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Evaluating the Performance of Indigenous Sugar Beet Genotypes for Improving Yield and Adaptability Under Indian Subtropical Conditions

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ABSTRACT

Sugar beet cultivation, traditionally confined to specific agro-climatic zones. However, with the demand for additional feedstocks for bioethanol it is gaining importance in the tropical and sub-tropical regions of India. The creation of indigenous varieties suited to Indian conditions requires a strategic combination of traditional breeding methods and advanced biotechnological approaches. Identifying and assessing specific traits is vital for the success of crop breeding programs, involving a meticulous process to improve the adaptability, productivity, and resilience of sugar beet varieties. This study introduced five new sugar beet genetic stocks, through the several field experiments conducted over the years at ICAR-Indian Institute of Sugarcane Research, Lucknow. Each variety had been meticulously identified and assessed based on quantitative, morphological, and biochemical traits to address specific challenges. Among these, LKC 2000 was found to be superior due to its tolerance to post-harvest deterioration and high bioethanol recovery. The other varieties, LKC 2006 and LKC 2007 were drought-tolerant additionally LKC 2007 possessed high brix and sucrose content. The variety LKC 2010 was found to have drought tolerance, high sucrose and bioethanol recovery, and root rot resistance. The variety LKC 2020 excelled in bioethanol recovery under both irrigated and drought conditions, high brix at late harvesting and high temperatures, and high sucrose content. The development of these sugar beet varieties into the current sugarcane and cereal-based ethanol production ecosystem presents a promising opportunity to diversify and enhance biofuel production.

Keywords : Sugar beet; Bioethanol; varieties; indigenous; India

INTRODUCTION

The development of sugar beet genetic stocks tailored to Indian agro-climatic conditions is crucial to meet the growing demands for food security, bioenergy, and sustainable agriculture. India, with its diverse climate ranging from arid to humid tropical regions, faces unique challenges in crop cultivation. Traditional sugar beet varieties, typically suited to temperate climates, do not perform optimally under the high temperatures, variable rainfall, and different soil types prevalent in India. Developing indigenous sugar beet varieties with high sucrose and ethanol content, coupled with high root yield and resilience to abiotic and biotic stresses, is essential. This is imperative in the context of ethanol blending policies. The ethanol blending policies aim to reduce reliance on fossil fuels and mitigate the environmental impact of transportation (Saikia et al. 2024). By blending ethanol with gasoline, countries can lower greenhouse gas emissions and decrease their carbon footprint (Dias et al. 2005; Hanaki et al. 2018). Sugarbeet, with its high sugar content and potential for bioethanol production, presents a sustainable alternative to fossil fuels (Mall et al. 2024; Misra et al. 2022). However, to maximize the efficiency of ethanol production from sugarbeet, it is essential to enhance both sucrose content and root yield. High sucrose content ensures a greater yield of fermentable sugars, while high root yield increases the overall biomass available for ethanol production. Increased production of high-yielding sugar beet varieties not only

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contributes to the biofuel industry but also diversifies income sources for agricultural communities. Moreover, high root yield varieties can enhance agricultural productivity and resilience, especially in regions prone to climatic variability and resource constraints (Mall et al. 2022). By developing genetic stocks tailored to local agro-climatic conditions, farmers can mitigate risks associated with unpredictable weather patterns and optimize resource utilization. Therefore, the development of genetic stocks optimized for sucrose content and root yield is critical to meet the demands of ethanol blending policies and promote the transition towards renewable energy sources.

ICAR-IISR, Lucknow has been working on sugarbeet for the last 50 years. The study focused on testing sugarbeet germplasm for Indian conditions and developing sugarbeet varieties at its Satellite Centre, Mukteshwar, Uttarakhand (IVRI Campus) (Mall et al. 2024). The National Biofuel Policy 2018 encourages blending of ethanol with petrol and ethanol blending has reached nearly 12% during 2022-23 (Anonymous, 2023). Further, GOI fixed a target of 20% blending by 2025-26 (Roadmap for ethanol blending in India 2020-25). Currently, sugarcane meets most of the demand for bioethanol requirement in the country (Malik et al. 2019), however, there is a limitation of expanding sugarcane area as well as diversion of more sugarcane for ethanol production. Hence, it is imperative to look for alternative feedstocks for ethanol production including sugarbeet, maize, sweet sorghum, etc. With this background, this study focused on the identification and evaluation of novel sugar beet genetic stocks aimed at achieving improved productivity and resilience.

MATERIALS AND METHOD

Assessment of physical traits in indigenous sugarbeet genetic stocks

Sugar beet color was typically assessed through visual inspection under natural daylight conditions. The beets were compared against a color chart or standardized color codes to ensure consistent and accurate classification. Leaf color assessment was conducted by visually inspecting the leaves, preferably at the same growth stage to ensure uniformity. The skin color of the beetroot was evaluated similarly to the beet color, by observing the outer surface of the root. The skin color could vary from white to red, purple, or yellow. Flesh color was assessed by cutting open the root and examining the internal tissue. The color ranged from white to deep red, depending on the variety. The assessment involved comparing the flesh color to a standard color chart to ensure uniformity and accuracy.

The shape of the beet was assessed by examining the root in both longitudinal and transverse sections. The longitudinal section revealed the length and overall shape, while the transverse section showed the cross-sectional shape. The assessment was done by slicing the beet and visually inspecting the sections, noting the symmetry and uniformity of the shape. Additionally, the sugar beet root's position in the soil, which can affect its growth and ease of harvesting, was assessed by observing the growth habit of the beet in its natural environment. This involved carefully digging up the plant to observe the depth and orientation of the root in the soil. Root division, describing the extent to which the beetroot was divided into multiple sections or lobes, was assessed by visually inspecting the harvested roots and noting any natural divisions or lobes. The degree of division was recorded based on the number and depth of the divisions. Furthermore, the presence and depth of grooves on the surface of the root were assessed by visual and tactile inspection. The roots were examined for any longitudinal or transverse grooves, which could affect the root's marketability and susceptibility to disease. The grooves were measured and categorized based on their prominence. Additionally, ring formation thickness in sugar beet, a crucial trait affecting the quality, processing, and overall marketability of the beet, was visually assessed.

Morphological traits assessment of indigenous sugarbeet genetic stocks

Single root weight, root width, and root length were assessed in each genetic stock developed. The weight of each individual cleaned sugar beet root was measured using a precise digital scale that provided readings in kilograms. The root width was measured at the widest point of the beetroot using a flexible measuring tape. The root length was measured from the top of the root (where the leaves began) to the tip of the root using measuring tape.

Juice quality analysis of indigenous sugar beet genetic stocks developed

Sucrose was estimated using lead acetate method utilizing sucrolyzer. Brix was assessed by hand refractometer. Purity was calculated by the formula (sucrose/brix)* 100

In the case of post-harvest assessment of sugar beet genetic stocks, juice quality analysis was performed at 0 h of harvest and after 24 h of harvest. Reducing sugars was assessed by Nelson Somygii method (Nelson, 1944). Dextran was assessed by the Haze method (Keniry et al. 1969). Titrable acidity index was assessed by the phenolphthalein method. Juice pH was assessed by pH meter. Total microbial count was assessed by using serial dilution of juice and 100 µl of diluted juice was poured on nutrient agar plates which were sprayed uniformly through a spreader. The plates were then incubated at 24–48 h at 37 °C for obtaining isolated colonies. Similarly, Leuconostoc load was also assessed in a similar manner wherein the use of Leuconostoc specific media was used. Colonies were calculated manually by colony forming units/100 µl = No. of colonies obtained/100 µl.

In the case of drought tolerance potential of sugarbeet genetic stocks, drought was imposed by withholding the irrigation until temporary wilting in susceptible genotype was not seen. Twenty per cent available moisture was seen as a low threshold for the imposition of drought. Relative water content was assessed by Banchioetal (2008). Leaf chlorophyll content was analyzed by Arnon (1996). Malondialdehyde content in leaves was quantified by adopting a method developed by Madhava Rao and Sresty (2000) method.

RESULTS

LKC 2000

The beet was characterized by its white color and narrow obtriangular shape when viewed longitudinally, with an intermediate shape in the transverse section. Its leaves were a light green. The root grew deeply in the soil and exhibited minimal fangy root division. There was no root groove present. The skin was light brown, and the flesh was white. The root rings were very thin (Table 1). The weight of a single root ranged from 0.85 to 1 kg, with a width of 14.22 cm, length of 29.88 cm, and an ethanol recovery of 8.32% (Table 2).

This genotype was assessed for post-harvest deterioration losses. Results showed the superiority of less sucrose deterioration was seen in LKC 2000 followed by LKC 2006 after 6 h of extraction which was even maintained later after 24 h of extraction. The least purity deterioration was observed in LKC 2000 under both the time interval against check. Reducing sugars and dextran were not increased to such a high extent in LKC 2000 after 6 and 24 h of extraction. In the case of the Titrable acidity index, LKC 2000 maintained its performance even in staled beet juice as compared to other genotypes against check. Plate with freshly extracted sugar beet juice showed very little growth of microbial colonies of Leuconostoc spp. in LKVC 2000. Furthermore, the growth of this bacterium was

Table 1 : Physical characteristics of novel genetic sugar beet varieties developed

Characteristics	LKC 2000	LKC 2007	LKC 2010	LKC 2020
Beet colour	White	Light green	Half green	Light green
Beet shape (LS)	Narrow Obtriangular	Broad elliptic	Broad elliptic	Narrow Obtriangular
Beet shape (TS)	Intermediate	Intermediate	Irregular	Regular
Position in soil	Deep	Deep	Deep	Deep
Root division	Little Fangy	Single	Single	Little fangy
Root groove	Absent	Present	Present	Present
Skin colour	Light Brown	White	White	White
Flesh colour	White	Light brown	White	White
Ring thickness	Very Thin	Thin	Very thin	Very Thin
Leaf colour	Light green	Green	Green	Dark green

Table 2 : Morphological traits assessment of novel genetic sugar beet varieties developed

Characteristics	LKC 2000	LKC 2007	LKC 2010	LKC 2020
Single root weight (Kg)	0.85-1.00	0.80-0.93	0.80-0.85	0.95-1.13
Root width (cm)	14.22	26.74	28.78	27.60
Root length (cm)	29.88	17.48	12.85	13.50

enhanced in all the genotypes but LKC 2000, LKC 2006, LKC 2010 maintained their superiority against the check variety. Results revealed that LKC 2000 had a root yield of >80 t/ha on an average with an ethanol production ranging from 90 to 100 L per tonne under Indian conditions (Table 3). This genetic stock was evaluated as tolerant to post-harvest deterioration with high bioethanol recovery.

The beet displayed a light green color and a broad elliptic shape in the longitudinal section, with an intermediate shape in the transverse section. The leaves were green. The root extended deeply into the soil and showed a single root division. A root groove was present. The skin was white, while the flesh was light brown. The root rings were thin (Table 1). Each root weighed between 0.80 and 0.93 kg, with a width of 26.74 cm and a length of 17.48 cm (Table 2).

This genotype was evaluated for its drought tolerance, and the findings indicated that LKC 2007 exhibited high root yield, root length, and root diameter in both drought and irrigated conditions. Juice extraction from plants grown under both conditions demonstrated that LKC 2007 consistently outperformed other genotypes in terms of sucrose content, purity, and brix levels (Table 4). Additionally, LKC 2007 showed enhancements in dry matter accumulation from both leaves and roots. Evaluations of relative water content (RWC) and total chlorophyll revealed variability among the genotypes tested. These parameters are useful for selecting high-yielding genotypes that maintain cell turgor under water stress, thereby producing relatively high yields, with LKC 2007 significantly maintaining its superiority. Moreover, malondialdehyde levels in LKC 2007 remained stable under both drought and irrigated conditions.

Table 3 : Post-harvest juice quality analysis of sugar beet varieties, LKC 2000

Post-harvest Juice Quality		@ 0.0 hr	@ 24 hrs
Sucrose (%)	:	19.6	18.9
Purity (%)	:	90.15	89.2
Brix	:	21.74	21.2
Reducing sugar (mg/ml)	:	0.8	2.5
TAI	:	24.3	30.9
Dextran (mg/ml)	:	0.7	11.4
Total Microbial load (cfu/100ml)	:	10.0	48.0
Leuconostoc load (cfu/100ml)	:	8.0	24.0
pH	:	6.3	6.0
Juice density	:	1.0	1.8

LKC 2010

The beet exhibited a half-green coloration and had a broad, elliptic shape when viewed longitudinally, while the transverse section revealed an irregular form. The leaves were green, and the root penetrated deeply into the soil, displaying a single root division. A root groove was present, and the skin and flesh were white. The root rings were notably very thin (Table 1). Each root weighed between 0.80 and 0.85 kg, with a width of 28.78 cm and a length of 12.85 cm (Table 2).

This genotype was also evaluated for its drought tolerance and demonstrated notable attributes. LKC

2010 exhibited high sucrose content and excellent bioethanol recovery. Under drought conditions, LKC 2010 outperformed other genotypes due to its higher chlorophyll content and improved relative water content. Additionally, LKC 2010 maintained consistent malondialdehyde levels in both irrigated and drought conditions. Under drought conditions, it achieved the highest root diameter, root length, and individual root weight. The reduction in sucrose content, purity coefficient, and brix percentage in LKC 2010 was less pronounced under drought conditions compared to irrigated conditions (Table 4). Furthermore, LKC 2010 excelled in ethanol recovery, achieving 7.72% and 7.12% under drought and irrigated environments, respectively.

Drought resistant sugar beet varieties/genetic stocks are essential for sugar beet cultivation in India. Many regions in India suffer from water scarcity and erratic rainfall, conditions that can severely impact crop yields. Developing drought-tolerant varieties ensures that sugar beet remains a viable and profitable crop, even in regions with limited water availability. High sucrose content in drought-tolerant varieties translates to better economic returns for farmers. This will help farmers maintain productivity even under adverse conditions, stabilizing their incomes and contributing to food security. Drought-tolerant sugar beet varieties can thrive with less water, making them an ideal crop for regions facing water shortages. These varieties help conserve precious water resources, reduce the reliance on irrigation, and lower the overall water footprint of agriculture. Furthermore, the increased ethanol production capacity under drought stress conditions aligns with India's energy sustainability goals. Drought-tolerant varieties ensure consistent bioethanol production, contributing to the country's renewable energy targets and reducing greenhouse gas emissions.

LKC 2020

The beet displayed a light-green hue and featured a narrow obtriangular shape in the longitudinal section, while the transverse section showed a regular form. The leaves were dark green, and the root extended deeply into the soil, exhibiting slight fangyness in its division. A root groove was present, and both the skin and flesh were white. The root rings were exceptionally thin (Table 1). Each root weighed between 0.95 and 1.13 kg, with a width of 27.60 cm and a length of 13.50 cm (Table 2).

This was another genotype assessed for drought tolerance, exhibiting remarkable characteristics. LKC 2020, a sugar beet genotype, demonstrated superior single root weight, root length, and root diameter under both irrigated and drought conditions. During drought conditions, LKC 2020 experienced minimal reduction in chlorophyll content, consistently outperforming other genotypes. Additionally, LKC 2020 had the highest sucrose content, brix, and purity coefficient under drought conditions. The malondialdehyde levels were lowest in irrigated conditions at 74.19 moles, and slightly higher under drought at 78.23 moles (Table 4). Root length measured 20.60 cm under irrigated conditions and extended to 28 cm under drought conditions. Conversely, root diameter was 8.50 cm in irrigated conditions and slightly reduced to 8.34 cm under drought conditions. Moreover, LKC 2020 excelled in ethanol recovery, achieving 9.14% under irrigated conditions and 8.32% under drought conditions. Its resistance to Spodopteralitura (Armyworm) was evaluated based on leaf damage intensity, with LKC 2020 showing only 0 to 20% leaf damage. This genotype also exhibited superior juice quality at high temperatures during May.

This genetic stock resistant to Insects like Spodopteralitura reduces the need for chemical pesticides, lowering production costs and minimizing environmental impact. This resistance also promotes sustainable agricultural practices by reducing the chemical load on the ecosystem and ensuring healthier crops. Furthermore, pest-resistant varieties enhance the overall reliability and consistency of crop yields, which is particularly important for smallholder farmers who rely heavily on stable harvests for their livelihoods.

DISCUSSION

The development of advanced sugar beet varieties such as LKC 2000, LKC 2010, LKC 2020, LKC 2006, and LKC 2007 represents a significant advancement in the quest for sustainable bioethanol production in India. Each of these varieties offers unique traits that contribute to enhanced bioethanol recovery, resilience to environmental stress, and overall agronomic

Table 4 : Performance of sugar beet varieties under drought stress condition

Traits/Environments	LKC 2007		LKC 2010		LKC 2020	
	Irrigated	Drought	Irrigated	Drought	Irrigated	Drought
Sucrose (%)	19.53	18.75	19.42	18.21	19.31	18.84
Purity (%)	90.83	82.23	90.49	81.87	90.14	83.21
Brix	21.50	22.80	21.46	22.24	21.42	22.64
Malondialdehyde (moles)	68.39	69.77	52.45	50.41	74.19	78.23

performance. LKC 2000 stands out due to its remarkable tolerance to post-harvest deterioration and high bioethanol recovery rates. Post-harvest deterioration is a critical issue in bioethanol production as it affects the quality and yield of fermentable sugars (Vargas-Ramirez 2015).

Developing sugarbeet genetic stocks with reduced postharvest deterioration is crucial. Postharvest losses significantly reduce the marketable yield of sugar beet, leading to lower profits for farmers (Polash et al. 2022). By developing sugar beet varieties that resist postharvest deterioration, the economic returns for farmers can be improved. This is especially important for smallholder farmers who rely heavily on their crop yields for income. Higher quality and quantity of marketable produce translate to better prices and higher income stability. Furthermore, a significant portion of agricultural produce in India is lost during storage, transportation, and handling due to inadequate infrastructure and poor postharvest management practices. Varieties with reduced postharvest deterioration can withstand the challenges of the supply chain better, maintaining their quality and reducing the need for expensive storage solutions. This can lead to more efficient supply chains and lower overall costs. Additionally, sugar beet varieties bred for lesser postharvest deterioration are likely to be more resilient to these climatic stresses, ensuring that the harvested crop retains its quality for longer, even under adverse weather conditions (Schnepel and Hoffmann, 2016). By reducing losses during storage and transport, LKC 2000 ensures a consistent and high-quality feedstock for ethanol production, making it an invaluable variety in the bioethanol supply chain.

LKC 2010 brings additional advantages with its drought tolerance, high sucrose content, and resistance to root rot. Drought tolerance is crucial in the context of India's varying climatic conditions and water scarcity issues. This trait ensures stable yields even under water-limited conditions, thereby safeguarding farmers' livelihoods and securing a steady supply of raw material for ethanol production. The high sucrose content of LKC 2010 directly translates to increased ethanol yield per unit of biomass, enhancing the overall efficiency of the bioethanol production process. Additionally, root rot resistance further ensures the health and productivity of the crop, minimizing losses due to disease and reducing the need for chemical interventions. Water scarcity is a critical issue in India, affecting not only agriculture but also the overall sustainability of ecosystems (Falkenmark, 2013; Kumar and Kumar, 2024). Traditional crops often require substantial water inputs, which are becoming increasingly unsustainable. Drought-tolerant sugar beet varieties can thrive with less water, making them an ideal crop for regions facing water shortages (Ober et al. 2004; Pidgeon et al. 2006). These varieties help conserve precious water resources, reduce the reliance on irrigation, and lower the overall water footprint of agriculture. By optimizing water use efficiency, drought-tolerant sugar beets contribute to sustainable agricultural practices and help mitigate the impacts of water scarcity on the environment.

LKC 2020 is another exceptional variety, known for excelling in bioethanol recovery under both irrigated and drought conditions. This dual capability makes LKC 2020 highly versatile and adaptable to diverse agricultural environments. In regions with reliable irrigation, it can maximize yields, while in drought-prone areas, it still performs robustly, ensuring consistent production levels. This adaptability is particularly important for meeting the demands of India's bioethanol blending policy, which aims to increase the ethanol content in petrol to reduce dependency on fossil fuels and lower greenhouse gas emissions. The drought-tolerant varieties LKC 2006 and LKC 2007 further bolster the resilience of bioethanol production. Their ability to thrive under water-scarce conditions makes them suitable for cultivation in arid and semi-arid regions of India. This not only expands the geographic scope of sugar beet cultivation but also reduces the pressure on water resources, aligning with sustainable agricultural practices. Drought resistant sugar beet varieties/genetic stocks are essential for sugar beet cultivation in India. Many regions in India suffer from water scarcity and erratic rainfall, conditions that can severely impact crop yields (Sharma, 2023; Suna et al. 2023). Developing drought-tolerant varieties ensures that sugar beet remains a viable and profitable crop, even in regions with limited water availability. High sucrose content in drought-tolerant varieties translates to better economic returns for farmers. This will help farmers maintain productivity even under adverse conditions, stabilizing their incomes and contributing to food security. Drought-tolerant sugar beet varieties can thrive with less water, making them an ideal crop for regions facing water shortages. These varieties help conserve precious water resources, reduce the reliance on irrigation, and lower the overall water footprint of agriculture. Furthermore, the increased ethanol production capacity under drought stress conditions aligns with India's energy sustainability goals. Drought-tolerant varieties ensure consistent bioethanol production, contributing to the country's renewable energy targets and reducing greenhouse gas emissions.

The Indian government has directed sugar mills and distilleries to avoid using sugarcane juice or sugar syrup in ethanol production during 2023-24 ethanol supply year. Anticipating a decrease in sugar output for the 2023-24 season, the central government has mandated that all sugar mills should not utilize sugarcane juice or syrup for producing ethanol. Instead, they are advised to rely solely on B-heavy and C-heavy molasses for ethanol production. As the sugarcane crushing season reaches its sixth month, the production outlook remains less promising. Consequently, the government has implemented measures such as stopping imports and increasing the monthly release quota, along with instructing mills to refrain from ethanol production methods that consume a substantial amount of actual sugar. Industry experts note that producing ethanol directly from sugarcane juice or syrup leads to the highest diversion of actual sugar, while the diversion percentage is lower when ethanol is produced from molasses. Moreover, ethanol production from C-heavy molasses does not divert any sugar. Given that sugar production is expected to marginally surpass consumption in the 2023-24 season, the government, with input from industry experts, has decided to prevent further diversion of actual sugar for ethanol production to avoid complications with sugar availability for public consumption. The Indian Sugar Mills Association (ISMA) has forecasted a 9 percent decline in gross sugar production, estimating it at 337 lakh tonnes for the 2023-24 marketing year, spanning from October 2023 to September 2024. This issue has prompted a shift from sugarcane to alternative crops like rice, corn, and grains for ethanol production, aligning with India's ambitious goal of achieving a 20 percent ethanol blending rate by 2025, aimed at reducing dependence on fossil fuels (Mall et al. 2024). With this perspective of bioethanol production in current system, sugar beet varieties like LKC 2000, LKC 2010, LKC 2020, LKC 2006, and LKC 2007 present significant advantages over traditional feedstocks such as sugarcane and cereal crops. Sugarcane, while a major source of bioethanol, requires substantial water and has a longer growing cycle. The advanced sugar beet varieties offer shorter cycles and require less water, making them more sustainable and cost-effective. Moreover, the higher sucrose content and bioethanol recovery rates of these sugar beet varieties can potentially lead to greater ethanol yields per hectare compared to many cereal crops, which are often diverted to food and feed purposes, thus avoiding competition with food security.

Integrating advanced sugar beet varieties that are rich in ethanol, sucrose, and yield into the current sugarcane and cereal-based ethanol production ecosystem presents a promising opportunity to diversify and enhance biofuel production. This integration addresses critical agricultural challenges, promotes sustainable practices, and provides competitive economic advantages. By leveraging their unique traits, farmers can optimize land use, improve productivity, and contribute to a more sustainable and diversified agricultural sector. Sugar beets have a higher sugar concentration than many cereal crops traditionally used for ethanol, such as corn. This higher sucrose content translates to more efficient fermentation processes and higher ethanol yields per unit of biomass. In regions where water scarcity or land limitations constrain sugarcane or cereal crop production, sugar beets offer a less resource-intensive alternative. They require less water and can grow in a variety of soil types, including those not suitable for cereals or sugarcane. Integrating sugar beets into the existing ecosystem also provides economic advantages. Farmers can benefit from crop rotation with sugar beets, which improves soil health and reduces pest and disease cycles associated with monoculture practices in sugarcane and cereal farming. This rotation can lead to higher yields in subsequent crops, providing a sustainable farming practice that maximizes land use efficiency. Furthermore, the byproducts of sugar beet processing, such as beet pulp, can be used as animal feed or for producing biogas, adding additional revenue streams and reducing waste. The volatility of the corn market, heavily influenced by food demand and weather patterns, often leads to fluctuating ethanol prices. In contrast, high-yield sugar beet varieties like LKC 2020 and LKC 2010, with their high ethanol content and reduced dependency on market fluctuations, offer a more predictable and stable supply of raw materials for ethanol production. This stability can attract investment and foster innovation in biofuel technologies and infrastructure.

CONCLUSION

The development of sugarbeet varieties with high sucrose for potential ethanol production, and root yield, along with abiotic and biotic stress resistance, is essential for adapting to India's diverse agroclimatic conditions. The study aims to meet the rising demand for bioethanol feedstocks by developing sugar beet varieties that are optimized for high sucrose content and substantial root yield. This initiative is crucial, given the increasing emphasis on renewable energy sources and sustainable agriculture. India, with its diverse agroclimatic zones, faces significant challenges in maintaining crop productivity and resilience in the face of climate change and resource constraints. The development of sugarbeet varieties that possess high sucrose and ethanol content, combined with root yield, is essential for enhancing the crop's adaptability to various environmental conditions. These genetic advancements not only promise to increase the economic viability of sugar beet cultivation but also promote sustainable agricultural practices and bolster the resilience of farming communities.

Thus, the advanced sugar beet varieties developed by breeding programs in India are poised to play a crucial role in the country's bioethanol blending policy. By offering high bioethanol recovery, drought tolerance, and disease resistance, they provide a sustainable and efficient alternative to traditional feedstocks. Their adaptability to diverse growing conditions ensures a reliable supply chain, contributing to energy security and environmental sustainability in India.

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