shown in Figure 1, based on their area, yield, and production.

Sugar beet grown in the above-mentioned countries contributes 75% of the total area for 76% of the beet production worldwide. In terms of production, the Russian Federation attained first place with a 51.366 M t beet production, followed by France, the USA, Germany, and Turkey, with 33.794, 33.457, 25.497, and 19.465 M t, respectively. Pakistan placed 40th in this regard [25].

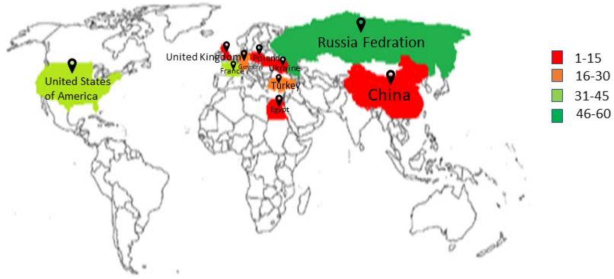

Figure 1. Worldwide (top ten countries) production of sugar beet; numbers indicate million tons. Source: [19].

3.1. Nutrient Management in Sugar Beet

The growth, yield, and quality of beet are affected by different sowing dates. It has been reported that the early sowing of beet (in September–October) produced a higher sugar yield and sucrose content per unit area in Egypt [26]. The late sowing of beet in November produced a reduced yield, length, and diameter, as well as sugar content, compared to early sowing in October [27].

In addition to the sowing date of beet, other parameters such as NPK also affect the growth, yield, and quality of beet. A proper and suitable application of nitrogen, phosphorus, and potassium improve the quality and yield of sugar beet. The sugar yield and other quality parameters can be improved by managing the fertility status of the soil [28].

The beet length, diameter, and yield increased with the increment of the N application in sugar beet, but the reverse result was recorded in the case of the TSS, sucrose percentage, and juice purity. The application of N at the right time plays a significant and effective role in maximizing the N utilization by reducing the losses of N [29]. The beet and recoverable sugar yield were increased with an N split application at the four- to eight-leaf stage of the sugar beet plant. The sucrose percentage and sugar yield improved significantly, as affected by the interaction between the rate and time of the N split application. Based on a pre-sowing analysis of the soil, we determine the diameter and root, as well as sugar yield, of sugar beet by a moderate split application of N [30]. The quality of sugar beet deteriorated with a high N application [31].

Phosphorous (P) is considered an essential nutrient for plants. It is an important and integral part of nucleic acid, lipids, and the production and transportation of sugar in sugar beet. It plays a significant role in plants, including energy generation, photosynthesis, glycolysis, nucleic acid synthesis, carbohydrate metabolism, respiration, and nitrogen fixation. A significant effect of the P application was recorded by [32] compared to the control for sugar beet production.

Potassium (K) plays a vital role in protein synthesis, and the photosynthesis process and assimilate translocation have an effect on the resulting yield and growth of beet plants. It has been reported that the root yield and sugar percentage are enhanced by the K application at a rate of 90 kg ha^{-1}. Potassium application, along with N, showed effective results, owing to its synergistic effects when applied in various varieties of sugar beets [33].

3.2. Major Pest and Diseases

3.2.1. Curly Top

The beet curly top virus (BCTV) belongs to the family *Germiniviridae* and genus *Curtovirus*. A single-stranded DNA genome of ~3000 nucleotides has been found in the BCTV. It has a twinned icosahedral structure with encapsidation virions. It causes the curly-top disease in many crops, especially in the common bean, tomato, and sugar beet. It shows a wide range of symptoms including interveinal chlorosis, severe leaf curling, yellowing, deformation, shortening of the internode, and stunting. It is transmitted by the beet leaf hopper (*Circulifer tenellus*) in nature. This disease has resulted in several devastating effects on the sugar beet industry in western USA and caused the loss of tomato production in California. In the new world, the beet leaf hopper and BCTV were introduced through anthropogenic activities, and the biology of this disease is very complex owing to the migratory nature of the vector. The BCTV genome revealed the role of recombination in viral evolution after analyzing it. The beet industry was saved due to the development and release of new curly-top-resistant varieties. The most effective strategy to control it is integrated pest management, because resistant varieties are not available for all crops [34,35].

3.2.2. Rhizomania

Rhizomania is a disease caused by the beet necrotic vein virus (BNYVV). The sugar beet roots are affected by the soil-born fungus (*Polymyxa betae* Keskin), which is the main source of this disease. The infected roots of sugar beet plants show symptoms such as the development of rootlets around the tap root. The wine-glass-shaped roots would appear around the necrotic rings of the root tip, resulting in low-quality beet which has a low sugar content. An immuno-enzymatic test (ELISA) can be performed to quantify the disease easily. The reduction in sugar yield by this virus has been reported to be up to 80% [36]. In the beginning, it was reported in Italy, and now it prevails all over the cultivated lands of sugar beets. It has also been confirmed after RNA analysis that three pathotypes such as A, B, and P affect the sugar beet crop. Cultural practices are the best way to control this disease, or growing disease-resistant cultivars of sugar beet. These cultural practices, including growing the crop early in cool soil, avoiding soil compaction, minimizing watering, and employing crop rotation, can reduce the chances of disease spread [37,38].

3.2.3. Cercospora Leaf Spot

The causal agent of Cercospora leaf spot (CLS) is *Cercospora beticola.* This disease mostly spreads in humid regions of the world, including China, southern France, Austria, Greece, Japan, northern Italy, Michigan, northern Spain, etc. Necrotic lesions are the main symptoms that later damage the leaves of sugar beet. The crop shows immunity against this disease after 80–90 days of sowing. This shows the inhibitory mechanism in the plant leaves; then, the resistance develops. Different sea beets from the coasts of the Adriatic Sea have been crossed to develop genotypes that are resistant against CLS [39], and this led to the development of different resistant lines. In the United States and Italy, the selection was carried out for commercial sugar beet varieties against this disease [40]. To control it, many fungicides are used. An appropriate application of fungicides is one method of controlling this disease, while, on the other hand, a resistant disease cultivar is the best way to control it. The latter is more effective than the former owing to its environment-friendly behavior [41,42].

3.2.4. Beet Cyst Nematode

The sugar beet plants are affected by cyst nematodes (*Heteroderma schachtii*), which is a highly damaging pest. The yield and sugar reduction are affected by this, causing a reduction in beet size. The beet size and leaves do not develop properly in infected sugar beet plants under intense and high-temperature conditions. Cyst nematodes can be easily detected on the roots with the naked eye. It is very challenging to control this disease owing to the restrictions on fumigation usage and the wide range of host plants for this pest. The nematodes can be controlled effectively by practicing crop rotation. The embryo rescue and grafting techniques are the best methods to control cyst nematodes. Interspecific hybridization can be easily introduced in sugar beet to develop a resistance to this disease [43,44]. There is a gene that has been identified for its resistance against cyst nematodes in sea beets. Different varieties of sugar beet have been introduced by the United States and Europe for their resistance to this disease. The resistant cultivars of beet have been developed by crossing *B. procumbens* and *B. vulgaris* ssp. Maritime. To decrease the loss of yield in sugar beet plants, the characters from *B. vulgaris* ssp. have been effectively introduced [45,46].

3.3. Harvesting and Processing

The growing season of sugar beet is late winter or early summer in temperate-clime regions and the harvesting starts after 5–6 months. In contrast, the sowing time of sugar beet in Mediterranean-climate regions is autumn, and harvesting starts in early summer. The beet is lifted mechanically at the maturity stage (the leaves having turned yellow and the beet having gained its maximum weight, about 180–200 days after sowing) of the crop; then, the leaves are parted from the beet as it contains a lower sugar content and more impurities. The beet is quickly transported to the processing unit for the extraction of sugar to avoid the harsh condition of the environment, such as hot weather, which deteriorates the quality of the beet [47]. Sugar beets are cut into pieces such as slices for in order to extract the sugar. The hot water diffusion method is used to complete this step. Lime and carbon dioxide are passed many times through it to remove the impurities. The evaporation process starts after this to concentrate the extracted juice. It continues until a 60% sucrose purity has been attained. The thick juice starts to convert into crystals. A high temperature and partial pressure are the prerequisites to complete this process. The centrifugation process starts afterwards for obtaining molasses, which has a 45% sucrose concentration with a brown-like morph. White sugar is obtained after further purification, which is then transported to the markets [48,49].

3.4. Yield and Quality

The average production of sugar beet has been recorded as 40–60 t ha^{-1}; sometimes, the range may go as high as 70–80 t ha^{-1}. The purpose of the cultivation of sugar beet is to attain the optimum yield using cost-economic resources. The weight and size of the beet impart its quality, such as its sugar content. Its sugar yield and extractable sugar must be considered as quality parameters. Improving the yield of beet is the main output, but along with it, the total sugar yield must be enhanced. Climatic conditions determine the sugar yield, which is a quantitative character [27]. The root production and sugar content are controlled by non-additive and additive variance [50].

There is an inverse strong relation between the root yield and sugar yield; a higher weight of beet reduces its sugar content, and vice versa. In addition to the size and weight of the beet, many other physical and chemical traits also affect the extractable sugar during processing in the beet-processing industry [51]. Two methods control the extraction of sugar genetics and agronomic practices such as harvesting, storage, and transportation. Therefore, the quality of beet can be controlled by the grower through the selection of seed variety, plant density (number and distribution of plants), sowing and harvesting date, field preparation, irrigation practice, fertilization, and plant-protection measures. The yield and quality of beet decrease when the number of plants is less than 70 thousand ha^{-1}. The yield and quality parameters of beet can also be deteriorated by a higher or lower plant density in the rows [52].

The non-sugar impurities such as Na, K, and α-amino N in sugar beet affect its quality as well as the sugar extraction process. There is a great need to reduce these non-sugar products in beet [53]. The effect of non-sugar impurities can be reduced following mass selection. It becomes more complex for breeding beet between non-sugar impurities, root weight, and concentration of sugar. In addition to impurities, the smoothness and soil attached to beet can also affect the extraction of sugar in the industry. The slicing and diffusion during the extraction of sugar are also affected by soil remaining on the beet after the crop has been harvested. Therefore, the quality and quantity of sugar beet can be improved by adopting agronomic as well as breeding practices [54].

4. Challenges of Sugar Beet Cultivation in the Tropics and Subtropics

4.1. Bolting Concerns

The cultivation and breeding of sugar beet are affected by controlling its bolting and flowering stages. A prolonged vegetative growth phase determines the high root yield, as breeders noted that the bolting B gene (B allele) exists during the selection process;

thereby, the recessive allele is found with the gene locus. The beet plant containing the B allele showed reproduction under the condition of long days (LDs: 12–14 h light exposure) compared to the vernalization phase (long cold-temperature exposure) that took place. Those plants that do not have the dominant B allele must be vernalized first (in winter) before starting LDs, a process known as thermal induction in plants [55].

4.2. Lack of Farm Mechanization

The survey conducted to find out the machinery used by the farmers for the cultivation of sugar beet made clear that most of the farmers used hand tools for the cultivation and growing of sugar beet. There were many reasons for the limited use of machinery. Most of the farmers were unable to hire tractors; hence, less machinery was available for the cultivation of sugar beet, which directly affected the production of beet. More suitable machinery is the key to successfully obtaining profitable yield.

The researchers reported in [56] that a plowing depth of at least 25 cm is required to achieve a high beet yield. The manual tools used by most respondents do not meet the requirements for the beet-plowing depth in one operation. To achieve the right requirements for the beet-plowing depth with the current tools, the family will spend more time and labor for additional cultivation. Manually planting sugar beet is a slow process that takes time and requires hours per hectare. Therefore, it can be said that the tools used by most respondents, especially those for soil preparation and sowing, may not be suitable for growing commercial beets. Another scientist noted [57] that the lack of necessary tools is one of the key factors preventing the use of dual-use cowpea by a large number of farmers in Nigeria's dry savannah. This example shows how important it is to use the right tools. Access to the appropriate technology is a very important determinant of the extent to which smallholders in the region cultivate sugar beet.

Successful development in the agricultural field needs very high and mechanized tools for sowing, harvesting, watering, spraying, etc. This is very necessary for obtaining a more profitable yield. Some machines are locally prepared for potatoes, maize, wheat, and cotton. A few years ago, some tools were exported in order to gain a high yield of crops. The record has shown that tractors are manufactured at a large scale locally, but threshers and other sugarcane machines are recorded, to some extent, officially. The local machines are easily available, such as potato diggers, soil levelers, tiller drills, multipurpose threshers, and water sprinklers. Therefore, in order to obtain a high production, more money must be invested in the mechanization of farming activities.

4.3. Increased Processing Cost

There are different steps of processing sugar beet in the industry. After harvesting, the beet must be delivered to the processing unit as soon as possible, because the degradation of sucrose starts after that. Once the beet is delivered to a processing factory, the first step is to remove the dirt and debris from the beet. Then, the beet is sliced so that they can be fed into the machine, and they are made into long skinny pieces called cossettes. These cossettes are transferred to a hot-water tank called a diffuser. The diffuser draws the sugar from the cossettes and leaves a sugary solution. After extracting the sugar from the cossettes, beet pulp remains and is used as a livestock feed source. The sugary solution is boiled to remove the surplus water, and a thicker sugar juice is attained. Sugar crystals begin to form in the thick sugary solution. These crystals are then separated by a centrifugal machine at high speed. After this, the sugar is passed through hot dry air to remove the moisture from the crystals and then transferred to silos for packing. Sugar beet processing is a quicker and more cost-economic method than cane refining for sugar production (Figure 2). During the harvesting of sugar beet, the processing unit runs all the time, 24 h a day and 7 days a week, until all the beets have been processed. All the practices which are mentioned above for processing sugar beet are cost-effective and tricky; there is a need of more care for it [58].

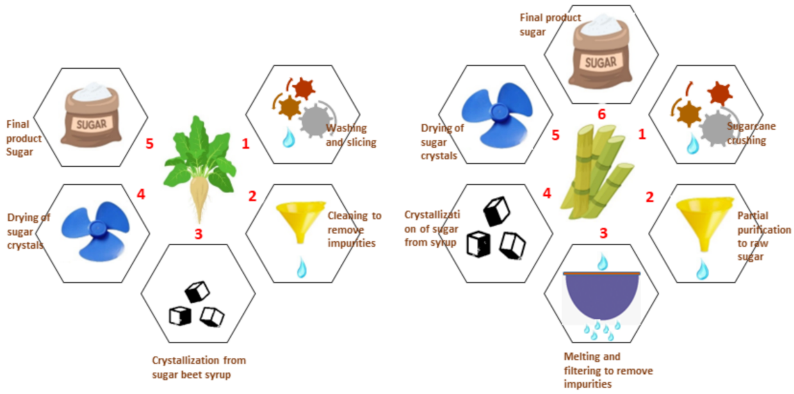

Figure 2. Sugar-beet-processing and sugarcane-refining steps for sugar production in an industry. Sugar beet processing comprises five steps (**left side**), while the sugarcane-refining process consists of six steps (**right side**).

4.4. Marketing

In December 2015, the government of Pakistan decided to produce 500,000 t of sugar for export until March 2016. At that time, the sugar prices in the national as well as the international markets were low, and the production cost was so high. Due to this reason, it was not feasible to achieve the target with the export. The government decided the sugarcane's indicative prices of Rs. 182/40 kg in Sindh and Rs. 180/40 kg in Punjab and KPK for that year due to the increased production prices over and above the international market. Such types of problems were exposed to the federal government, and a lot of letters were received for allowing these incentives. The Pakistan Sugar Mills Association (PSMA) convinced the government that the price of Rs. 13 kg^{-1} was allowed. The decision was made that this price would be equally shared by the federal as well as the provisional government. Then, the export was allowed for the Asian republic and Afghanistan by land routes with a minimum price of US Dollar 450/M t. The State Bank of Pakistan announced the quota allocation on a first-come-and-first-receive basis in the allocated time, but some sugar mills could not apply in the given time. Due to this plethora of problems, sugarcane, as well as sugar beet, cultivation has been discouraged.

5. Perspectives of Sugar Beet Production in Tropics and Subtropics

5.1. Low Soil Fertility

Fertilizer application and nutrient availability play a significant role in plant growth and development [59–61]. The yield and quality of sugar beet depend on many important factors such as the weather, soil characteristics, varieties, and plant nutrition. Among these, the use of plant nutrients or fertilizer is the most susceptible to operational management, but it is influenced by several other factors [62,63]. The optimization of the production and input costs, changes in the soil nutrient supply, and degradation of quality must be taken into account, especially those factors that influence the economic yield of sugar. Nitrogen fertilizers, whether from fertilizer or soil reserves, can lead to significant changes in yield and quality. Increasing N input increases the soil fertility in soils of varying fertility statuses [64].

The effects on quality and sugar yield are more complicated in plants with an increased N supply, which transfer more energy from the sugar (sucrose) storage to the root-growth metabolism. The concentration and accumulation of amino-N compounds determine the extractability of sugar during processing [65]. The comparative impact on yield and quality is, therefore, important for quantifying the impact of N on a given soil and the applications of P and K, which play a significant role in respiration and photosynthesis. Although sugar beet has a higher K demand for carbohydrate translocation, its impact may not be as great as that of N:K, at least for low to medium applications, not negatively affecting the quality [23]. Poor soil quality affects sugar beet production in the tropics and subtropics due to high temperatures, resulting in the degradation of soil organic matter. It is suggested that these soils must be fertilized for the cultivation of sugar beet.

5.2. Water Scarcity

Pakistan is a developing country and has more demand for water for the growing of sugar crops such as sugarcane and sugar beet. The need of the country for sugar production is fulfilled by 75% from sugarcane and 25% from sugar beet. The water availability in the Indus river is five-fold in Kharif than that of the Rabi season. The former crop is also planted in Rabi; its water requirement is three-fold that of the later one. Therefore, growing cane will put pressure on water resources, while growing beet will not face that much of a problem. This means we can grow three crops compared to the water consumptive use from the growth of one sugarcane. However, the country is facing water-shortage problems and is interested in growing sugar crops that have a lower water requirement in order to utilize the natural resources at optimum levels without deteriorating them. Utilizing the same amount of water, two sugar beet crops can be grown as opposed to growing one sugarcane crop [66].

The lack of water for crop production is an important issue that often occurs in agricultural production. One possible solution to this problem is selecting a genotype that does not show a reduced yield at an economically acceptable level under water scarcity. A major challenge in the genotyping process is the selection of suitable plant-specific types for the current agro-ecological conditions. Water scarcity has a complex impact on plant physiology [67]. In tropical regions, there is comparatively low water availability for crop production. Sugarcane requires much higher irrigation (16–20 times) than sugar beet (8–10 times) depending upon the soil type and climatic conditions. Water plays a vital role in the production of sugar; scarcity and the unavailability of water are the key factors for the reluctance of farmers to grow sugarcane on their lands, but sugar beet has a better mechanism for growing under these conditions.

5.3. Salt-Affected Soils

Salt stress is the major growth factor that affects plant growth. About 960 M ha of arable land is currently affected by salt stress at a global level [68,69]. This increase has been calculated to be due to poor irrigation practices, climate change, and the improper utilization of fertilizers. It is a great threat to natural resources required to feed the growing population, which will be 9.7 billion in 2050 [70].

Therefore, there is a great need to improve the salt tolerance of plants for food security and agricultural production. Ion imbalance, osmotic stress, and secondary stresses are the major causes of salinity in plants. These stresses have an impact on crops at various stages, from germination to seed filling. Stomatal closure, leaf expansion, the inhibition of photosynthesis, and a reduced biomass are the plant's responses under salt stress [71]. However, some plants have evolved many physiological and biochemical processes to adapt to the salt environment. The adaptive responses of the plants under salt stress are grouped into three categories, e.g., osmotic stress tolerance, ion exclusion, and tolerance of tissue against salinity [72].

Sugar beet is a salt-tolerant crop compared to other crops but is very sensitive in the germination and seedling stage. Water uptake is reduced during germination under salt-stress conditions, which is essential for germination and seedling growth. However, the growth of sugar beet has not been affected at an EC level of soil of about 7 d Sm^{-1} [73]. To resolve this problem, sugar beet seeds require seed priming with NaCl before sowing under salt-stress conditions (up to EC~12 d Sm^{-1}) [74]. The plants eliminate excessive Na^+ via the plasma membrane or tonoplast Na^+/H^+ antiporter to maintain the cytosolic Na^+ concentration. This mechanism uses the electrochemical gradient of the proton for removing Na^+ into the vacuole or outside the cell via the plasma membrane. In salt-tolerant plants, the activity of the Na^+/H^+ antiporter is different versus salt-sensitive plants [75].

The activation of the sodium proton antiporter (NHX) and vacuolar H^+ pumps V-H-ATPase is also enhanced under salt stress (Figure 3). Under such circumstances, plants uptake Na^+ via non-selective channels and K^+ transporters, substituting K^+ to maintain homeostasis. Therefore, the cost of the K fertilizers can be reduced by utilizing the inherent soil Na^+ under saline–sodic conditions. Surprisingly, sugar beet has an adaptive mechanism to partially fulfill the K^+ requirements by Na^+. It is an important crop that has developed various adaptations after exposure to salts such as osmotic adjustment, and it can activate an antioxidant defence system to control the reactive oxygen species (ROS) as studied by [76]. Such types of adaptations and mechanisms in sugar beet help the plants to grow on poor-quality soil without losing its yield.

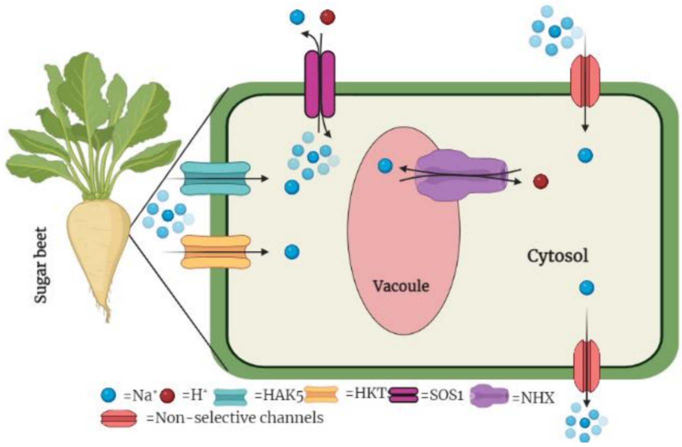

Figure 3. Schematic representation of Na^+ uptake, sequestration, and extrusion via HKTs, NHX, and SOS1 transporters in the plant cell.

The most commonly used biochemical markers for abiotic stress, including salinity, are ROS, lipid peroxidation products, carbonylated proteins, and enhanced ion loss. On the other hand, as numerous studies prove, salinity tolerance is often associated with a large number of compatible solutes, a high activity of antioxidant enzymes, and an efficient distribution [77].

Similarly, in areas with boron (B) stress, appropriately selected varieties should be utilized. High B in the soils of cotton-growing areas in Pakistan has been reported but, as with other areas such as Anatolia, B deficiency is a more widespread problem [78,79]. Considering the fact that there is genetic variation in terms of B stress, tolerant varieties such as KWS1197 should be utilized in sensitive areas [80], and appropriate B-enriched fertilizers may be highly beneficial for the deficiency conditions in terms of yield and quality. More specifically, B applications at deficient conditions were found to enhance the root yield, root traits, and root quality in sugar beet [81,82]. Additionally, salt stress effects on different crop plants, including sugar beet, were also shown to be alleviated by B applications [83].

Sugar beet plants show a positive response for improving growth traits after B application. It mitigates the toxic effects of salts on plant growth by reducing the Cl^- uptake under saline conditions. Sugar beet growth traits such as plant height, biomass, leaf area, and photosynthetic activity were reduced under a 300 mM NaCl condition, but a foliage B (750 µM) application under these conditions reduces the chances of plant-growth inhibition [84]. CARBONBOR fertilizer as a source of B improves sugar beet's agronomic performance as well as yield parameters [85]. It has been found that a 80 ppm B application on beet as a source of boric acid improves its growth and yield parameters [80].

This plays a significant role in the N metabolism in beet. The deficiency and sufficient range of B are very narrow for crop plants. Beet plants showed similar deleterious effects under both above-mentioned conditions, reducing the nitrate reductase enzyme—a precursor for N metabolism. It has been found that N accumulation in beet reduces the quality of its sugar content; this can be ameliorated by B application [86]. Interestingly, an N-, Zn-, and B-integrative application significantly improves the sugar yield and technological sugar content under semi-arid climatic conditions [87].

5.4. Use of Soil for Additional Crops Compared to the Production Technology of Sugarcane

There has been public criticism due to the use of large quantities of pesticides to control the insects and pests in sugar beet plants. This is a great threat to feeding the population, which is growing at an exponential rate. To control both these problems, ecological intensification was adopted. The practice of crop rotation in a well-designed manner is the best strategy to overcome the pathogens in a beet field; it also promotes the beet yield without deteriorating the natural resources by pesticides. The cyst nematode (*H. schachtii*) and black rot (*Aphanomyces cochliodes*) disease are stimulated by the growing of sugar continuously on the same land. There is a reduction in beet yield and quality enhancement with the growth of these agents. The sugar beet crop cannot be grown on the same land in monoculture but the cultivation of beet in a rotation is an effective tool to control the above-mentioned problems [88].

The pests survived on the residues of preceding crops; in other words, crop rotation has a great impact on the nutrient availability for plants. This practice improves the soil structure due to the rooting and resealing of the nutrients for the next crops. Soil tillage and machinery usage contribute to the pulverization of the soil and improve the aeration of plant roots [89]. It was reported in [90] that the practice of monoculture and short rotation improves the soil–physicochemical properties and yield of the cultivated crop less, compared to diverse rotation, considering various biotic and biotic factors. It was stated that a rotation which included sugar beet cultivation with a diversity of crops provided an additional yield using the same land by cultivating the other crop in the following season, compared to sugarcane cultivation, as sugarcane requires more time. It is concluded that pathological effects may result in future harm if crop rotation is not adopted [91].

The cultivated area of sugar beet in Europe declined, owing to the low prices of sugar in 2005, and then the area was extended due to a more economic framework in 2015. The extended area provided more sugar for improving the economy of a country [92]. The beet production and processing took place, utilizing the same existing resources, on farms located in traditional growing regions. The same type of changes took place by reducing the beet production and increasing the silage of maize (*Zea mays* L.) and leguminous crops such as the pea (*Pisum sativum* L.), considering the ecological focus in Germany [93]; thereby, shortening the beet-cropping interval may cause a lower beet yield. The short duration of this crop provides an opportunity for growers to sow and grow more crops, utilizing the same piece of land, while such benefits can never be achieved during the cultivation of sugarcane.

6. Conclusions and Future Outlooks

Sugar beet is a source of almost 25% of the sugar production in the world. It plays a significant role in terms of sucrose production on a less-economical basis. However, due to multifaceted factors, sugar beet is not well-adopted in the farming system of the tropics and subtropics. Keeping in mind that sugar beet has double the sugar content compared to sugarcane, a lower growing duration of the crop (5–6 months), lower water requirements and input cost, and salt resistance, we proposed that sugar beet can be a promising sugar crop in the tropical and subtropical regions.

It can be grown in poor-quality soil such as saline and saline–sodic soil, owing to the sugar beet potentially requiring Na^+ as a beneficial nutrient and having the potential to reclaim these soils without wasting natural resources, i.e., water as compared to the cultivation of rice on these soils and applying plenty of water for leaching the salts from the root zone. The farmers can use their lands for other crops after 5–6 months, but in the case of sugarcane, this is not possible. In terms of a crop disease attack, the borer attack is very common in sugarcane, which deteriorates the quantity as well as the quality of the crop, but in the case of sugar beet, no such disease has been investigated; ultimately, the cost of the spray is lower. Apart from hoeing, tillage, or crop rotation, “Roundup” weedicide can be applied to the soil before sowing to discourage the incidence of weeds.

A progressive farmer should cultivate sugarcane on some piece of his land as well as sugar beet. This practice will also play a significant role in strenghtening the economy of the country, because sugarcane harvesting starts in January–February and its processing continues till April–May. Then, the sugar industry starts to close down for the whole year until the next season. If an industrialist installs a beet-processing unit along with a sugarcane-processing one, the industry will operate until August–September because, at that time, sugarcane processing starts to end, and then the harvesting of sugar beet starts. The above-mentioned practice can improve the socio-economic status of a laborer, farmer, and industrialist. The production technology of sugar beet should be developed by the provisional government as well as by the federal government.

Sugar beet is not being picked up much by farmers for cultivation for commercial purposes as there is a lack of market. Being an industrial crop, there is no incentive or seed money sanctioned by the government for industries to install the additional machinery required for beet processing. Moreover, there is no such governmental policy involved in establishing this crop for commercial purposes. There is a need for the government to be involved in this crop, considering its rich byproducts and ethanol production which will fulfill the future needs of the country. Thus, the government comes forth with grants or easy loans, tax holidays, seed subsidies, etc., for the cultivation of this crop. Until and unless this is done, this crop will not be given that much importance if the lack of a governmental policy on sugar beet persists, regardless of how well it can perform under Indian agro-climatic conditions.

There is a need to provide a well and a mechanized planter to the farmers for the sowing of sugar beet seeds, because the seeds are very small; there is a possibility that a seed will be placed in a deep-root zone and cannot germinate. Seed coating is important not only for sensitive mechanized-planter applications, but it also provides an opportunity for fungicide and insecticide application as well as the application of some plant nutrients and seed- or seedling-enhancement agents [94,95]. However, there are some apparent advantages of seed coating; the process increases the cost of the seeds substantially, and its subsidization should also be considered. For the proper sowing of the plants and maintaining of the number of plants (1,00,000 plants ha^{-1}), innovative and mechanized machinery is required. Similarly, beet processing and the extraction of juice need different types of equipment in a sugar mill compared to the sugarcane-processing unit. These include steam-generation plants, multiple-effect evaporators, crystallizers, juice heaters, power generators, vacuum pans, continuous centrifuges, sugar dryers, and packing plants. The governing bodies should subsidize sugar mill owners for the machinery cost [96]. The mill owners can play a significant role in the production of beet as well as its processing.

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