Effect of *Ascophyllum nodosum* Extract (Acadian) as Natural Organic Inputs on Performance of Some Sugar Beet Varieties

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ABSTRACT

This study evaluated the impact of *Ascophyllum nodosum* extract (Acadian) as a natural, eco-friendly biostimulant on the performance of five sugar beet varieties under reduced nitrogen fertilizer levels. Field experiments were conducted at the El-Sabahia Research Station (latitude 31° 12' N), Agricultural Research Center, Alexandria, Egypt, using a split-split plot design in a complete block arrangement during the 2021/2022 and 2022/2023 seasons. Treatments included foliar application of Acadian extract (AE) at two concentrations (1 ml/L and 2 ml/L), combined with two urea levels (50% and 75% of the recommended rate), alongside 1 ml/L AE without urea, and a control receiving 100% urea. The results showed that foliar spraying with AE at 2 ml/L combined with 75% urea significantly improved physiological and technological traits, leading to an increase in root and sugar yield by 25.97% and 20.97%, respectively, compared to the control. The Dina variety achieved the highest sugar yield (4.71 tons/fed), while the Panther variety surpassed Dina in root yield (29.19 tons/fed). A significant negative correlation (r ≈ -0.88) was observed between sugar yield and impurity percentage in roots, which was notably higher in the LP17B4011 variety. The interaction between the Mammut variety and AE (2 ml/L) + 75% urea recorded the highest root yield (35.81 tons/fed) and sugar yield (5.80 tons/fed). The phylogenetic tree closely aligned with the results of principal component analysis, indicating that the Dina and Mammut varieties have superior adaptability, followed by the Kn-627 variety. We conclude that the Acadian extract can be effectively used to sustain and enhance sugar beet productivity while improving the adaptability of varieties to environmental changes.

Keywords: Acadian extract, biostimulant, foliar applications, phylogenetic tree.

INTRODUCTION

Enhancing and sustaining productivity in the sugar sector is a national objective, as the sugar industry plays a vital role in ensuring both food and economic security in Egypt. According to Zhang *et al.* (2016), sugar beets (*Beta vulgaris* L.) provide approximately 35% of global sugar production annually. In 2023, Egypt's sugar output reached 1.79 million tons, which was obtained from 14 million metric tons of sugar beet cultivated on an area of 618 thousand feddans, as reported by the Sugar Crops Export Council of Egypt's Ministry of Agriculture (Sugar Crops Export Council, 2023).

Egypt's growing population, increasing food requirements, and plateauing sugar yield have resulted in a significant imbalance between sugar production and consumption. Given the challenges posed by increasing climate variability, the Egyptian government is developing a strategy to maintain agricultural sustainability. This strategy focuses on the conservation of natural resources, especially soil and water, to enhance the productivity of sugar beet cultivation and ensure food security. Furthermore, the researchers are concentrating on increasing the productivity of sugar beets per unit area to help bridge the disparity between sugar consumption and demand.

Agriculture often relies on chemical fertilizers to enhance crop yields. However, recent studies have shown that the excessive application of these fertilizers leads to soil degradation and various environmental challenges (Renganathan *et al.*, 2024). The extended and excessive application of chemical fertilizers has resulted in changes to soil pH, a decrease in organic matter levels, a reduction in the activity of beneficial organisms, and an increase in pest populations. These factors collectively have adverse effects on plant growth, productivity, and quality (Zaki *et al.*, 2018). The accumulation of detrimental substances in plants has adverse effects on both human and animal health (Damalas & Koutroubas, 2016 and Mitra *et al.*, 2022). Consequently, there is a pressing need for the adoption of environmentally friendly agricultural fertilizers, including biofertilizers and biostimulants. These alternatives are considered promising solutions that can alleviate the adverse impacts of climate change on agriculture while enhancing agricultural productivity (Van Oosten *et al.*, 2017).

Biofertilizers and biostimulants derived from seaweed, particularly microalgae, play a significant role in enhancing soil health through the synthesis of various biomolecules, including nitrogen-fixing enzymes, phytohormones, polysaccharides, soluble amino acids, polyunsaturated fatty acids, and bioactive peptides. These substances promote crop growth and improve quality by stimulating germination, boosting plant

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metabolic activity, enhancing photosynthesis, and increasing nutrient utilization efficiency, ultimately leading to greater plant productivity (Renganathan *et al.*, 2024). Among these, the brown seaweed *Ascophyllum nodosum*, often known as rockweed, represents a novel type of agricultural input, exhibiting positive impacts on the physiological, morphological, and biochemical characteristics of soil and plants. This species is predominantly found in the cold waters of the North Atlantic Ocean, extending from eastern Canada to parts of northern Europe (Moreira *et al.*, 2017).

Ascophyllum nodosum is a seaweed that contains a diverse array of nutrients, including carbohydrates, poly uronic compounds, proteins, lipids, and minerals. It is also notable for its unique bioactive compounds, such as quaternary ammonium compounds, which encompass laminine, glycine betaine, , δ-aminovaleric acid betaine and γ-aminobutyric acid betaine(Moreira et al., 2017). Research has demonstrated that extracts from *Ascophyllum nodosum* can enhance various soil properties, including capillary action, aeration, and the structural integrity of soil particles. Furthermore, these extracts have been found to boost microbial activity in the soil, fortify plant root systems, and improve the absorption and availability of minerals, thereby facilitating nutrient uptake through the regulation of genes associated with nutritional acquisition (Di Stasio *et al.*, 2018). Research by Shukla *et al.* (2019) demonstrates that the use of *Ascophyllum nodosum* extract on plants enhances stomatal conductance and boosts antioxidant activity in drought conditions, while also serving as a biocontrol agent (Kumari *et al.*, 2023). This extract has been shown to increase chlorophyll and flavonoid levels, thereby promoting plant growth, improving yield, and accelerating maturation when applied at a concentration of 0.5% across various crop species (Norrie *et al.*, 2001). Specifically, the application of 2 liters of Bio-algeen S90 per hectare during the 2-3 leaf stage of sugar beet significantly improved both root and sugar yields (Pospišil *et al.*, 2006). Furthermore, Pačuta *et al.* (2023) reported that a foliar application of 1 liter of *Ascophyllum nodosum* extract per hectare led to an increase in sugar content in sugar beet crops. In addition to enhancing sugar yield and root morphology, brown seaweed extract influences the expression of genes related to auxin and abscisic acid, promoting the morphological development of sugar beet roots, which facilitates soil colonization and improves the uptake of water and nutrients (Badr *et al.*, 2024). Moreover, the use of algae extract as a foliar spray has been found to significantly increase sugar cane yield (de Castro *et al.*, 2024). *Ascophyllum nodosum* extracts demonstrate significant potential as a biostimulant in agricultural practices, offering a safe application for both plants and soil, thereby contributing to sustainability efforts. These extracts can be employed through multiple methods, such as foliar spraying, soaking, soil irrigation, and in conjunction with chemical fertilizers. This research aims to investigate the potential of *Ascophyllum nodosum* extract (Acadian, AE) as an eco-friendly biostimulant to reduce nitrogen fertilizer usage and enhance the productivity and quality of sugar beet varieties. Principal Component Analysis (PCA) is employed in this research as a statistical method to identify significant variance components, their contributions, and associated traits among the sugar beet varieties.

MATERIAL AND METHODS

***Ascophyllum nodosum* extract:** An extract known as Acadian (AE) derived from the marine organism *Ascophyllum nodosum*. This extract was provided by Eng. Hisham Amin Abulfadl, the former sales and commercial director at Chema Industries in Alexandria, Egypt. The composition of AE includes sulfated polysaccharide chains, amino acids, organic acids, betaines, and a range of macro- and micronutrients such as potassium (K), magnesium (Mg), calcium (Ca), iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn). Furthermore, it is enriched with bioactive compounds, notably including laminarin, alginic acid, and mannitol.

Chemical compost: Ammonium nitrates (N), superphosphate (P_2O_5) and potassium sulfate (K_2O) were purchased from Ministry of Agriculture, Giza, Egypt.

Sugar beet varieties: Seeds of sugar beet varieties are Kn-627 (V1), Dina (V2), Panther (V3), LP17B4011 (V4) and Mammut (V5), that were supplied by Sugar Crops Research Institute, Agriculture Research Center, Ministry of Agriculture, Giza, Egypt.

Study Area Description

Field trials were conducted at the El-Sabahia station of the Agricultural Research Center in Alexandria, Egypt, from October (starting September 22) to March in the years 2021 and 2022. This station is situated at a latitude of 31° 12' N. The climatic conditions in this region exhibit temperatures ranging from 17° to 30°c, accompanied by relative humidity levels between 60% and 70%. The average annual rainfall in this area is approximately 250 mm. The physico-chemical properties of the soil, analyzed at a depth of up to 60 cm, reveal a clayey texture comprising 40% clay, 22% sand, and 27% silt. The soil is characterized as moderately alkaline, with a pH of 7.86, an electrical conductivity of 1.7 dS/m, and contains 5% calcium carbonate. Additionally, the soil has nitrogen levels of 50 ppm, potassium levels of 40 ppm, and available phosphorus levels of 20 ppm.

Field experiment and treatment

The experimental treatments were designed utilizing a split-split plot design with three replicates. The treatments were arranged with a horizontal factor consisting of five treatments alongside a control, while the vertical factor was represented by five sugar beet cultivars. Each subplot encompassed an area of 15 m², comprising five ridges, each measuring 5 m in length and spaced 60 cm apart, which allowed for approximately 125 plants per subplot. Sowing was conducted by placing two seeds of the sugar beet variety in each hole, achieving a seeding rate of 4 kg per fed.

Foliar treatments comprised two concentrations of Acadian extract (AE), specifically 1 mL/L and 2 mL/L, in conjunction with two urea application levels set at 50% and 75%. Additionally, a foliar application of AE at a concentration of 1 mL/L was applied at a volume of 350 mL /fed, in accordance with the protocols of the Chema Company. A control treatment was implemented, utilizing 100% urea at a dosage of 120 kg N/fed, in accordance with the recommendations from the Sugar Crops Research Institute, Agricultural Research Center. The experimental design included the following treatments: AE at 1 mL/L combined with 75% urea (T1); AE at 1 mL/L with 50% urea (T2); AE at 2 mL/L with 75% urea (T3); AE at 2 mL/L with 50% urea (T4); AE at 1 mL/L without urea (T5); and a control receiving 100% urea compost, which facilitated the assessment of growth and yield in the sugar beet crop. Foliar treatments were initiated 40 days after planting before the irrigation event. Each plant received three applications of AE treatment throughout the growing season. Irrigation and traditional cultivation methods were used during crop growth. Upon harvest on March 25, a random square meter was chosen from each replicate of the subplot to assess the growth and quality of root characteristics.

Evaluation of yield characteristics

Measurement of plant growth traits: The phenotypic characteristics were evaluated by measuring the fresh weight of the leaves, the leaf area index, and the root weight of samples exposed to six different treatments. The fresh weights of the leaves and the roots of the uprooted plants were determined using a precision balance. Additionally, the number of leaves per plant sample was documented, and the leaf area index was determined according to Watson (1958). The plant samples, including both leaves and roots, were dried in a hot air oven at 105 °C for 48 hours until a consistent weight was reached. The dried samples were then weighed to ascertain the dry biomass of the plants, in accordance with the procedures established by the A.O.A.C method.

Measurement of chlorophyll content on leaves: The chlorophyll content of the plant's middle leaves was measured using SPAD-502 chlorophyll meter (Minolta, Japan).

Technological quality traits of sugar beet: Ten roots from each subplot were collected for the evaluation of juice quality characteristics at the Nubaria Sugar Factory laboratory in El-Beheira Governorate, Egypt. The analysis was conducted by the official ICUMSA methods (ICUMSA, 2007), focusing on the assessment of sucrose content, purity, and α-amino N in the root juice (Carruthers and Oldfield, 1961). Total soluble solids were determined using an automatic digital refractometer. The concentrations of potassium (K) and sodium (Na) were measured using an atomic absorption spectrometer (model 300VA-50-60 Hz-100-240V, UK), in accordance with A.O.A.C. (2005). The determination of impurity percentages, represented as sucrose loss in molasses, was carried out by Harvey and Dutton (1993) using the formula [0.343(K + Na) + 0.094 α-amino N + 0.29]. The percentage of extractable sugar (ES %) was calculated according to the equation established by Dexter *et al.* (1967), expressed as follows: ES% = [sucrose % – (sugar lost to molasses % + 0.6)].

Yield evaluation: yields root (ton/fed) were computed on a plot basis. The calculation of white sugar yield (ton/fed) was performed by multiplying the root yield by the extractable sugar percentage divided by 100.

Statistical treatment

The analysis of the impact of treatments and genotypes on the studied traits during the 2022 and 2023 seasons was conducted as fixed effects using the GLM procedure in SAS (2012).

Analysis of treatment and genetic parameters

The data underwent variance analysis using R software. Mean values for all traits were used to conduct principal component analysis (PCA), cluster analysis, and correlation assessments. The PCA was carried out utilizing the base R hclust function, following the standardization techniques outlined by Sébastien *et al.* (2008). The principal components (PCs) with eigenvalues greater than 1 represented a significant portion of the variance, facilitating the evaluation of varieties across different traits in accordance with Kaiser’s criteria. The hierarchical cluster analysis was conducted using the unweighted pair group method with arithmetic mean (UPGMA) as its foundational approach (Maechler *et al.*, 2022) while a tree diagram based on Euclidean distances was developed by Ward’s method (Ward Jr, 1963).

RESULTS AND DISCUSSION

The results of the ANOVA demonstrated statistically significant differences ($p \leq 0.001$) among the various dilution levels of foliar application AE (T), the genotypes and their interaction (T×V) concerning all the selected physiological traits, as well as fresh and dry weights (g/plant), technological quality, and productivity of sugar beet varieties in the combined analysis conducted over two years (Table 1).

Impact of foliar application of Acadian on physiological characteristics.

The results indicated an enhancement in photosynthetic efficiency in the different AE dilution levels applied with 75% urea, compared to the combinations involving 50% urea or the control group with 100% urea (Figure 1 A, B, C, D, E, and F). An analysis of the average values for the treatments indicated that sugar beet plants treated with 2 ml/l of AE and 75% nitrogen (T3) exhibited superior measurements in leaf weight (1190.4 g), dry leaf weight (159.06 g), leaf area index (4.85 m^2/m^2), root weight (1146.1 g), dry root weight (146.69 g), and chlorophyll content (44.75%). These values reflected a significant increase of 3.6%, 1.50%, 8.9%, 17.35%, 25.90%, and 8.88%, respectively, when compared to the control. Following the T3 treatment, the foliar application of 1 ml AE/l combined with 75% nitrogen (T1) exhibited a statistically insignificant improvement in the previously evaluated parameters when compared to the control (Figure 1). The application of urea at a reduced rate of 50% in treatments T2 (with 1 ml AE/l) and T4 (with 2 ml AE/l) resulted in a significant decrease in the physiological traits of sugar beet across both growing seasons.

Table 1. Means values and statistical analysis (p-values) for impact of treatments and variety and their interaction on the physiological, technological, and productivity traits of sugar beet during the two seasons

Traits and Source of Variation	Means	Treatment			Varieties			Treatment x varieties		
		Mean Squares	F-value	*p*- value	Mean Squares	F-value	*p*-value	Mean Squares	F-value	*p*-value
Growth traits										
Leaves weight (g)	1044.6	279409.88	1364.12	0.000***	250919.52	1225.022	0.000***	131418.99	641.60	0.000***
Leaves dry weight (g)	145.71	5876.22	2103.10	0.000***	1264.92	452.716	0.000***	2147.42	768.56	0.000***
LAI (m^2 m^2)	4.184	4.502	25.348	0.000***	6.89	38.767	0.000***	3.83	21.57	0.000***
Root weight(g)	919.0	383007.03	10972.28	0.000***	70372.62	2016.015	0.000***	11518.50	329.98	0.000***
Root dry weight(g)	125.91	5138.95	329.10	0.000***	7698.32	493.002	0.000***	1422.01	91.07	0.000***
Chlorophyll content										
Chlorophyll (%)	39.826	232.28	52.67	0.000***	92.766	21.032***	0.000***	20.482	4.64	0.000***
Technological traits										
T.S.S %	21.22	1.59	3.14	0.0140**	9.28	18.361	0.000***	3.86	7.64	0.000***
Sucrose%	16.911	1.88	11.04	0.000***	35.22	206.96	0.000***	1.20	7.05	0.000***
Purity%	85.605	5.13	8.05	0.000***	348.58	547.371	0.000***	7.07	11.10	0.000***
Alfa-amino N (mmol /100 g)	0.874	0.15	58.28	0.000***	0.649	261.338	0.000***	0.03	10.34	0.000***
Potassium (mmol /100 g)	4.977	0.29	3.94	0.004**	17.80	239.997	0.000***	0.23	3.075	0.001***
Sodium (mmol /100 g)	0.872	0.19	26.62	0.000***	3.18	442.135	0.000***	0.15	21.00	0.000***
Impurity (%)	2.378	0.05	4.19	0.003**	4.28	396.685	0.000***	0.06	5.84	0.000***
Extractable sugar (%)	14.532	2.06	11.27	0.000***	63.15	344.584	0.000***	1.62	8.84	0.000***
Production parameters										
Root yield(ton/fed)	27.571	344.71	10972.28	0.000***	63.34	2016.02	0.000***	10.37	329.98	0.000***
Sugar yield (ton/fed)	4.0134	9.48	676.21	0.000***	5.45	388.47	0.000***	0.21	14.87	0.000***

Means in a row not sharing the same letter are significantly different at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

Spraying of *Ascophyllum nodosum* (L.) extract promotes leaf development, enhances plant growth, increases photosynthetic efficiency, and improves overall plant performance as well as helps plants endure abiotic stresses (Nikoogoftar-Sedghi *et al*., 2023). In treatment T2, there was a significant decrease of 21.93% in leaf weight, 19.68% in dry leaf weight, and 15.13% in root weight, as well as a 7.50% reduction in chlorophyll content and a non-significant decline of 5.39% in leaf area index when compared to the control treatment. The T4 treatment recorded a statistically significant reduction in leaf weight and leaf area while showing a marked increase in root weight in comparison to T2 (Figure 1 A, E, and C). Moreover, the application of AE at a concentration of 1 ml/l without the addition of urea (T5) resulted in a significantly higher decrease in the values of these characteristics, except leaf area index (Figure 1), compared to control. Nitrogen (N) is a crucial component of nucleic acids, amino acids, proteins, and chlorophyll, making it a vital nutrient for improving photosynthetic efficiency (Fathi, 2022).

The observed improvement of physiological traits in plants treated with AE and 75% urea can be attributed to the presence of betaine in AE, which may act as a nitrogen source at low concentrations while serving as an osmolyte at higher concentrations (Silva *et al.*, 2024). Furthermore, the impact of AE cytokinins has been shown to stimulate cell division and improve nutrient transport to the leaves, thereby playing a significant role in the regulation of source-sink dynamics, which ultimately leads to notable improvements in growth traits (Bertoldo *et al.*, 2023). Likewise, the application of 1.5 g/L *Spirulina* extract combined with 100 kg N/h resulted in a significant increase in growth parameters, particularly in root yield, when compared to the control (Badr *et al.*, 2024).

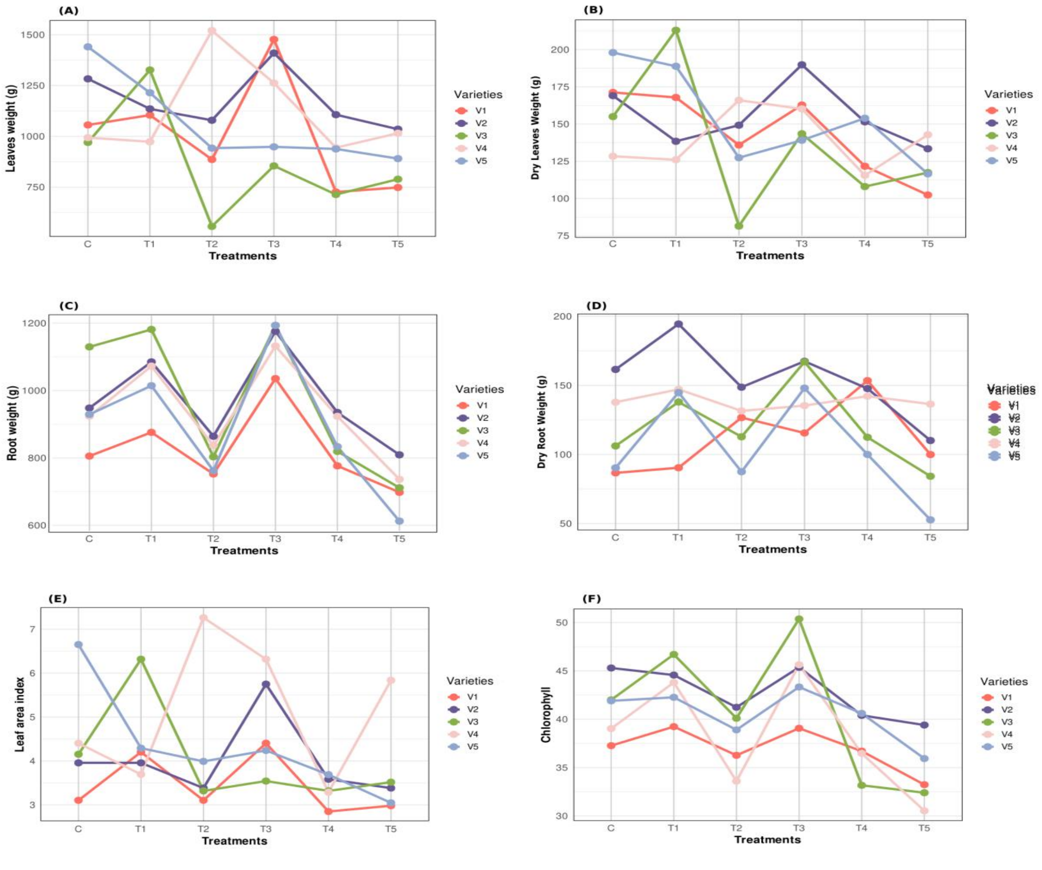

Fig. 1. Physiological parameters of sugar beet varieties (V1: Kn-627, V2: Dina, V3: Panther, V4: LP17B4011 and V5: Mammut) under different treatments (1 mL AE /L + 75% urea (T1); 1 mL AE /L +50% urea (T2); 2 mL AE /L + 75% urea (T3); 2 mL AE /L + 50% urea (T4); AE at 1 mL/L without urea (T5); and control (C)

The AE treatments had a significant impact on chlorophyll content, as illustrated in Figure (1 F). The application of a foliar spray containing AE resulted in an increase in chlorophyll concentrations in the treatment combined with 75% urea. In contrast, the use of AE with 50% urea caused a decrease in chlorophyll content compared to the control (41.1%). Additionally, the treatment T5, which did not include urea, recorded the lowest average chlorophyll content (34.3%). The observed enhancement in chlorophyll levels in leaves treated with AE may be due to the bioactive compounds present in AE, such as betaines, which enhance photosynthetic efficiency by enhancing light absorption and inhibiting chlorophyll degradation (Chen *et al.*, 2021). Furthermore, AE extracts are rich in magnesium, an essential element for chlorophyll synthesis (Almaroai and Eissa, 2020). According to Patel *et al.* (2020), the application of AE can significantly enhance the growth of sugarcane leaves. This growth enhancement was correlated with an increase in chlorophyll biosynthesis in the leaves, which subsequently contributed to a rise in sugarcane yield (Rouphael *et al.*, 2018). The use of *A. nodosum* extract increased the fresh weight of crops when compared to control groups, and the cytokinin levels in the extract led to improved quality (De Saeger *et al.,* 2020).

Impact of foliar application of Acadian on the roots quality characteristics

The technological quality of sugar beet roots is significantly affected by the concentration of soluble components present within the roots, which are crucial for the sucrose crystallization process. An increase in these soluble components in the juice may lead to a subsequent loss in the amount of sucrose that ends up in the molasses (Dutton and Huijbregts, 2006). The quality traits of root juice were significantly influenced ($P \leq 0.05$) by the use of AE as compared to the control (Table 2). In control conditions, the contents of total soluble solid, sucrose, purity, α-amino nitrogen, potassium (K), sodium (Na), impurity, and extractable sugar were recorded at 21.6%,16.80%, 85.39%, 0.84 mmol /100 g, 4.99 mmol /100 g, 0.96 mmol /100 g, 2.41 mmol /100 g, and 14.39%, respectively (Figure 2). The T1 and T3 achieved the highest mean values in most genotypes for sucrose content, purity, and extractable sugar percentage, as illustrated in Figures (2 B, C, and H). The average sucrose content for T1 was determined to be 17.35%, while T3 showed 17.31%; purity levels were recorded at 86.18% for T1 and 86.34% for T3, and the extractable sugars were recorded at 14.93% and 15.02% for the roots treated with T1 and T3, respectively. The extract of *Ascophyllum nodosum* (L.) seaweed improves root quality and has the potential to enhance nutrient absorption, making it a viable option for organic agriculture (Sharma *et al.***,** 2017)**.** As shown in Figure (2 A), T1 had the lowest mean value for total soluble solids at 20.64%, with T3 closely following at 21.12%, which is similar to T2's value (21.14%). T3 exhibited a significant increase in α-amino nitrogen (1.07 mmol/100 g) and an insignificant increase in K (5.05 mmol/100 g), while showing a significant decrease in sodium (0.79 mmol/100 g) and an insignificant change in the impurity percentage (2.38), as presented in Figure (2 D, E, F, and G). The sodium is the most effective component of beet juice impurities in determining relative sucrose concentration (Campbell and Fugate, 2015). The T5 treatment recorded the lowest mean values for root juice quality characteristics, exhibiting increased levels of sodium and impurity percentage in comparison to the other treatments. Conversely, the mean values for sucrose content, purity, and extractable sugar in the roots treated with T2 and T4 were statistically similar to those observed in the control treatment. The data indicates that the enzymes that are involved in sucrose metabolism in sugar crops, such as sucrose phosphate synthase and invertase, are influenced by the application of SE. Additionally, the constituents of Acadian extract may promote the synthesis and accumulation of sucrose while concurrently inhibiting its conversion into reducing sugars. These results are consistent with the findings of Enan *et al.* (2016), who reported that the quality index was significantly affected by the addition of 2.5 and/or 3.5 g/l of algal extract. Similarly, El-Sharnoby *et al.* (2021) indicated that the foliar application of *Spirulina platensis* extract at doses of 1.0 g/l or 2.0 g/l led to an increase in extractable sugar content, sucrose, and purity, along with significant effects on total soluble solids percentage, α-amino nitrogen, potassium percentage, sodium percentage, and sugar loss percentage, all influenced by the concentration of the algal extract. On the other hand, the results did not agree with those of Bertoldo *et al.* (2023), who stated that the foliar applications of AE solutions at concentrations of 4 mL/L, 2 mL/L, and 1 mL/L did not significantly change the purity of sugar, particularly in relation to potassium, sodium, and α-amino nitrogen levels in sugar beet roots.

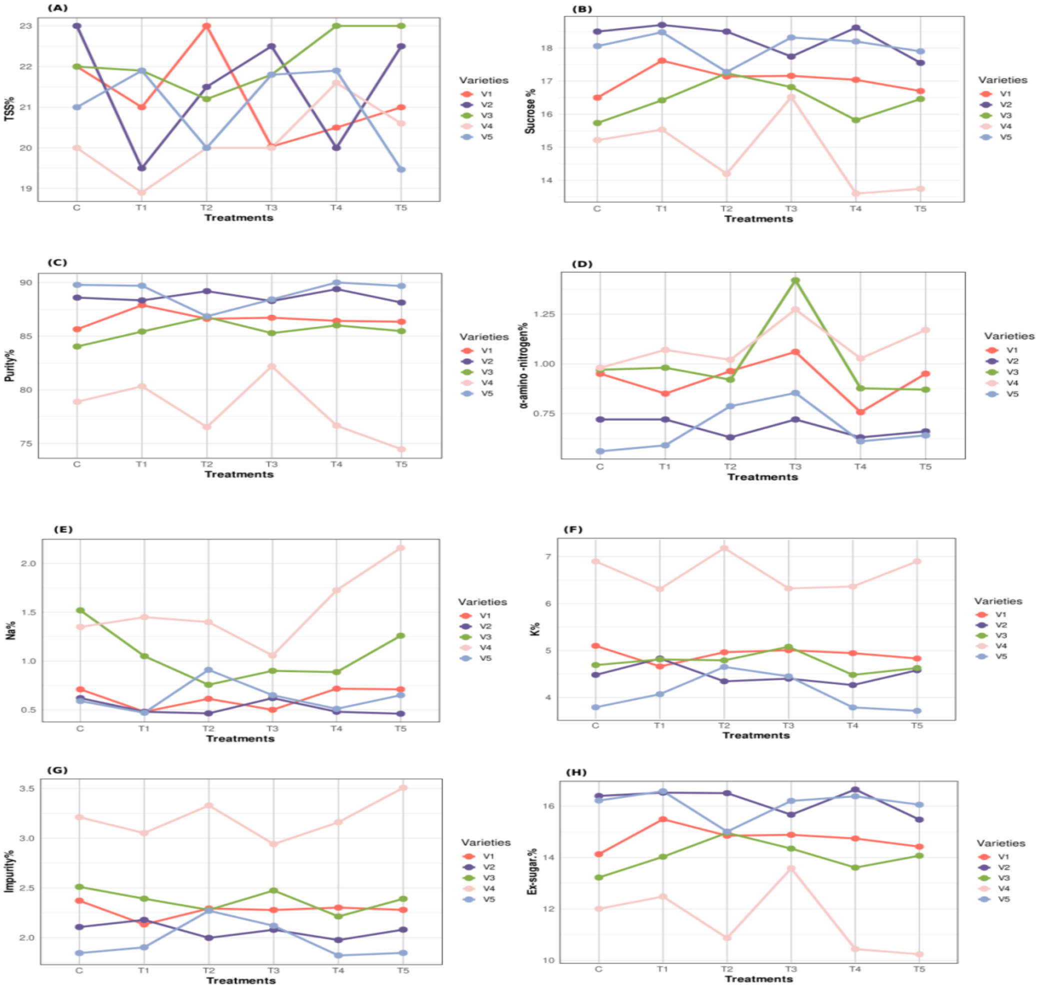

Fig. 2. Technological quality parameters of sugar beet varieties (V1: Kn-627, V2: Dina, V3: Panther, V4: LP17B4011 and V5: Mammut) under different treatments (1 mL AE /L + 75% urea (T1); 1 mL AE /L +50% urea (T2); 2 mL AE /L + 75% urea (T3); 2 mL AE /L + 50% urea (T4); AE at 1 mL/L without urea (T5);and control (C)

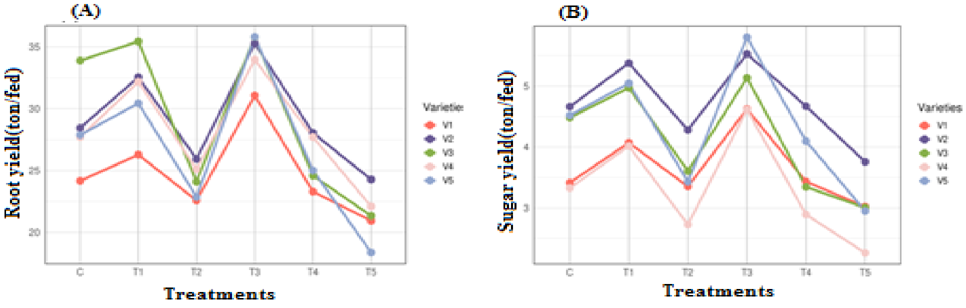

Fig. 3. Root yield (A) and sugar yield (B) of sugar beet varieties (V1: Kn-627, V2: Dina, V3: Panther, V4: LP17B4011 and V5: Mammut) under different treatments and control

Impact of foliar application of Acadian on crop productivity

The data illustrated in Figure (3) indicate that the application of AE combined with 75% urea resulted in a significant improvement in crop yield. In contrast, the treatments that included a 50% reduction in urea combined with AE (T2 and T4) as well as the treatment of AE alone without urea (T5) recorded a significant decrease in crop productivity. The results indicated that treatment T3 gave the highest increase in crop yield, closely followed by treatment T1. The T3 achieved an average root yield of 34.38 tons/ fed (Figure 3a), and a sugar yield of 5.14 tons/ fed (Figure 3 b).

This indicates increases of 20.97% in root yield and 25.97% in sugar yield compared to the control, as well as increases of 9.57% in root yield and 9.45% in sugar yield relative to T1. Furthermore, the data in Figure 3 indicate that the root yields for treatments T2, T4, and T5 were 24.12, 25.73, and 21.41 tons/ fed, respectively (Figure 3 a). Similarly, the sugar yields for these treatments were 3.48, 3.69, and 2.99 ton/fed, respectively (Figure 3 b). This could be due to the role of AE acting as a biostimulant by influencing plant metabolic functions, attributed to the diverse range of bioactive compounds found in the extracts which intended to mitigate both biotic and abiotic stresses with promoting growth and enhancing productivity (Bajpai *et al.*, 2019). Enan *et al.* (2016) highlighted the significant improvement in vegetative growth, chlorophyll levels in leaves, and the yield of sugar beets treated with *Spirulina platensis*. This enhancement is attributed to the mineral content of *Spirulina*, which promotes the absorption and retention of these vital nutrients within the plants. The application of seaweed extract improved yields in sugar crops due to several factors, including enhanced resilience to various stressors, better nutrient absorption resulting from enhanced root architecture, and the significant contribution of microbial activity in this process (Arioli *et al*., 2020).

Varieties performance concerning their physiological and quality traits under foliar application

The data shown in Table (1) also indicate that all the sugar beet varieties studied demonstrated significant differences in all yield criteria. These differences might be due to the genotypic variation (Refay, 2010). Among the different sugar beet varieties assessed, the Dina variety exhibited enhanced growth traits when compared to the other varieties, including leaf weight (1174.75 g/plant), dry leaf weight (154.996 g), dry root weight (154.99 g), and chlorophyll content (42.71 %), as shown in Figure (1).

Additionally, the Dina variety exhibited superior performance regarding the quality parameters of sugar beet roots, which included sucrose content (18.27 %), purity (89.07 %), extractable sugar (16.20 %), K (4.48 mmol /100 g), Na (1.52 mmol /100 g) and achieved the highest sugar yield at 4.71 tons / fed (Figure 2). Following closely was the Mammut variety, which had a sucrose content of 18.04 %, a purity level of 88.67 %, extractable sugar of 16.07 %, and a sugar yield of 4.31 tons/fed. Nevertheless, the root yield for the Mammut variety was noted at 26.73 tons/fed, likely as a result of the AE treatment's stimulating effects on this variety. Moreover, The Panther variety surpassed the Dina variety for root weight, achieving an average of 973.05 g/plant, resulting in a root yield of 29.19 tons per fed. However, it showed reduced performance relative to the Dina and Mammut varieties regarding sugar yield, producing 4.09 tons/fed. This indicates that the differences observed among the cultivars are largely due to variations in their genetic makeup and their adaptability to the environmental conditions experienced during their growth. In comparison, both variety LP17B4011 and variety Kn-627 showed the least measured parameters across the two seasons. Specifically, LP17B4011 showed the lowest average percentages of sucrose (14.80 %), purity (78.18 %), extractable sugar (11.60 %), and sugar yield (3.31). Additionally, it had the highest average concentrations of α-amino nitrogen (1.09 mmol/100 g), potassium (6.66 mmol/100 g), sodium (1.52 mmol/100 g), and impurity levels (3.20). The increased levels of impurities suggest a lower quality of the crop. Both the LP17B4011 and Kn-627 varieties exhibited reduced adaptability under the experimental conditions when compared with the other varieties examined. The Kn-627 variety recorded the lowest root weight at 824.02 g and a root yield of 24.72 tons / fed, but it achieved a sugar yield of 3.65 tons / fed, which was greater than that of the LP17B4011 variety. The treatments had a significant impact on the performance metrics, with Dina, Mammut and Panther demonstrating better adaptability under certain conditions. The observed differences may be attributed to the genotypic variation present among these sugar beet varieties. The application dosage of AE significantly influences the performance of different plant varieties, in conjunction with agronomic and environmental aspects (Rajput *et al.*, 2020). The AE functions as a biostimulant, enhancing plant growth and contributing to increased production.

Influence of the interaction between treatments and sugar beet varieties on root and sugar yields (ton/fed)

The interaction between various varieties and treatments had a significant influence on all studied sugar beet traits (Table 1). The quality of roots is a key indicator of production efficiency and effective sugar beet cultivation, which is significantly affected by the composition of the sugar beet root (Hoffmann, 2010). As shown in Table (2), the interactions resulting in the highest average values for sucrose content (18.70 %), purity (90.0 %), and extractable sugar (16.64 %) were T1 × Dina, T4 × Mammut, and T4 × Dina, respectively. In contrast, the interaction T4 × LP17B4011 showed the lowest sucrose content at 13.60 %. The interaction T5 × LP17B4011 produced the lowest average results for purity (74.47 %) and extractable sugar (10.24 %). Determination of sugar loss indicates that the highest values were found in the interactions of LP17B4011 with T5 and T2, recording 3.51 % and 3.33 %, respectively. Evaluating impurities is crucial for determining root quality indicators related to sugar loss in molasses, thereby minimizing the chances of sucrose crystallization. As indicated in Table (2), the interaction of the T3 treatment with all tested varieties resulted in significant improvements in both root and sugar yield. The interaction between T3 × Mammut achieved the highest average root yield of 35.81 tons/fed, which was statistically similar to the average root yield of 35.79 tons/fed observed with the T3 × Panther interaction. This was followed by the T1 × Panther interaction, which produced an average root yield of 35.44 tons/fed, and then the interaction of T3 × Dina, which yielded 35.28 tons/fed. The Kn-627 (V1) and Mammut (V5) varieties exhibited a positive response to the T3 treatment, showing a significant increase in root yield when compared to the other treatments applied to those varieties. The interactions of T3 × Kn-627 (V1) and T3 × Mammut (V5) exhibited increases of 28.55 % and 28.44 %, in root yield respectively, when compared to the control with these varieties interactions. Furthermore, the interaction of T3 × Dina (V2) and T3 × LP17B4011 (V4) showed increases of 22.56 % and 24.24 %, respectively, when compared to the interactions control treatment with those varieties. On the other side, the interaction between T5 with various varieties recorded the lowest recorded root yield values. The lowest average root yield recorded was 18.38 tons/fed for the interaction between T5 × Mammut. Following that, T5 × Kn-627 yielded 20.94 tons/fed, with T5 × Mammut producing 21.34 tons/fed, and T5 × LP17B4011 resulting in 22.10 tons/fed. Regarding sugar yield, the T3 × Mammut interaction recorded the highest average sugar yield (5.80 tons/fed), followed by the T3 × Dina interaction (5.53 tons/fed), which was statistically similar to T1 × Dina (5.38 tons/fed), and then T3 × Panther (5. ton/fed). Meanwhile, the T5 × LP17B4011 interaction gave the lowest average sugar yield of 2.26 tons /fed, followed by the T2 × LP17B4011 interaction which yielded 2.73 tons/ fed, and this result was statistically similar to the T4× LP17B4011 interaction, which achieved a sugar yield of 2.89 tons per fed. Enan *et al.* (2016) showed that the use of 3.5 g/l of algal extract resulted in enhanced yields of roots, tops, and sugar, which were recorded at 3.05 tons/fed, 1.57 tons/fed, and 0.67 tons/fed, respectively. The cultivars recognized for their stability are those that demonstrate minimal interaction between environmental factors and genotype and exhibit broad adaptability across all environmental conditions. *A. nodosum* seaweed have plant growth-stimulating activity, leading to its application as an organic fertilizer in agricultural practices (Koh, 2016). An application of 1 L/ha−1 of an *A. nodosum* extract positively impacted the leaf area index, normalized difference vegetation index, photochemical reflectance index, root, and sugar yield (Pačuta *et al.*, 2023). This natural alternative to chemical fertilizers can help mitigate environmental pollution and health issues associated with the use of synthetic fertilizers.

Correlation analysis between sugar beet traits

Figure (4) displays a Pearson correlation matrix coefficient highlighting relationships among physiological, quality, and productivity traits in sugar beet varieties under different treatments. Chlorophyll content demonstrated a moderate positive correlation (r ≈ 0.60 - 0.70) with growth traits such as leaf area index and root yield. Also, chlorophyll content significantly impacted technological traits, including sucrose content (r ≈ 0.42) and purity (r ≈ 32), which have an influence sugar productivity. This highlights its importance in photosynthetic efficiency and its contribution to increased biomass production and overall yield. At the same time, impurities (sugar loss) including sodium, and potassium, concurrently showed a negative effect on the quality characteristics of sugar (Rašovský *et al.*, 2022). Sugar loss exhibited a significant negative correlation with sugar quality traits such as sucrose content (r ≈ - 0.73 to - 0.99), extractable sugar (r ≈ - 0.89 to - 0.99) and sugar yield (r ≈ - 0.55 to - 0.88). Additionally, a higher root yield may also be correlated with increased levels of these impurities. Nevertheless, treatment, T3 exhibited a negative correlation (r ≈ - 0.137) between impurities and root yield suggesting a trade-off between biomass production and sugar quality under specific conditions.

Table 2. Average values of root yield, quality traits and sugar yield as affected by the interaction between treatments and sugar beet varieties

Interaction	Root yield (ton/fed)	Sucrose%	Purity%	Sugar loss%	Extractable sugar%	Sugar yield (ton/fed)
Control× Kn-627	24.17^{o}	16.5^{ij}	85.65^{hijk}	2.37^{efg}	14.13^{ghi}	3.41^{i}
T1× Kn-627	26.28^{k}	17.62^{defg}	87.9^{efg}	2.13^{hijkl}	15.49^{cde}	4.07^{f}
T2 ×Kn-627	22.58^{r}	17.14^{fghi}	86.62^{ghij}	2.29^{fgh}	14.85^{ef}	3.35^{i}
T3× Kn-627	31.07^{f}	17.16^{fghi}	86.72^{ghij}	2.28^{fghij}	14.88^{ef}	4.62^{d}
T4× Kn-627	23.3^{p}	17.04^{ghij}	86.43^{hijk}	2.3^{fgh}	14.74^{fg}	3.43^{hi}
T5×Kn-627	20.94^{u}	16.7^{hij}	86.35^{hijk}	2.28^{fghi}	14.42^{fgh}	3.02^{j}
Control× Dina	28.44^{h}	18.5^{ab}	88.6^{bcde}	2.11^{jkl}	16.39^{a}	4.66^{d}
T1×Dina	32.55^{d}	18.7^{a}	88.34^{de}	2.18h^{ijk}	16.52^{a}	5.38^{b}
T2×Dina	25.93^{l}	18.5^{ab}	89.3^{abcde}	1.1^{lm}	16.5^{a}	4.28^{e}
T3× Dina	35.28^{b}	17.74^{cdef}	88.28^{de}	2.08^{kl}	15.66^{bcd}	5.53^{b}
T4× Dina	28.05^{i}	18.62^{a}	89.39^{abcd}	1.98^{lmn}	16.64^{a}	4.67^{d}
T5×Dina	24.28^{o}	17.55^{defg}	88.14^{def}	2.08^{kl}	15.47^{cde}	3.76^{g}
Con × Panther	33.89^{c}	15.73^{l}	84.04^{l}	2.51^{e}	13.22^{j}	4.48^{d}
T1× Panther	35.44^{b}	16.42^{jk}	85.43^{jk}	2.39^{ef}	14.03^{hi}	4.97^{c}
T2× Panther	24.1^{o}	17.24^{efgh}	86.78^{ghi}	2.28^{fghi}	14.96^{ef}	3.61^{gh}
T3× Panther	35.79^{a}	16.82^{hij}	85.29^{kl}	2.47^{e}	14.35^{fgh}	5.13^{c}
T4× Panther	24.59^{n}	15.82^{kl}	86.01^{hijk}	2.21^{ghijk}	13.61^{ij}	3.35^{i}
T5× Panther	21.34^{t}	16.46^{jk}	85.47^{ijk}	2.39^{ef}	14.07^{ghi}	3.00^{j}
Control × LP17B4011	27.71^{j}	15.22^{l}	78.89^{o}	3.21^{bc}	12.01^{k}	3.33^{i}
T1× LP17B4011	32.18^{e}	15.53^{l}	80.34^{n}	3.05^{cd}	12.48^{k}	4.02^{f}
T2× LP17B4011	25.1^{m}	14.2^{m}	76.54^{p}	3.33^{b}	10.87^{l}	2.73^{k}
T3× LP17B4011	33.96^{c}	16.52^{ij}	82.2^{m}	2.94^{d}	13.58^{ij}	4.61^{d}
T4× LP17B4011	27.71^{j}	13.6^{m}	76.67^{p}	3.16^{bc}	10.44 ^{l}	2.89^{jk}
T5× LP17B4011	22.1^{s}	13.74^{m}	74.47^{q}	3.51^{a}	10.24 ^{l}	2.26 ^{l}
Control ×Mammut	27.88^{ij}	18.06^{abcd}	89.78^{ab}	1.84^{mn}	16.22^{ab}	4.52^{d}
T1×Mammut	30.44^{g}	18.48^{ab}	89.7^{abc}	1.9^{mn}	16.58^{a}	5.05^{c}
T2×Mammut	22.87^{q}	17.28^{efgh}	86.85^{fgh}	2.27^{fghij}	15.01^{def}	3.43^{hi}
T3×Mammut	35.81^{a}	18.32^{abc}	88.43^{cde}	2.12^{ijkl}	16.2^{ab}	5.8^{a}
T4×Mammut	25.01^{m}	18.2^{abcd}	90.01^{a}	1.82^{n}	16.38^{a}	4.1^{ef}
T5×Mammut	18.38v	17.9^{bcde}	89.68^{abc}	1.85^{mn}	16.05^{abc}	2.95^{j}

*Means in a column that are not sharing the same letter are significantly different at $p \leq 0.05$

A highly significant positive correlation (r ≈ 0.99) was observed between sucrose and extractable sugar traits indicating a direct impact on the technological quality of sugar beet roots and the efficiency of sugar recovery. Furthermore, a positive correlation (r ≈ 0.84) was found between root yield and sugar indicating that an increase in root yield is directly associated with enhanced sugar yields. The results agree with those of Abdelwahab *et al.* (2022), who found a complex relationship between the physiological and biochemical characteristics of sugar beet plants. They found that an increase in the leaf area index increases photosynthesis, which in turn increases the cumulative sucrose content and sugar yields. Rašovský *et al.* (2022) demonstrated that there were significant relationships between root yield and white sugar content and polarized sugar production, with correlation values of r = 0.8346 and 0.8046, respectively.

Principal Component Analysis

Principal component analysis (PCA) helps identify the connections among the variables and provides an in-depth analysis of a multivariate dataset, facilitating breeding programs focused on enhancing both yield and crop quality. The complete variation has been extracted from 12 principal component axes along with eigenvalues, variability percentages (%), and cumulative percentages (%), which account for 100 % of the total variation (Table 3). The results showed that the three components (PCs) with eigenvalues ≥ 1 accounted for 86.82 % of the total variation. The variances explained for PC1 (Dim1), PC2 (Dim2), and PC3 accounted for 44.4%, 31.02 %, and 11.44 %, respectively of the total variation in the data (Table 3).

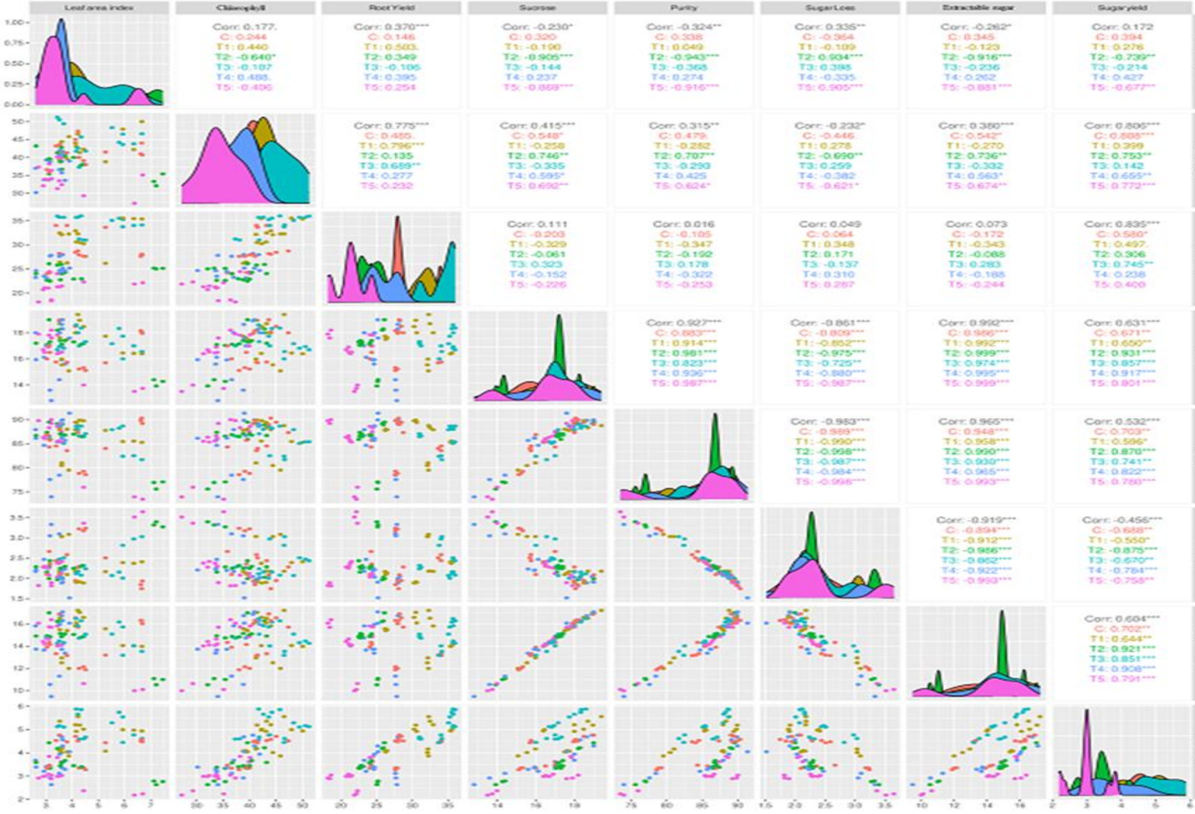

Fig. 4. Correlation matrix illustrating the relationships between among sugar beet production traits treated to different Acadian treatments compared to control conditions. The correlations are represented as Pearson correlation coefficients, with significance levels indicated as follows: ** $p < 0.01$, and *** $p < 0.001$, among sugar beet production traits

Table 3. Eigenvalues, variability and cumulative values

PC	Eigenvalue	Variance %	Cumulative %
PC1	6.655	44.367	44.37
PC2	4.652	31.015	75.38
PC3	1.716	11.438	86.82
PC4	0.660	4.403	91.22
PC5	0.395	2.632	93.85
PC6	0.283	1.884	95.74
PC7	0.251	1.673	97.41
PC8	0.171	1.140	98.55
PC9	0.133	0.887	99.44
PC10	0.078	0.521	99.96
PC11	0.005	0.031	99.99
PC12	0.002	0.011	100

The components beyond the third exhibit a negligible contribution, indicating that the initial three PCs account for the majority of the significant variation, thereby demonstrating their adequacy for purposes of dimensionality reduction and data analysis.

As can be seen from Table (4), the initial principal component (PC1) accounted for 44.4% of the overall variation and showed a positive correlation with leaf area index, α-amino nitrogen, potassium, sodium, and impurity, while exhibiting a negative correlation with other traits. This indicates that the traits with positive correlations tend to change together, although in contrast to the other traits (Figure 5, A). Furthermore, the highest coefficients in PC1 were recorded for extractable sugar (0.375), purity (0.371), sucrose (0.367), impurity (0.359), sodium (0.345) and potassium (0.335). The second principal component (PC2) represented 31.02 % of the total variation and showed a positive relationship with sucrose, purity, and extractable sugar. The trait vectors with the highest values in PC2 included root weight and yield (0.42), along with chlorophyll (0.310). In the third principal component (PC3), leaf weight had the highest coefficient of variation at 0.505, followed closely by leaf area index at 0.473, as shown in Table (4).

Table 4. Principle component analysis results of the studied physiological, and quality traits as well as productivity of sugar beet varieties

Variable	PC1	PC2	PC3
Leaves weight	-0.069	-0.302	-0.505
Dry Leaves weight	-0.137	-0.294	-0.450
Leaf area index	0.068	-0.297	-0.473
Root weight	-0.096	-0.420	0.198
Dry root weight	-0.022	-0.298	0.319
Chlorophyll	-0.197	-0.310	0.218
Sucrose	-0.367	0.049	0.031
Purity	-0.371	0.119	0.010
α.amino nitrogen	0.253	-0.175	0.252
Potassium	0.335	-0.158	0.026
Sodium	0.345	-0.090	0.011
Impurity	0.359	-0.148	0.033
Extractable sugar	-0.375	0.076	0.016
Root yield	-0.096	-0.420	0.197
Sugar yield	-0.280	-0.297	0.156

In the biplot presented in Figure (5 A), a positive correlation is observed between sucrose, purity, and extractable sugar, as well as between chlorophyll content and leaf weight, as indicated by their alignment in similar directions on the PCA biplot. On the other hand, the levels of impurities, specifically α-amino nitrogen, sodium (Na), and potassium (K), were negatively associated with sugar quality traits. The traits evaluated, such as sucrose content, purity, and extractable sugar, strongly influence the clustering observed in Figure (5 A), as indicated by the proximity of high-performing varieties to these traits in PCA analysis. The variety LP17B4011 is notably characterized by high levels of impurities, including potassium, sodium, and α-amino nitrogen, which are closely linked to its cluster. In comparison, the varieties Dina and Panther showed stronger connections to traits like sugar yield and sucrose content, as indicated by their closeness to these variables. Furthermore, Figure (5 B) presents a PCA biplot that highlights the impact of different treatments (Control, T1–T5) on the five sugar beet varieties (V1–V5) performance. In alignment with the previous analysis, Dim1 and Dim2 account for 44.4% and 31% of the variance, respectively. Treatments T1 and T3 optimized quality traits, especially for the varieties Dina (V2) and Panther (V3). Varieties that showed significant reactions to T3 (such as Mammut and Dina) are grouped closely together, highlighting the effect of the treatment on their clustering. The clusters for Mammut (V5), particularly in foliar treatments T4 and T5, were notably distinct from one another, indicating a unique response in comparison to other varieties. On the other hand, Panther and LP17B4011 exhibit a greater level of overlap, suggesting they have similar performances or responses to the treatments applied. The biplots underscore the effectiveness of combining Acadian extract with reduced urea levels, promoting sustainable agricultural practices. Varietal selection and treatment optimization can significantly enhance sugar beet productivity and quality.

Phenotypic clustering of sugar beet varieties based on physiological, and quality traits

The phylogenetic tree constructed from phenotypic traits delineates clear clustering patterns, emphasizing the genetic and phenotypic distinctions among the varieties. The dendrogram presented in Figure (6) effectively categorizes the five sugar beet varieties (Kn-627, Dina, Panther, LP17B4011 and Mammut) based on their phenotypic characteristics across six different treatments. The distances between branches illustrate the degree of phenotypic similarity or dissimilarity among the varieties, with longer branches signifying greater differences. Dina and Mammut varieties demonstrated a closer phenotypic relationship, indicative of their comparable superior performance in yield and sugar-related traits under treatments.

The unique clustering observed in the Mammut variety can be attributed to its specific traits, particularly the high root and sugar yields recorded under treatment T3**.**

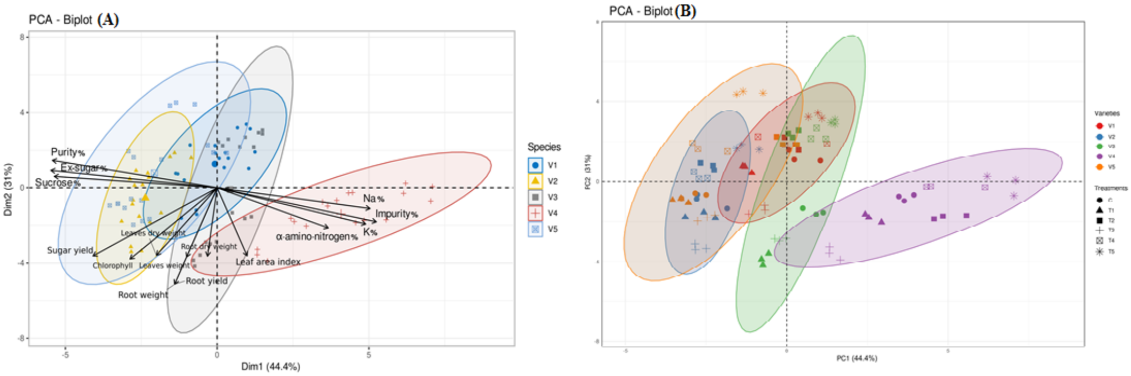

Fig. 5. Principal Component Analysis (PCA) biplot illustrates the distribution of five sugar beet varieties (V1: Kn-627, V2: Dina, V3: Panther, V4: LP17B4011 and V5: Mammut) based on their Physiological and quality traits (A), and treatments (B) in each of the first two principal components PC1 (Dim 1) and PC2

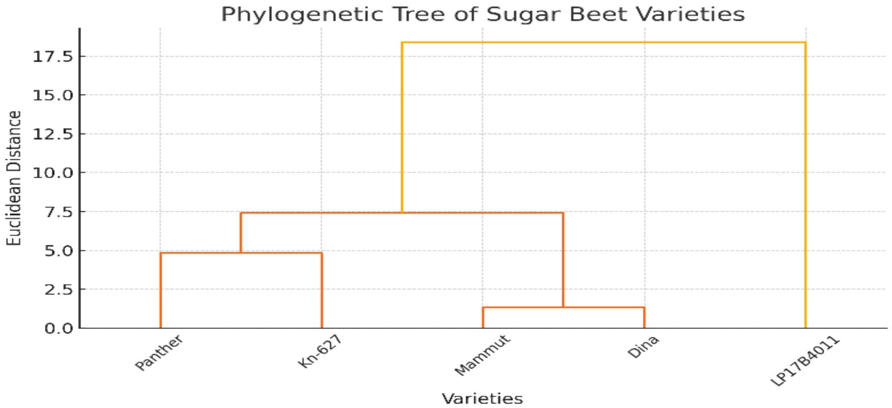

Fig. 6. The dendrogram of the hierarchical clustering of the five sugar beet varieties based on their phenotypic traits

The position of LP17B4011 in the cluster corresponds to its relatively lower performance, marked by higher levels of impurities (potassium, sodium) and reduced sucrose and purity levels, as indicated in the PCA biplots. Kn-627 demonstrated a moderate level of dissimilarity because its root and sugar yields were lower, but this did not show as clear a contrast as the LP17B4011 variety. Furthermore, the phylogenetic tree aligns well with the findings from the PCA analysis, suggesting that characteristics such as sucrose, purity, and extractable sugar effectively differentiate high-performing varieties like Dina and Mammut from those with lower performance, represented by the LP17B4011 variety.

CONCLUSION

Based on the aforementioned results, it can be concluded that the foliar application of AE combined with 75% of the recommended urea dosage achieved significant enhancements in quality characteristics and productivity of sugar beet when compared to the control. Dina and Mammut varieties demonstrated superior adaptability and response to AE treatments, particularly AE 2 ml/l + 75% urea. In contrast, LP17B4011 exhibited the lowest performance metrics, marked by high impurity levels and reduced extractable sugar, indicating the effects of genotype-treatment interactions. The implementation of advanced statistical techniques, such as Principal Component Analysis (PCA), underscored the traits that contributed to variations in yield and quality, accounting for 86.82 % of the overall variability. The phylogenetic tree created from phenotypic traits illustrates distinct clustering patterns, highlighting the phenotypic differences among the varieties. The Acadian extract can be utilized in sustainable agricultural practices by reducing chemical fertilizer dependency while maintaining high productivity and quality in sugar beet cultivation, as well as having the potential to enhance the adaptability of certain crop varieties with varying environmental conditions.

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الملخص العربي

تأثير مستخلص أسكوفيلوم نودوسوم (أكاديان) كمدخلات عضوية طبيعية على أداء بعض أصناف بنجر السكر

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تهدف هذه الدراسة إلى تقييم تأثير مستخلص أسكوفيلوم نودوسوم (أكاديان) كمحفز عضوى حيوي طبيعي صديق للبيئة على أداء خمسة أصناف من محصول بنجر السكر تحت تركيزات منخفضة من الأسمدة النيتروجينية. أجريت التجارب الحقلية في محطة بحوث الصبحية (خط عرض ٣١ درجة و١٢ شمالاً)، مركز البحوث الزراعية، الإسكندرية، مصر، بإستخدام تصميم القطع المنشقة مرتين بتوزيع القطاعات الكاملة العشوائية خلال موسم النمو عام ٢٠٢١/٢٠٢٢-٢٠٢٢/٢٠٢٣. تم الرش الورقى بمستخلص أكاديان (AE) بتركيزين (١ مل/لتر و٢ مل/لتر)، إلى جانب معدلين من سماد اليوريا (٥٠٪ و٧٥٪ من التركيزات الموصى بها)، بالإضافة إلى تركيز ١مل مستخلص AE /لتر بدون يوريا، مع معاملة١٠٠%بسماد اليوريا (الكنترول). أظهرت النتائج أن الرش الورقى ب AE بمعدل ٢ مل/لتر مع ٧٥% يوريا أدى إلى تحسين معنوى في الصفات الفسيولوجية والتكنولوجية وزيادة فى إنتاجية محصول الجذر ومحصول السكر بنسبة ٢٥,٩٧% و٢٠,٩٧% على التوالي، مقارنة بالكنترول. كما أوضحت النتائج أن الصنف دينا سجل أعلى قيم فى حاصل السكر (٤,٧١ طن/فدان)، في حين تفوق الصنف بانثر على الصنف دينا في كمية حاصل الجذور (٢٩,١٩ طن/فدان). كما تبين من معامل التلازم وجود إرتباط سلبي معنوى (r ≈ - 0.88) بين حاصل السكر ونسبة الشوائب فى الجذور، التى ارتفعت نسبتها فى الصنف LP17B4011. وكما سجل التفاعل بين الصنف ماموت والمعاملة بمستخلص أكاديان ٢مل/لتر + ٧٥% يوريا أعلى قيم فى إنتاجية حاصل الجذور (٣٥,٨١ طن/فدان) وحاصل السكر (٥,٨٠ طن/فدان). تتوافق شجرة القرابة بشكل وثيق مع نتائج تحليل المكونات الرئيسية والتى بينت أن الصنف دينا والصنف ماموت لهم قدرة متفوقة على التكيف تحت ظروف التجربة، يليهما الصنف Kn-627. نستنتج من ذلك إمكانية إستخدام مستخلص أكاديان فى إستدامة وتحسين إنتاجية بنجر السكر وتعزيز قدرة الأصناف على التكيف مع التغيرات في الظروف البيئية.