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Enhancement of Sugar Beet (*Beta vulgaris* L) Growth, Sugar Yield productivity by Arbuscular Mycorrhiza and Environment Friendly Growth Stimulant Materials

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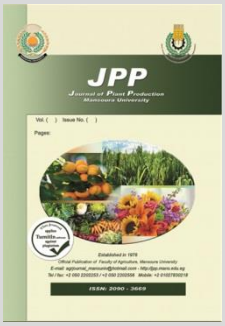

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ABSTRACT

Increasing sugar beet production in the face of climate change using environmentally friendly materials is a challenge for scientists in the next coming years. Two field experiments were carried out at the Research Farm of Sakha Agricultural Research Station, Kafr El-Sheikh Governorate, Egypt during 2022/2023 and 2023/2024 seasons to study the effects of Arbuscular mycorrhizal as a soil amendment (without, 200 and 400 spore/g soil) and spraying canopies with four nutrition (without, Salicylic acid, Chitosan and Alginic acid). A Randomized Complete Block Design in a split-plot arrangement with three replications. The results of revealed application of arbuscular mycorrhizal fungi (AMF) significantly improved all plant growth traits investigated as well as the yields of both sugar beet roots and sugar, especially for plants that received the higher application rate of AMF at a rate of 400 spore/g soil Such increases ranged from 1.2 up to 2-fold higher than the control. The application of AMF, especially at its highest rate, significantly improved sugar beet root quality during the two seasons of study, specifically the percentage of the extracted sugar, sucrose %, alpha amino (2nd season only), in addition to the percentages of K and Na (1st season only) in roots. The AMF and foliar spraying significantly enhanced various physiological and metabolic traits in sugar beet during the two seasons. Our study concludes that the application of AMF and foliar spraying proven to increase all sugar beet parameters especially at its highest rate (400 spore/g soil), with preserving the environment and achieving sustainability.

Keywords: Arbuscular mycorrhizae; Growth promoting stimulates; Sugar beet; Root yield; Sugar quality

INTRODUCTION

Sugar beet is one of the most important sugar crops not only in Egypt but worldwide. Nowadays, sugar cane (*Saccharum officinarum* L.) accounts for the majority of the world's sugar output, while sugar beets (*Beta vulgaris* L. subsp. *vulgaris*) account for only 20%. According to the Egyptian Society Sugar Technologies and Sugar Crops Research Institute (2014), sugar beet has emerged as the primary source of sugar production. Because of its suitability to grow in temperate climate zones (such as Central and Southern Europe, the United States, etc.), sugar beet plays a vital role in the agricultural sector of 52 countries.

Cane sugar is generally less expensive than beet sugar since it is a perennial crop and its bagasse provides free energy for processing, whereas a 10,000-ton-per-day beet processing facility requires at least 15–20 Mw/h of power, which is fully produced from non-renewable energy sources (Glover *et al*., 2007; Jordan *et al*., 2007). Agriculture must strike the correct balance between present and future output levels to meet all sustainability requirements without endangering long-term potential. Therefore, to prevent discharges into the atmosphere and groundwater, fertilizers need to be used more efficiently. It is unquestionably necessary to improve the utilization of both new and existing genetic sources for exploitable variation governing tolerance and/or resistance to biotic and abiotic stressors. Biotechnology and molecular genetics developments are anticipated to play a major role in achieving this goal. Strong monoculture is frequently linked to annual crops, which is an extremely unnatural and expensive practice that seriously impairs natural ecosystems' capacity to offer farmers, the general public, and the environment all the services they require (Tilman *et al*., 2002). Actually, this capacity is correlated with the ecosystem's biodiversity. Proper crop rotations can help reduce soil-borne illnesses, avoid or delay weed resistance to herbicides, and mitigate the negative consequences of monoculture (Martindale, 2013).

Arbuscular Mycorrhizae (AM) are an important component of the ecosystem that demonstrates a serious concern for plant nutrition by giving plants access to nutrients derived from the soil, Naturally, there is a close relationship between AM and plant roots. In both biotic and abiotic stress circumstances, such as drought, severe temperatures, heavy metals, salinity, pathogens, and metal pollution, AM contributes to improvements in soil water regime and nutrient uptake and plays a big role in sustainability. It has been found that 80% of terrestrial plant species worldwide have this type of symbiotic connection between their roots and fungal hyphae. In plants AM association, the host plant's root is

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benefited by better uptake of water and nutrients from the soil surface, while fungal hyphae profits by getting sugar from the host plant's root. AM plays two roles in controlling the soil's zinc nutrition. For instance, AMF application increases zinc uptake below a certain concentration, whereas it restricts zinc translocation to plant shoots over the critical level. The synergistic relationship between zinc and AMF is critical for long-term quality and yield. It has been noted that applying AMF increases the amount of zinc in the grain in the field. Since zinc is necessary for the building of pollen tubes, AMF aids in the growth, development, and reproduction of plants. The primary source of P in traditional driven agriculture is the naturally occurring fertility of the soil, with sporadic manure supplies for the crops. However, overexploitation of the P because of agricultural modernity leads to low crop yields and farm profitability.

Chitosan is the primary constituent of arthropod exoskeletons and the second most renewable carbon source, chitosan is thought to be a safe and inexpensive substance derived from chitin (Kurita, 2006). Chitosan enhances plant drought tolerance and elicits a variety of defense responses, according to multiple reports. By accumulating osmolytes that buffer against stress, chitosan increased drought resistance. Chitosan contributes to the clearance of ROS by stimulating the hydrogen peroxide signaling pathways and antioxidant enzymes (El-Beltagi et al., 2022). The exogenous addition of chitosan significantly raises phenolic and flavonoid molecules, which may dismantle the hydrogen peroxide and free radical coalition while simultaneously activating the antioxidants (Salimgandomi and Shabrangi, 2016). Additionally, by improving the uptake of water and minerals as well as the accumulation of photosynthetic pigments, chitosan promotes plant development (Bakhoum et al., 2020).

A wide variety of bioactive substances found in alginic acid directly and indirectly promote plant development and defense mechanisms against infections (Khan *et al*., 2009). According to certain research, alginic acid bio stimulants can outperform commercial fertilizers in terms of plant growth characteristics (Kapoore *et al*., 2021). Responses from plants growing in soil treated with seaweed extracts, whether sprayed on the foliage or administered directly to the soil, vary greatly. These compounds have the ability to promote soil microflora, retain soil water, and aid in remediation when applied to the soil. Alginic acid can improve the balance of phytohormones and help plants that are lacking in certain nutrients (Kapoore *et al*., 2021).

The aim of this study is to evaluate the beneficial effects of the inoculation of Arbuscular Mycorrhiza and foliar spraying of chitosan and alginic acid on growth, physiological traits and root yield productivity and its relations to sustainability of sugar beet (*Beta vulgaris* L.).

MATERIALS AND METHODS

Two field experiments were carried out at the Research Farm of Sakha Agricultural Research Station (latitude of 31 °10 N and longitude 30º 93 E, at an elevation of 14 m above sea level), Kafr El-Sheikh Governorate, Egypt in 2022/2023 and 2023/2024 seasons to study the effects of Arbuscular Mycorrhizal as a soil amendment and foliar application as bio-stimulating growth materials on growth, yield, and quality of sugar beet (*Beta vulgaris* L.)*,* This work included twelve treatments representing the combinations of three soil application levels of Mycorrhizal (without, 200 and 400 spore/g soil) and spraying canopies with four bio-stimulating growth materials (without, Salicylic acid, Chitosan and Alginic acid), were applied as foliar application separately at the rate of 100 mg L^{-1} after 50, 65 and 80 days from sowing. A Randomized Complete Block Design (RCBD) in a split-plot arrangement with three replications was used, where levels of Mycorrhizal were distributed in the main plots, while spraying of bio-stimulating materials were allocated at random in the sub-plots. The sub-plot area was 20 m^2, including 8 ridges of 5 m in length and 50 cm in width, with 20 cm between hills. The Mono-germ sugar beet variety viz "JAMPOL" sown on the 2nd week of September during both seasons, while harvesting beets took place at the age of 210 days after sowing in both seasons. Plants were thinned at the 4-leaf stage to ensure one plant per hill. Fertilizer application of nitrogen was applied in the form of urea (46.5% N) at the rate of 80 kg N/fed in two equal doses: the 1st after thinning and one month later. Phosphorus fertilizer was added at 200 kg/fed in the form of calcium super phosphate (15 % P_2O_5) at seed bed preparation. Potassium fertilizer was added in the form of potassium sulphate (48% K_2O) at the rate of 50 kg/fed in two equal doses: with 1st dose of nitrogen fertilizer and just before canopy closer (75 days). The AM inoculum was made up of *Glomus mosseae*-NRC31 and Glomus fasciculataNRC15, which were initially isolated from Egyptian soils; it was allowed to grow on sterilized peat-vermiculite-perlite mixtures and added at 0, 200, and 400 spore/g to the soil pits immediately before planting of Sugar beet and it was repeated twice with second and third irrigation for each plot. Bio-stimulating growth materials treatment were obtained from Cairo Chemicals Company.

Soil samples were collected from the experimental site at 0 -30 cm depth to determine their properties as shown in Table 1.

Table 1. Physical and chemical properties of the experimental sites of the two seasons.

Properties	2022/2023	2023/2024
Sand %	22.77	20.89
Silt %	23.74	21.26
Clay %	53.49	57.85
Texture class	Clay	Clay
pH (1:2.5)	7.30	7.00
EC (dS m^{-1})	2.18	2.00
Organic matter %	1.30	2.10
Available N ppm	17.00	16.00
Available P ppm	9.30	9.20
Available K ppm	275.74	252.54

Growth and yield measurements

At harvest (210 days from sowing), the three guarded rows of each subplot harvested, cleaned, topped, and weighed, and the following characteristics were determined in both seasons: Root yield (Mg/ha): was calculated based on weight experimental plot, Sugar yield (Ma/ha): was determined according to the method described by McGinnus (1971), Leaf area index according to (Watson, 1952) as well as Specific leaf weight = (Lw /LA) g /cm^2.

Root quality and Chemical analysis

Quality traits i.e. Sucrose percentage was determined according to Le-Docte (1927), Extractable white sugar percentage (EXT %) was determined according to Reinefeld et al., (1974), Sugar loss to molasses percentage (SLM %), was determined as described by Carruthers et al., (1962).

Impurities traits i.e. Potassium and sodium concentrations (meq/100 g beet) in roots were determined using "flame photometer" according to Brown and Lilliand (1964), Alpha amino nitrogen concentration determined using Hydrogenation method according to Pergel (1945) and

Crud protein (mg/g) =total nitrogen (mg/g) x 6.25 as mentioned in A.O.A.C. (1990).

Photosynthetic pigments i.e. Total Chlorophyll and carotenoids were calorimetrically determined in the leaves of sugar beet plants at 120 days after thinning according to methods described by Wettstein (1957) and calculated as mg/g fresh weight. Also, Free proline in leaf tissue was estimated or determined according to the protocol of Bates *et al.* (1973), Total amino acids were determined using ninhydrin reagent as described by Rosen (1957) and Total phenolic compounds were determined using UV/Vis. Spectrophotometer, Jenway England at wavelength 750 nm as described by Singleton *et al*., (1999).

Statistical analysis:

The collected data was statistically analyzed according to Gomez and Gomez (1984) by using the SAS computer software package. Means were compared using Duncan's Multiple Range (DMR) test described by Waller and Duncan (1969).

RESULTS AND DISCUSSION

Plant growth parameters and sugar beet productivity

Application of arbuscular mycorrhizal fungi (AMF) as indicated in Figs. 1 and 2 significantly improved all investigated plant growth parameters (leaf area index LAI, specific leaf weight, leaf fresh weight, root fresh weight per plant) as well as the yields of both sugar beet roots and sugar, especially for plants that received the higher application rate of AMF at a rate of 400 spore /g soil. Such increases ranged from 1.2 up to 2-fold higher than the control.

These enhancements of sugar beet growth measurements can be attributed to the improvements in nutrient uptake and hormonal stimulation upon AMF inoculation (Wahab *et al*., 2023; Ahmed *et al*., 2025).

Similarly, application of plant growth stimulus substances induced the above-mentioned growth parameters as well as crop productivity versus the control ones. The positive impacts of alginic acid were likely due to its high content of bioactive compounds, including polysaccharides and trace elements, which stimulate plant metabolic processes, nutrient translocation, and cell division (Michalak and Chojnacka, 2015; Stirk *et al*., 2020; Deolu-Ajayi *et al*., 2022). Also, it increased resistance to pathogens and drought (Zhang *et al*., 2020). Similarly, chitosan acts as a biopolymer elicitor that increases nutrient uptake, cell division and elongation, enzymatic activation and synthesis of protein (Chakraborty *et al*., 2020), while salicylic acid contributes to plant growth through its role in stress signaling and modulation of stomatal conductance and photosynthesis (Zhong *et al*., 2021). Overall, the highest increases were for Alginic Acid > chitosan > salicylic acid > control.

The interactions between these two factors were significant on the plant growth parameters and sugar beet productivity studied. Overall, the highest increases in these parameters were recorded with AMF 400, especially with Alginic, then Chitosan, then with Salicylic acid applications, as shown in Table 2.

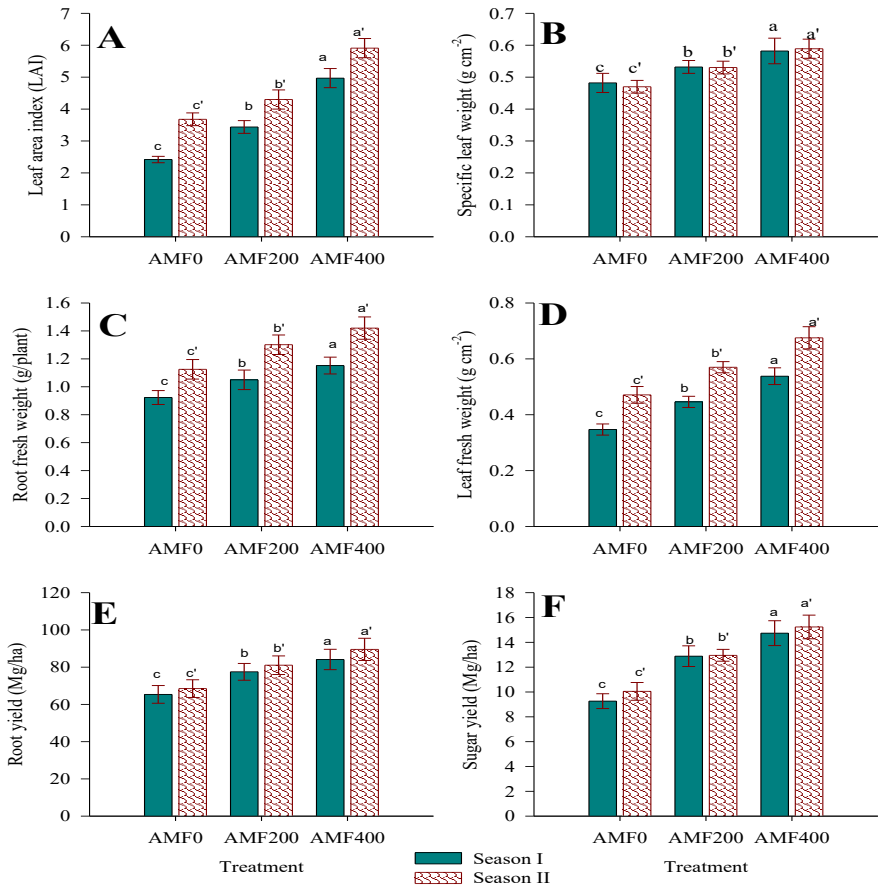

Fig 1. Effect of Arbuscular Mycorrhizal fungi (AMF) on leaf area index (LAI), specific leaf weight, leaf fresh weight, root fresh weight, root and sugar yields within 2022/2023 and 2023/2024 winter seasons. Differences between means were tested using Duncan's multiple range test at P ≤ 0.05.

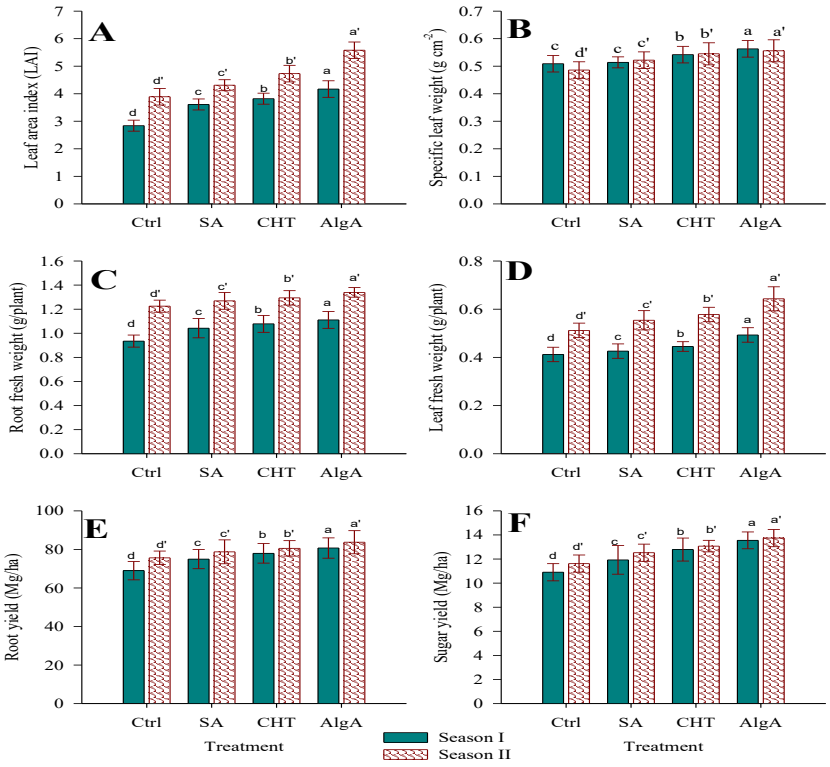

Fig 2. Effect of growth promoting stimulates (GPS) on leaf area index (LAI), specific leaf weight, leaf fresh weight, root fresh weight, root and sugar yields within 2022/2023 and 2023/2024 winter seasons. Differences between means were tested using Duncan's multiple range test at P ≤ 0.05. *Note: Control – Ctrl, Salicylic Acid – SA, Chitosan – CHT, Alginic Acid –AlgA*

Table 2. Interactions between AMF doses and plant growth promoting stimulates on leaf area index (LAI), specific leaf weight, leaf fresh weight, root fresh weight, root and sugar yields within 2022/2023 and 2023/2024 winter seasons.

	Season I				Season II			
	Ctrl	**SA**	**CHT**	**AlgA**	**Ctrl**	**SA**	**CHT**	**AlgA**
				Leaf Area Index (LAI)				
AMF0	1.363 g	2.637 f	2.717 f	2.977 f	2.943 g	3.693 f	4.003 e	4.080 e
AMF200	3.31 ef	3.39 e	3.447 e	3.593 de	4.160 e	4.277 de	4.350 de	4.397 de
AMF400	3.847 d	4.810 c	5.307 b	5.933 a	4.553 d	4.967 c	5.843 b	8.273 a
				Specific leaf weight (g cm^{-2})				
AMF0	0.444 d	0.456 d	0.514 c	0.515 c	0.385 f	0.469 e	0.511 de	0.515 cde
AMF200	0.522 bc	0.524 bc	0.535 bc	0.546 bc	0.519 cde	0.526 cd	0.532 cd	0.542 bcd
AMF400	0.562 bc	0.562 bc	0.578 ab	0.626 a	0.553 bcd	0.572 bc	0.592 ab	0.638 a
				Leaf fresh weight (g $plant^{-1}$)				
AMF0	0.313 g	0.331 g	0.349 g	0.395 f	0.374 i	0.467 h	0.507 g	0.537 f
AMF200	0.427 ef	0.437 de	0.452 de	0.470 cd	0.546 ef	0.561 e	0.569 e	0.601 d
AMF400	0.497 bc	0.511 b	0.533 b	0.613 a	0.617 cd	0.634 bc	0.657 b	0.789 a
				Root fresh weight (g $plant^{-1}$)				
AMF0	0.737 c	0.928 b	0.993 b	1.035 b	1.049 c	1.125 bc	1.138 bc	1.187 bc
AMF200	0.960 b	1.067 b	1.081 b	1.092 b	1.257 b	1.295 b	1.305 a	1.347 a
AMF400	1.109 b	1.132 ab	1.161 ab	1.206 a	1.370 a	1.387 a	1.440 a	1.483 a
				Root yield (Mg ha^{-1})				
AMF0	21.333 f	27.47 d	29.77 d	31.24 cd	26.480 e	28.760 d	29.140 d	30.620 cd
AMF200	31.75 cd	32.347 c	32.827 c	33.223 c	32.720 cd	33.840 c	34.16 bc	35.40 bc
AMF400	33.817 c	34.623 bc	35.637 b	37.223 a	36.08 b	36.62 b	38.20 a	39.48 a
				Sugar yield (Mg ha^{-1})				
AMF0	2.827 j	3.66 i	4.313 h	4.74 g	3.553 k	4.243 j	4.410 i	4.68 h
AMF200	5.197 f	5.367 ef	5.47 e	5.59 de	5.14g	5.35 f	5.49 f	5.773 e
AMF400	5.73 d	5.993 c	6.317 b	6.737 a	5.940 d	6.197 c	6.573 b	6.870 a

Differences between means were tested using Duncan's multiple range test at P ≤ 0.05. *Note: Control – Ctrl, Salicylic Acid – SA, Chitosan – CHT, Alginic Acid –AlgA*

Sugar beet root quality parameters

Figs 3 and 4 reveal that the application of AMF, especially at its highest rate (٤٠٠ spores/g soil), significantly improved sugar beet root quality during the two seasons of study (2022/2023 and 2023/2024 seasons), specifically the percentage of the extracted sugar, sucrose %, alpha amino (2nd season only), in addition to the percentages of K and Na (1st season only) in roots. The 400 spores/g soil treatment recorded the highest sucrose levels (19.69% and 19.80%) and exhibited the highest extractable sugar (17.52% and 17.00%) in the 1st and 2nd seasons, respectively. Mostly, AMF fungi increased the solubility of soil nutrients; hence facilitating their uptake by AMF hyphal networks (Khaliq *et al*., 2022; Bhupenchandra *et al*., 2024). Additionally, this symbiotic relation enhanced carbohydrate allocation (Salmeron-Santiago *et al*., 2022). The elevated impurities slightly increased in this study, probably due to sugar lost to molasses

(Mohamed *et al*., 2023), yet these reductions were still within acceptable agronomic limits. Additionally, increased photosynthetic activity because of larger and more efficient leaf area mostly the main reasons beyond the increases in biomass accumulation and sugar formation in roots.

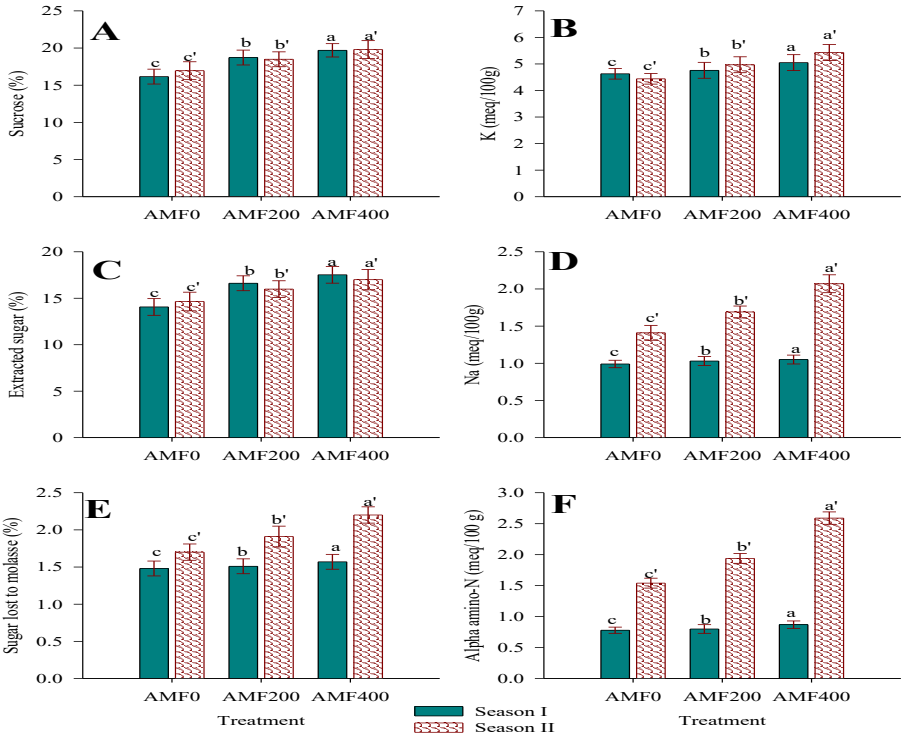

Fig 3. Effect of Arbuscular Mycorrhizal fungi (AMF) on sugar beet quality parameters within 2022/2023 and 2023/2024 winter seasons. Differences between means were tested using Duncan's multiple range test at P ≤ 0.05.

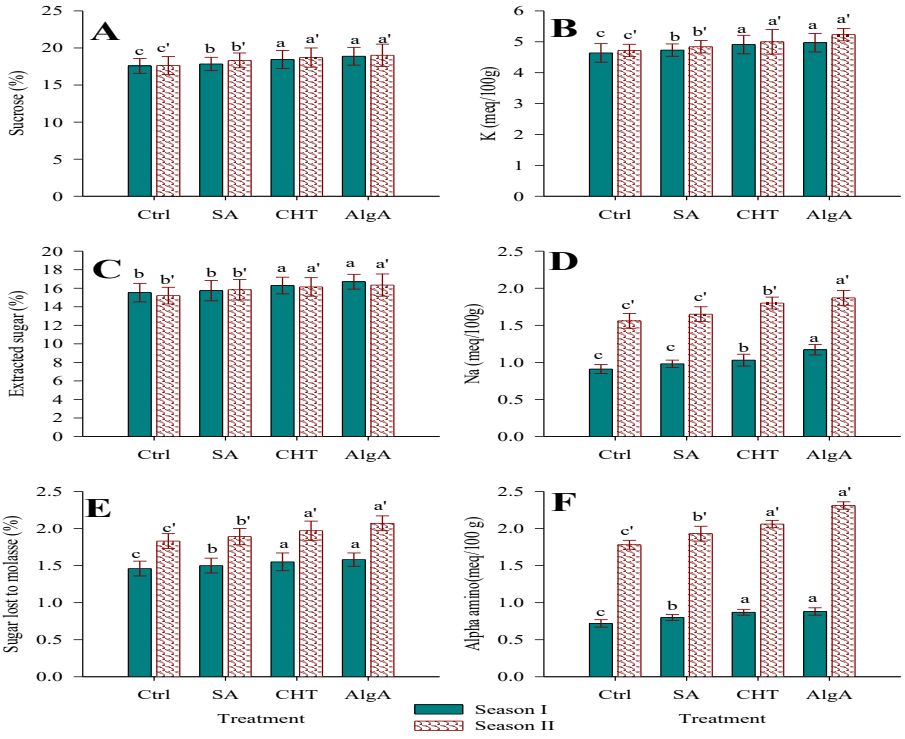

Fig 4. Effect of growth promoting stimulates (GPS) on the quality of sugar beet within 2022/2023 and 2023/2024 winter seasons. *Note: Control – Ctrl, Salicylic Acid – SA, Chitosan – CHT, Alginic Acid –AlgA.* Differences between means were tested using Duncan's multiple range test at P ≤ 0.05.

On the other hand, spraying plants with growth stimulants raised the abovementioned quality parameters in sugar beet roots, following generally the sequence of Alginic acid ≈ chitosan > salicylic acid. It seems that These results may be due to the bio-stimulant effects of algal extracts and chitosan on increasing physiological and metabolic processes within plants, for example photosynthesis, nutrient assimilation, and stress tolerance (Balusamy *et al*., 2022; Sarsekeyeva *et al*., 2024; Pandey and Dasgupta, 2025). These treatments also enhanced root activity and ion exchange

capacity (de Lima *et al*., 2022; Chanthini *et al*., 2024); thus, raised alpha–amino nitrogen, K, and Na concentrations.

Interactions between AMF inoculation and plant growth promoting substances were significant, except for sucrose in sugar beet tubers and Na content in their roots. Overall, AMF400 recorded the highest increases, especially for plants sprayed with AlgA ≈ CHT > SA for other tuber quality parameters, as shown in Table 3.

Table 3. Interactions between AMF and growth promoting stimulates (GPS) on the quality of sugar beet within 2022/2023 and 2023/2024 winter seasons.

	Season I				Season II			
	Ctrl	**SA**	**CHT**	**AlgA**	**Ctrl**	**SA**	**CHT**	**AlgA**
				Sucrose (%)				
AMF0	15.277 f	15.373 f	16.617 e	17.317 e	15.613 i	17.030 h	17.480 g	17.693 g
AMF200	18.437 d	18.683 cd	18.790 cd	18.967 cd	18.147 f	18.293 ef	18.610 df	18.907 cd
AMF400	19.030 cd	19.477 bc	19.913 ab	20.353 a	19.120 c	19.640 b	20.017 ab	20.420 a
				Extracted sugar (%)				
AMF0	13.267 f	13.317 f	14.495 e	15.177 e	13.427 h	14.757 g	15.130fg	15.287 ef
AMF200	16.363 d	16.590 cd	16.657 cd	16.820 cd	15.710de	15.807 d	16.070 cd	16.317 c
AMF400	16.943bcd	17.323abc	17.727 ab	18.100 a	16.470 c	16.930 b	17.207 ab	17.407 a
				Sugar lost to molasse (%)				
AMF0	1.410 g	1.457 fg	1.523 cde	1.540 bcd	1.587 j	1.673 ij	1.750 hi	1.807 gh
AMF200	1.473 ef	1.493 cdef	1.533 bcd	1.547 bcd	1.840 fgh	1.887 efg	1.940 def	1.990 de
AMF400	1.487 def	1.553 bc	1.587 b	1.653 a	2.050 cd	2.110 bc	2.210 b	2.413 a
				K (meq/100 g)				
AMF0	4.340 h	4.503 g	4.830 de	4.850cde	4.130 h	4.310h	4.600g	4.723 fg
AMF200	4.663 f	4.720 ef	4.807 de	4.860 cd	4.850 ef	4.947 def	4.987de	5.087 cde
AMF400	4.917 cb	4.980 bc	5.080 b	5.21 0 a	5.183 bcd	5.267 bc	5.400 b	5.873 a
				Na (meq/100 g)				
AMF0	0.903 b	0.953 b	1.011 b	1.097 b	1.243 g	1.330g	1.510 f	1.547 f
AMF200	0.960 b	1.010b	1.043 b	1.087 b	1.590 f	1.617 ef	1.727 de	1.813 cd
AMF400	0.853 b	0.970 b	1.037 b	1.333 a	1.860 c	2.003 b	2.177 a	2.243 a
				Alpha amino N (meq/100 g)				
AMF0	0.707 e	0.767 de	0.823 cd	0.837 cd	1.340 h	1.533 gh	1.573 gh	1.710 fg
AMF200	0.737 e	0.757 de	0.853 bc	0.867abc	1.757 fg	1.873 efg	2.003 def	2.107 cde
AMF400	0.723 e	0.887 abc	0.927 ab	0.947 a	2.250 cd	2.380 bc	2.590 b	3.120 a

***Note: Control – Ctrl, Salicylic Acid – SA, Chitosan – CHT, Alginic Acid – AlgA.* Differences between means were tested using Duncan's multiple range test at P ≤ 0.05.**

Physiological and metabolic traits

Figs 5 and 6 and Table 4 reveal that both the application of *Arbuscular Mycorrhizal fungi* (AMF) and foliar spraying significantly enhanced various physiological and metabolic traits in sugar beet during the 2022/2023 and 2023/2024 seasons.

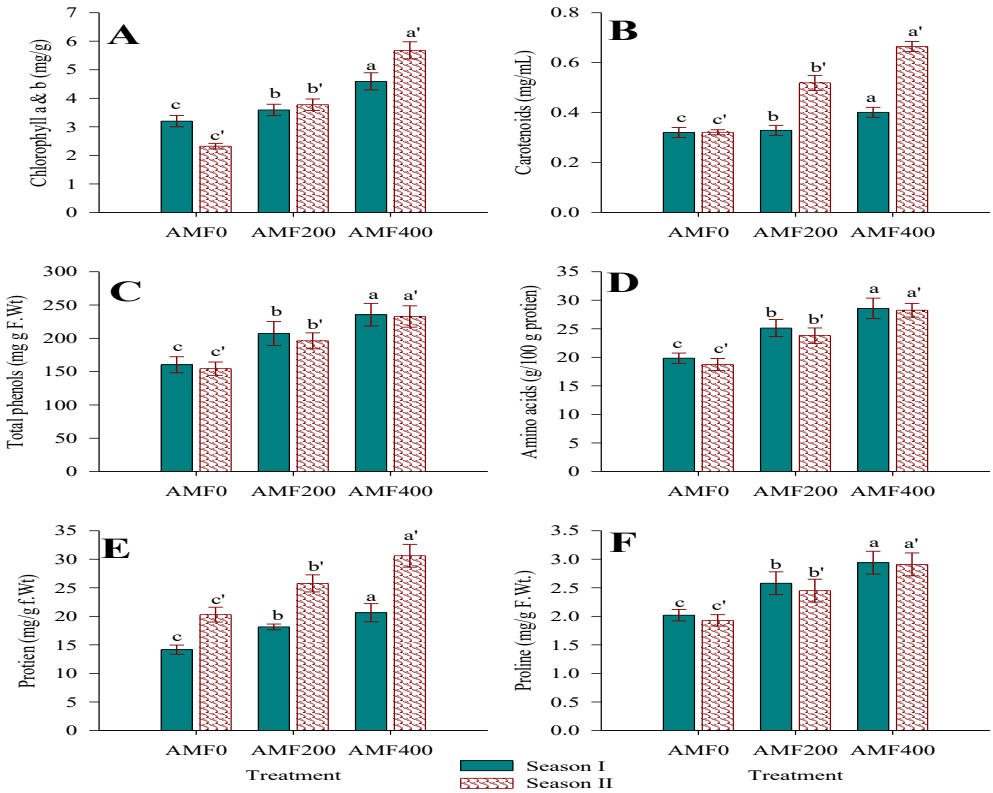

Fig 5. Effect of Arbuscular Mycorrhizal fungi (AMF) on sugar beet physiological and biochemical traits within 2022/2023 and 2023/2024 winter seasons. Differences between means were tested using Duncan's multiple range test at P ≤ 0.05.

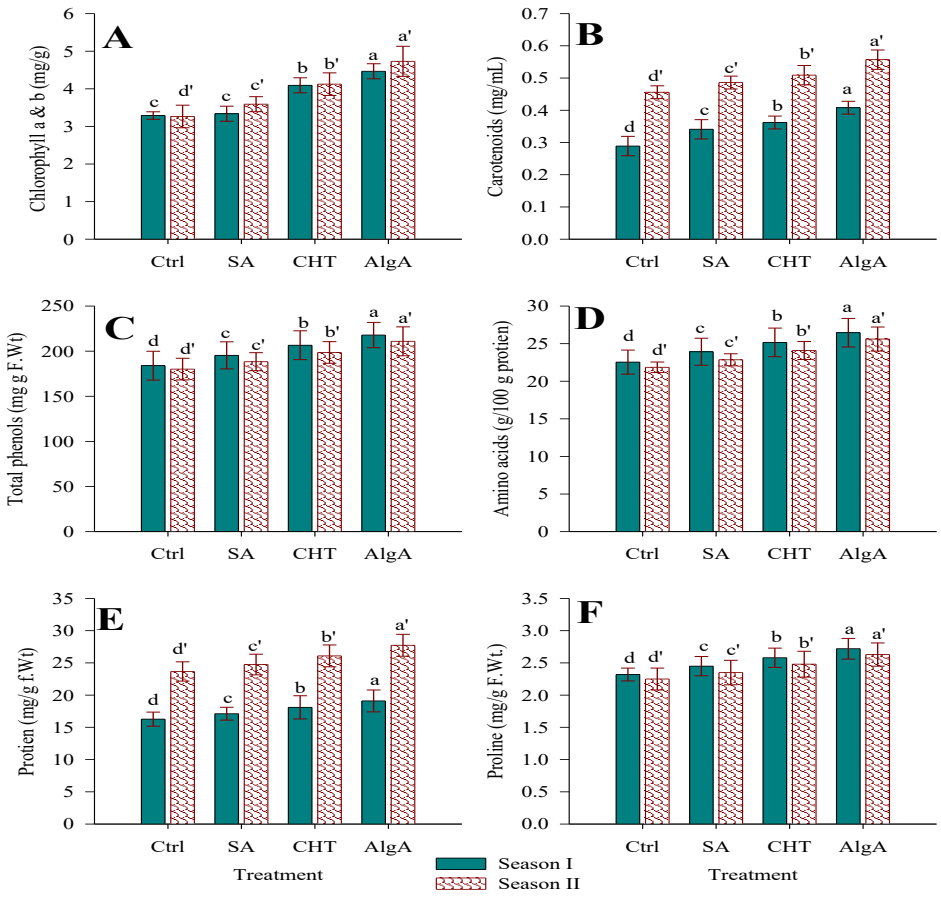

Fig 6. Effect of growth promoting stimulates (GPS) on sugar beet physiological and biochemical traits within 2022/2023 and 2023/2024 winter seasons. *Note:* Differences between means were tested using Duncan's multiple range test at P ≤ 0.05.

Table 4. Interactions between AMF and growth promoting stimulates (GPS) on sugar beet physiological and biochemical traits within 2022/2023 and 2023/2024 winter seasons.

	Season I				Season II			
	Ctrl	**SA**	**CHT**	**AlgA**	**Ctrl**	**SA**	**CHT**	**AlgA**
				Chlorophyll a+b (mg/g)				
AMF0	2.590 b	3.200 b	3.337 b	3.677 b	1.613 g	2.120fg	2.607ef	2.950 e
AMF200	3.810 b	3.527 b	3.477 b	3.553 b	3.117 e	3.293 de	3.980 d	4.720 c
AMF400	3.463 b	3.283 b	5.463 a	6.167 a	5.060bc	5.353bc	5.787 b	6.517 a
				Carotenoids (mg/mL)				
AMF0	0.257 c	0.317 bc	0.327 bc	0.380 ab	0.287g	0.320 g	0.330g	0.347g
AMF200	0.260 c	0.327 bc	0.340 bc	0.390 ab	0.473 f	0.500 ef	0.527 def	0.577 cde
AMF400	0.350 abc	0.380 ab	0.420 ab	0.453 a	0.607 bcd	0.637 bc	0.670 b	0.747 a
				Total phenols (mg/ g F.W)				
AMF0	136.333j	152.500 i	167.833 h	184.333 g	141.833 h	153.667gh	157.667 g	164.333 fg
AMF200	192.667 fg	204.501 ef	210.500de	220.667cd	175.833 ef	187.667 e	201.333 d	219.833 c
AMF400	222.667 cd	229.000 bc	241.333ab	248.500 a	222.500bc	223.500 bc	236.501ab	248.500 a
				Amino acids (g/ 100g protein)				
AMF0	17.23 f	19.113 e	20.67 de	22.377d	17.23 j	18.657 i	19.127 h	19.97 g
AMF200	23.373 cd	24.823 cd	25.54c	26.797bc	21.317 f	22.753 e	24.417 d	26.673 c
AMF400	27.01 b	27.81 b	29.277 a	30.173 a	27.003 c	27.137 c	28.697 b	30.173 a
				Protein (mg/g F.W)				
AMF0	12.433 ia	13.36 i	14.687h	16.16g	18.66 h	20.21gh	20.71 g	21.63 fg
AMF200	16.88 fg	17.927 ef	18.447de	19.347cd	23.1 ef	24.65 e	26.45 d	28.89 c
AMF400	19.507 cd	20.087 bc	21.153 ab	21.787 a	29.25 bc	29.4 bc	31.1 ab	32.68 a
				Proline (mg/g F.W)				
AMF0	1.77 i	1.923hi	2.093 h	2.297g	1.77 h	1.917gh	1.967 g	2.05 fg
AMF200	2.4 fg	2.553ef	2.627 de	2.757cd	2.193 ef	2.34 de	2.51 d	2.743 c
AMF400	2.777cd	2.863 bc	3.007ab	3.1a	2.777 bc	2.793 bc	2.95 b	3.1A

***Note: Control – Ctrl, Salicylic Acid – SA, Chitosan – CHT, Alginic Acid – AlgA.* Differences between means were tested using Duncan's multiple range test at P ≤ 0.05.**

For example, application of AMF at a rate of 400 spores/g soil led to significant increases in physiological and biochemical parameters, *i.e.* chlorophyll (a + b), carotenoids, total phenols, amino acids, proteins, and proline contents increased by approximately 1.4–2.5-fold, 1.3–2.1-fold, 1.47–1.51-fold, 1.46–1.51-fold, 1.46–1.51-fold, and 1.52-fold, respectively, compared to the control. Improvements in chlorophyll and carotenoid contents could be attributed to increased nutrient availability (Khan *et al*., 2022), which was facilitated by AMF-mediated root colonization (Saha *et al*.,

2022). Additionally, more nitrogen is taken up by plant roots to be involved in nitrogen metabolism (Tang *et al*., 2022), and also raised proline level in shoots. This well-known osmo-protectant could increase tolerance mechanisms against stress conditions (Lalarukh *et al*., 2022; Saad *et al*., 2023; El-Atrony *et al*., 2025).

Also, spraying plants with plant growth stimulates improved plant pigments, proteins, amino acids and proline. In this regard, the increases were as follows: Alginic Acid ≈ chitosan > salicylic acid. Alginic acid likely enhances photosynthetic pigments and protein synthesis via being rich in bioavailable minerals, polysaccharides, and hormones (Choudhary *et al*., 2021; Kumar *et al*., 2021), while chitosan acts as a biogenic elicitor that increases defense and metabolic responses (Khan *et al*., 2009 and Zewail *et al*., 2021). These growth stimulating materials also played important roles in the induction of secondary metabolism, important for plant stress mitigation and productivity as mentioned before.

CONCLUSION

In this direction, inoculating plants with AMF raised significantly all physiological and biochemical traits under investigation, following the sequence **of** AMF400 > AMF200 > AMF0 across both seasons. Also, foliar sprays with AlgA had the greatest impact on these parameters in both seasons. The highest increases were recorded for AMF400+AlgA in both seasons of study, and also AMF400 + CHT recorded comparable results. It seems as if the effect of fungi exceeded that of the growth promoting stimulus. Overall, our study could be a guide to exploring more arbuscular mycorrhiza and growth stimulants material for profitable sugar beet production.

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تحسين خصائص النمو وانتاجية ومحصول السكر لبنجر السكر باستخدام الميكروهيزا والمواد المستحثة للنمو والصديقة للبيئة

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الملخص

يشكل زيادة إنتاج بنجر السكر في ظل تغير المناخ باستخدام مواد صديقة للبيئة تحديا أمام العلماء في السنوات القادمة. أُجريت تجربتان حقليَّتان في المزرعة البحثية التابعة لمحطة سخا للبحوث الزراعية بمحافظة كفر الشيخ، مصر، خلال موسمي ٢٠٢٢/٢٠٢٣ و٢٠٢٣/٢٠٢٤م لدراسة تأثير فطريات الميكروهيزا (الفطريات الجذرية) كمحسن للتربة (بدون إضافة، ٢٠٠ و٤٠٠ جرثومة/جرام تربة) والرش بمحلول أربع مغذيات (بدون رش، حمض الساليسيليك، الشيتوزان، وحمض الألجينيك)، حيث تم الرش بمعدل ١٠٠ ملجم/لتر لكل منها على حدة. وتم تنفيذ التجربة باستخدام تصميم القطاعات الكاملة العشوائية في ترتيب القطع المنشقة بثلاث مكررات. أظهرت النتائج أن تطبيق فطريات الميكروهيزا الجذرية (AMF) قد حسن بشكل معنوي جميع مؤشرات النمو للنبات التي تم دراستها، بالإضافة إلى محصولي الجذور والسكر، خاصة في النباتات التي تلقت المعدل الأعلى من التطبيق بمعدل ٤٠٠ جرثومة/جرام تربة. حيث تراوحت هذه الزيادات من ١,٢ إلى ٢ ضعف مقارنة بمعاملة الكنترول. كما أدى استخدام فطريات الميكروهيزا الجذرية (AMF)، وخاصة عند أعلى معدل إلى تحسن معنوي في جودة جذور بنجر السكر بشكل ملحوظ خلال موسمي الدراسة، وتحديدا نسبة السكر المستخلص، ونسبة السكروز، وألفا أمينو (في الموسم الثاني فقط)، بالإضافة إلى نسبة البوتاسيوم والصوديوم (في الموسم الأول فقط) في الجذور. كما حسن معاملات فطريات الميكروهيزا الجذرية والرش الورقي بشكل ملحوظ مختلف الصفات الفسيولوجية والأيضية في بنجر السكر خلال الموسمين. وتلخص دراستنا أن تطبيق فطريات الميكروهيزا والرش الورقي قد ثبتت قدرتهم على زيادة جميع مؤشرات النمو وإنتاجية بنجر السكر، خاصة عند أعلى معدل تطبيق (٤٠٠ جرثومة/جم تربة)، مع الحفاظ على البيئة وتحقيق الاستدامة.