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Efficacy of anti-transpiration on yield and quality of sugar beet subjected to water stress

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ABSTRACT

The current study took place at Shandaweel, Sohag governorate, Egypt, (latitude of 24.54° N and longitude of 32.94° E) and included two seasons, 2019/2020 and 2020/2021, to study the efficacy of anti-transpiration on yield and quality of sugar beet subjected to water stress. Three replications in a split-plot randomized complete block design were used in the experiment. The treatments included three irrigation levels (100, 80, and 60% of the recommended irrigation) in cases 12, 10, and 7 irrigations were applied and given at an average interval of 15, 18, and 26 days, which were randomly in the main plots, while, three anti-transpirant substances (Chitosan, Glycerol, and Magnesium carbonate), as well as water-sprayed plants (control) were placed in subplots randomly. Plant growth, chlorophyll, relative water content, cell membrane stability index, sugar production, and quality index were all lowered by drought stress in both seasons. Furthermore, under drought conditions, proline, free radical scavenging activity, and sucrose levels all increased significantly. In both seasons, the application of anti-transpiration substances had a substantial effect on improving the examined features when compared to the control. Foliar spray of chitosan or glycerol had a beneficial effect on physiological, morphological, and quality characteristics of the examined plants, compared to the control treatment. Generally, anti-transpirants reduced water use and increased water production in general when irrigation water was scarce. Furthermore, spraying anti-transpirants, which were responsible for lowering water use, considerably enhanced most of the growth and yield measures as well as quality.

Keywords: anti-transpiration, chitosan, irrigation, quality, sugar beet, yield

INTRODUCTION

Sugar beet (*Beta vulgaris* var. saccharum, L.) is a member of the Chenopodiaceae, it is considered a very important sugar crop all over the world, it is one of the most essential raw materials for sugar manufacturing, and it is Egypt's second most important crop after sugarcane. Sugar beet is regarded as a deep-rooted crop that is generally resistant to water stress due to the physical and physiological features of its root system (Topak et al., 2011). Water is the most important factor for the life function of plants, the amount of it within the plant tissues has a agreat effect on vegetative growth and productivity (Gawad, 2015). Agriculture is considered the main consumer of freshwater (El-Azm and Youssef, 2015), crop growth and development consume less than 5% of the water absorbed by roots, and the remaining amount about 95% is transpired by the plant (Abdullah et al., 2015). A sustainable goal for various agricultural research is to maximize crop yield using limited irrigation water, particularly in arid and semi-arid locations (Al-Mansor et al., 2015; El-Azm and Youssef, 2015), therefore, the increasing global shortage of fresh water requires rationalization of water in agriculture, as a result, scientists are focusing their efforts on improving water efficiency by producing new drought-tolerant plant species, managing water for arid and semi-arid locations, adopting new forms of agricultural production that lead to save water (Topak et al., 2011) or using compounds that reduce water evaporation by the transpiration process (Singh et al., 2021).

Transpiration is a physiological process in which plants lose water in the form of water vapors. Due to a global water deficit and high temperatures that accelerate evaporation, reduced transpiration is an effective and required strategy for conserving irrigation water while ensuring plant survival and preserving leaves from drought damage, resulting in improved water use efficiency (Gawad, 2015). Foliar spraying of anti-transpirants is one of the most important ways of lowering transpiration rates and reducing the negative effects of drought stress (El-Azm and Youssef, 2015).

There are four categories of anti-transpirants, based on the mode of action (Degif and Woltering, 2015; El-Azm and Youssef, 2015; Mphande et al., 2020; Singh et al., 2021). Anti-transpirants have been classified as 1) Film-forming anti-transpirants like glycerol and silicone oils that can create a physical barrier between the leaf and the surroundings and hinder the escape of water vapour from the leaves, 2) Reflecting types such as magnesium carbonate and kaolin inhibit solar energy absorption, lowering leaf temperatures, and consequently the rate of transpiration, 3) Physiologically active stomata closing types such as abscisic acid, chitosan, and K_2SO_4 that prevent stomata from fully opening, reducing water vapour loss from plant leaves and are capable of influencing metabolic processes in leaf tissues; and 4) growth retardants such as cyocel that control water vapour losses by retarding root and shoot growth and thus allow the plant to resist drought.

Crustacean shells derived from shellfish processing enterprises are the principal sources of chitin (Aam et al., 2010; Kaya et al., 2015). Glycerol is a sweet-tasting trihydroxy sugar alcohol that is odorless, colorless, and viscous. It can be derived naturally as well as from petrochemical feedstock (Wernke, 2014; San Kong et al., 2016). Magnesium carbonate $MgCO_3$ is an inorganic salt that is a white solid (El Mantawy and El Bialy, 2018).

Aims of the study

Water deficit (WD) is becoming an increasingly serious problem in many parts of the world; as a result, this research aims to reduce transpiration rates to alleviate drought stress by evaluating and comparing the efficacy of three anti-transpirants, i.e., chitosan, glycerol, and magnesium carbonate, as well as control (water spraying), in attenuating the unfavourable effect of drought stress on sugar beets.

MATERIALS AND METHODS

Experimental site

The current experiment took place in the Shandaweel Agricultural Research Station, Sohag Governorate, Egypt, (latitude of 24.54° N and longitude of 32.94° E) over two winter seasons, 2019/2020 and 2020/2021, to investigate the efficacy of anti-transpiration on yield and quality of sugar beet subjected to water stress. Sugar beet variety *viz* “Lilly” was sown in both growing seasons, in the 1st season, the planting was on 20 October 2019 and the harvest was on 2 May 2020 “ a growth period of 195 days” while, in the 2nd season the planting was on 22 October 2020 and the harvest was done on 6 May 2021 " growth period of 195 days". Soil samples were randomly selected from the experimental field area at a depth of 0-30 cm below the soil surface to evaluate the mechanical and chemical parameters of the soil (Table 1) and the weather data were obtained from the Central Laboratory of Meteorology, Ministry of Agriculture, Egypt (Table 2).

The experimental design was a randomized complete block design as it used a split plot with three replications and involved 12 treatments. The treatments included three irrigation levels (100, 80, and 60% of the recommended irrigation), in which case 12, 10, and 7 irrigations were applied given an average interval of 15, 18, and 26 days, respectively, which were randomly distributed in the main plots, and three anti-transpirant substances (Chitosan, Glycerol, and Magnesium carbonate), as well as water-sprayed plants (control), which were also randomly distributed in the subplots. The experimental

Table 1. Soil properties of the experimental sites during 2019/2020 and 2020/2021seasons

Season		2019/2020	2020/2021
Mechanical analysis	Fine sand%	21%	37%
	Coarse sand%	1.46%	1.14%
	Silt%	42%	32%
	Clay%	35.54%	29.86%
Soil texture		Clay loam	Clay loam
Chemical analysis	Organic matter (%)	0.62	0.65
	Available N%	0.164	0.220
	$CaCO_3$%	1.40	1.50
	Soluble ions (meq/100g soil (1:5))		
	CO_3^-	----	----
	H CO_3^-	0.26	0.33
	Cl^-	0.79	0.90
	SO_4^{--}	1.00	1.15
	Ca^{++}	0.50	0.55
	Mg^{++}	0.24	0.34
	Na^+	1.17	1.33
	K^+	0.14	0.16
	EC, dS/m (1:5)	0.21	0.24
	pH (1:2.5)	7.3	7.2

plot consisted of five rows; each was 3.5 m long and 0.6 m wide, with 20 cm between hills, so the plot area was 10.5 m^2. All plots were thoroughly irrigated for two weeks after seeding, and then irrigation treatments were applied by optimum irrigation.

Chitosan (0.5 gm), Glycerol (6%) and suspension of Magnesium carbonate (6%) were foliar sprayed by using the dorsal sprinkler. The concentrations of anti-transpirant utilized were chosen based on previous research (Gawad, 2015; El-Mantawy and El-Bialy, 2018). The control plants were sprayed with water. Early in the morning, all foliar sprayings were performed to completely cover the entire plant leaves. Foliar spraying was done twice at three-week intervals, starting 45 days after sowing and ending at 65 days from sowing. Chitosan is characterized by a medium molecular weight, from carb shells poly-(1,4 - B - D- glucopyranosamine); 2 - Amino - 2 - deoxy- (1->4) - B - D-glucopyranan. Glycerol ($C_3H_8O_3$) is characterized by a density of 1.261 kg/l, a melting point of 18.2 °C, and a boiling point of 290 °C under pure conditions. Magnesium carbonate ($MgCO_3$) is light and characterized by a molecular weight of 84.31.

During both growing seasons at the experimental location, all cultural activities (fertilization, weed management, and pest and disease control) were carried out according to the Egyptian Ministry of Agriculture's recommendations for sugar beet production.

Table 2. Meteorological data was recorded at Shandaweel Agricultural Research Station during 2019/2020 and 2020/2021 seasons

Item	Season	Month							
		October	November	December	January	February	March	April	May
Max.-Temp. (°C)	2019/2020	35.4	30.8	23.5	21.9	24.9	30.0	34.2	38.7
	2020/2021	38.7	28.3	26.1	25.1	26.4	31.0	36.1	41.7
Min.-Temp. (°C)	2019/2020	17.1	12.7	5.8	5.1	6.7	13.1	16.4	20.4
	2020/2021	18.6	10.9	7.5	6.5	6.6	14.5	15.3	21.3
Max.-R.H. (%)	2019/2020	76.6	78.7	86.6	86.3	82.1	61.0	58.3	48.00
	2020/2021	73.9	85.8	86.0	85.2	80.2	69.0	49.3	43.0
Min.-R.H. (%)	2019/2020	18.2	18.1	19.1	18.6	15.9	15.4	15.6	17.1
	2020/2021	17.8	20.9	20.3	15.5	15.8	13.6	12.6	14.6
Precipitation (mm)	2019/2020	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2020/2021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Weather bureau station, Where: Max.-Temp = Maximum temperature; Min.-Temp = Minimum temperature; R.H. = Relative humidity %

Studied traits

Determination of physiological traits

All vegetative traits were done after 120 days after planting.

- Chlorophyll: A portable chlorophyll metre was used to measure leaf chlorophyll readings (SPAD) on attached leaves (SPAD - 502, Konica Minolta Sensing, Inc., Japan) according to Minolta (1989).
- Relative water content (RWC): The relative water contents (RWCs) of leaves were estimated using Karrou and Maranville's (1995) equation:

  $$RWC (\%) = (FW – DW) / (TW – DW) \times 100$$

  where: FW= fresh leaf weight, DW= dry leaf weight, and TW= turgid leaf weight.
- Leaf Cell Membrane Stability Index (MSI): Cell membrane stability index of a leaf was measured by EC conductivity meter (Altronix model CTX-II, USA) according to Franca et al. (2000). The following formula was used to compute the percentage of electrolyte leakage:

  $$MSI (\%) = [1 – (EC_1 / EC_2)] \times 100$$

where: EC_1 and EC_2, are the electrical conductivity measurements taken before and after boiling.

Determination of antioxidant enzyme activities

Leaves samples were collected and immersed immediately in liquid nitrogen followed by a freeze and stored until use. A 0.5 g of sample was homogenized in 5 mL 50 mM sodium phosphate buffer (pH 7.8) by using a mortar and pestle, then centrifuged at 15,000 × g for 20 min. at 4 °C. The enzyme extract was stored at 4 °C for analysis.

- Peroxidase assay: According to Ghanati et al. (2002) peroxidase activity was measured by the oxidation of guaiacol in the presence of H_2O_2.
- Proline contents: Proline contents were assayed as described by Bates et al. (1973). A JENWAY spectrophotometer from the United States was used for all of the spectrophotometric analyses.

Morphological root traits

Root length and diameter (cm) were measured at harvest by measuring tape.

Quality parameters

At harvest (after 195 days from sowing), ten plants were taken randomly from the guarded ridges of each plot to determine the following characteristics:

- Sucrose percentage: The proportion of sucrose was obtained using a saccharometer according to Ouda (2009),
- Impurities (K, Na, and α-amino N concentration) in root were estimated as meq/100gm beet according to the procedure described by the sugar company using Auto Analyzer (Nemeata Alla, 2017),
- Sugar lost to molasses (SLM%) = 0.14 (Na + K) + 0.25 (α-amino N) + 0.5 (Nemeata Alla, 2017),
- Extracted sugar % (ES%) = Sucrose% - SLM% - 0.6 (Nemeata Alla, 2017),
- Quality index (QI) measures according to Nemeata Alla (2017) by the equation,

$$QI\ (\%) = (ES\ /\ Sucrose) \times 100$$

Yield and yield contributing traits

The plants were harvested from the three middle rows of each plot were chosen and cleaned, roots and tops were separated and weighted in kg, then collected and converted to estimate:

- Root yield (ton/fed),
- Top yield (ton/fed),
- Sugar yield (ton/fed).

The following equation was used to determine sugar yield:

$$Sugar\ yield\ (ton/fed) = ES \times Root\ yield\ (ton/fed)$$

Water relations

- Water consumptive use (CU) was estimated by using the soil samples taken immediately before irrigation and 48 hours later and oven dried at 105 °C, calculate water consumptive (CU) of sugar beet as mm depth according to the technique used according to the equation (Hansen et al., 2016);

$$CU = D \times B_d \times [(Q_2 - Q_1) / 100]$$

where: CU= water consumptive use in mm,

D = Soil layer depth,

B_d = Soil bulk density (g/cm^3),

Q_1 = Soil moisture%, before irrigation,

Q_2 = Soil moisture%, 48 hours after irrigation.

Water consumptive use (CU) of sugar beet as m^3/fed was calculated as follows;

$$CU\ (m^3/fed) = CU\ (mm) \times 4.2$$

- Water use efficiency (WUE) was calculated as kg roots or kg sugar per water consume (m^3) according to the following formula of Vites (1966);

$$WUE\ (kg\ Root\ or\ sugar/m^3) = \frac{Root\ or\ sugar\ yield\ (kg/fed.)}{Water\ consumptive\ use\ (m^3/fed.)}$$

All measurements were performed once in each growing season.

Statistical analysis

Collected data were subjected to the proper analysis of variance (ANOVA). The proper statistical of all data was carried out according to Gomez and Gomez (1984). Homogeneity of variance and differences among treatments were evaluated by the least significant difference test (LSD) at 5%.

RESULTS AND DISCUSSION

Impacts of irrigation levels

Tables 3 and 4 includes the effect of irrigation levels on sugar beet growth and yield parameters, respectively. During both seasons, decreasing irrigation levels reduced chlorophyll, relative water content, and cell membrane stability index, while caused an increase oxidative enzyme and proline content (Table 3). The reduction in chlorophyll concentration in stressed plants could be due to thylakoid membrane disorder, with more chlorophyll degradation than synthesis via the development of proteolytic enzymes like chlorophyllase, which degrades chlorophyll and damages the photosynthetic machinery (El-Mantawy and El-Bialy, 2018). One of the most significant and dependable physiological markers is RWC (Jahirul Islam et al., 2020), our results demonstrated that plants subjected to adequate irrigation and 80 % irrigation level had higher RWC% than water-stressed plants, mostly because the amount of water given was sufficient to sustain the leaf tissue's turgidity (Segura-Monroy et al., 2015). Unyayar et al. (2004) reported the same results, stating that under drought stress, the RWC percentages of sunflower leaves were reduced. Furthermore, Ibrahim et al. (2016) discovered that water stress induced a large decrease in relative water content in sunflower plants but a considerable rise in proline content.

The stability of the cell membrane is a crucial criterion in a growing plant to maintain cell integrity and good functioning (Yeilaghi et al., 2012; Jahirul Islam et al., 2020), reduced transpiration and efflux of solutes involved in the osmoregulation process of plant leaves could explain the greater membrane stability index (MSI) of tolerant plants (Ghaffari et al., 2019). Evidence showed that protecting the cell membrane helps from reducing sugar beet root yield under drought stress in different genotypes (Al-Jbawi and Abbas, 2013). Thus, the plants with higher MSI under drought conditions may be considered tolerant plants.

Under drought stress, proline accumulation increases, which is an important osmoprotectant that helps with osmotic adjustment, ROS quenching, and redox equilibrium during abiotic stress (Matysik et al., 2002; Ashraf and Foolad, 2007; Hidangmayum and Dwivedi, 2018). As part of an adaptation strategy, metabolic factors such as free proline content in leaves increased dramatically under severe drought stress (Gzik, 1996). By reducing the leaf water potential, proline buildup helps to minimize water loss. It also enhances the turgor of leaves by facilitating water transfer. Amino acids including isoleucine, threonine, lysine, and aspartic acid have also been found as osmoregulants, which provide sustenance to plants when they are stressed by abiotic or biotic factors (Hidangmayum and Dwivedi, 2018).

In the present experiment, reducing the amount of water used for irrigation resulted in water stress on the sugar beet crop (Jahirul Islam et al., 2020), which resulted in a reduction in sugar, top and root yield in both seasons, while root length, sucrose content, potassium, quality index, and extracted sugar were increased with

Table 3. Impact of irrigation levels on sugar beet growth and yield parameters in 2019/2020 and 2020/2021 seasons

Irri.	Traits									
	Chl. (SPAD Un.)	RWC (%)	MSI (%)	POX µmol/g fw.min	Proline mg/g d.wt	Root length (cm)	Root diameter (cm)	Sugar yield (ton/fed)	Root yield (ton/fed)	Top yield (ton/fed
	2019/2020 season									
100%	49.49	81.29	88.35	7.03	5.34	31.83	8.94	3.96	35.56	8.89
80%	49.58	83.12	87.29	12.30	5.55	31.33	8.11	4.19	32.79	8.20
60%	43.09	78.90	79.15	21.55	7.32	32.25	7.61	3.70	27.64	6.91
$LSD_{0.05}$	1.35	0.92	1.50	1.55	1.48	1.80	0.28	0.13	1.21	0.30
	2020/2021 season									
100%	52.39	80.23	88.48	7.60	6.55	26.83	9.31	4.28	37.13	9.28
80%	51.27	82.89	86.95	13.80	4.86	27.50	8.53	4.01	34.55	8.64
60%	45.94	78.19	78.69	19.12	7.42	29.33	8.25	3.89	29.58	7.40
$LSD_{0.05}$	0.86	1.62	1.13	2.34	0.86	0.19	0.23	0.18	0.86	0.21

Chl: chlorophyll, RWC: Relative water content, MSI: Membrane stability index, POX: Peroxidase activity an irrigation level of 60% in both seasons. In general, no differences were observed between the use of irrigation levels of 100% and 80% in both seasons in most traits (Table 4). Sugar beet is a well-known crop sensitive to water stress. It is also known that drought stress can inhibit seedling growth, resulting in a terminal decline in biomass production. Furthermore, the rate of photosynthesis can be affected and reduced (Jahirul Islam et al., 2020; Mou et al., 2017).

Impacts of foliar applications of anti-transpirants

The effect of foliar applications of anti-transpirants on sugar beet growth and yield parameters are presented in Tables 5 and 6, respectively. Concerning the effect of foliar spraying of anti-transpirants, all biochemical parameters analyzed were significantly increased in response to spraying of foliar application. Chitosan spraying increased chlorophyll content, membrane stability index, root length, root diameter, sugar, top and root yield in both seasons. While glycerol spraying increased chlorophyll and relative water content in both seasons, this is based on their beneficial effect on reducing the hazardous effect of water stress. On the other hand, the control treatment (without foliar spraying of anti-transpirants) recorded the lowest values of all parameters, in both seasons. Table 6 shows that foliar spraying with chitosan and glycerol followed by $MgCO_3$ treatment produced the highest values for sucrose percent and quality index. This indicates that chitosan is a potent anti-transpirant chemical because it reduces transpiration by inducing ABA production and activity, which leads to stomatal closure (Hidangmayum et al., 2019).

Also, chitosan spraying can stimulate the development of crops and will be enhanced nutrients and water uptake, thereby contributing to increased reactive oxygen species (ROS) scavenging activities (Guan et al., 2009; Khokon et al., 2010).

Spraying glycerol as an anti-transpirant dramatically enhanced RWC in plant leaves, as seen in Table 5. This could be because the anti-transpirant provides a physical barrier between the leaf and its surroundings. Therefore, it can reduce water loss from the leaves of plants (Degif and Woltering, 2015).

Table 4. Impact of irrigation levels on sugar beet quality parameters in 2019/2020 and 2020/2021 seasons

Irri.	Traits						
	Sucrose (%)	K (%)	Na (%)	α-a N	QI (%)	SLM (%)	ES (%)
				2019/2020 season			
100%	15.65	3.57	2.29	5.01	81.95	2.57	11.11
80%	16.45	4.28	1.65	3.94	83.43	2.31	12.75
60%	17.12	4.29	1.32	3.65	84.92	2.20	13.35
$LSD_{0.05}$	0.65	0.71	0.42	0.70	0.66	0.18	0.72
				2020/2021 season			
100%	15.71	5.04	1.79	3.36	81.25	2.29	11.51
80%	15.97	4.58	2.01	3.84	81.76	2.38	11.57
60%	16.15	4.25	1.91	4.02	82.61	2.37	13.13
$LSD_{0.05}$	0.33	0.77	0.42	0.24	0.79	0.09	0.30

α-a N: Alpha-amino nitrogen, SLM%: Sugar lost to molasses%, ES %: Extracted sugar% and QI: Quality index

Table 5. Impacts of foliar applications of anti-transpirants on sugar beet growth and yield parameters in 2019/2020 and 2020/2021 seasons

Treats	Traits									
	Chl. (SPAD Un.)	RWC (%)	MSI (%)	POX µmol/g fw.min	Proline mg/g d.wt	Root length (cm)	Root diameter (cm)	Sugar yield (ton/fed)	Root yield (ton/fed)	Top yield (ton/fed)
	2019/2020 season									
Control	46.43	78.86	82.87	17.67	7.81	31.89	8.02	3.36	30.39	7.60
Chitosan	49.26	81.82	86.08	9.09	4.95	32.56	8.50	4.38	33.93	8.48
Glycerol	48.01	83.25	85.56	15.60	5.93	32.11	8.20	4.16	32.49	8.12
$MgCO_3$	45.86	80.49	85.21	12.15	5.59	30.67	8.16	3.91	31.17	7.79
$LSD_{0.05}$	1.63	0.93	1.42	1.77	1.39	1.51	0.18	0.38	0.61	0.15
	2020/2021 season									
Control	48.80	78.53	82.11	19.18	8.04	27.22	8.47	3.46	32.32	8.08
Chitosan	51.63	81.28	85.81	10.11	5.08	28.67	8.93	4.60	35.50	8.88
Glycerol	49.99	82.75	85.52	13.23	5.83	28.44	8.72	4.18	34.06	8.52
$MgCO_3$	49.04	79.17	85.39	12.50	6.14	27.22	8.66	3.99	33.12	8.28
$LSD_{0.05}$	1.75	0.99	1.137	1.36	1.78	0.86	0.14	0.25	0.70	0.17

Chl: chlorophyll, RWC: Relative water content, MSI: Membrane stability index, POX: Peroxidase activity

Table 6. Impacts of foliar applications of anti-transpirants on sugar beet quality parameters in 2019/2020 and 2020/2021 seasons

Treats	Traits						
	Sucrose (%)	K (%)	Na (%)	α-a N	QI (%)	SLM (%)	ES (%)
	2019/2020 season						
Control	15.56	4.31	2.17	4.54	81.08	2.54	11.13
Chitosan	17.17	3.86	1.34	4.16	85.03	2.27	13.07
Glycerol	16.65	4.10	1.68	3.91	84.02	2.29	12.83
$MgCO_3$	16.24	3.84	1.81	4.18	83.60	2.34	12.58
$LSD_{0.05}$	1.13	0.75	0.30	0.74	0.98	0.14	1.27
	2020/2021 season						
Control	15.31	5.06	2.09	4.05	79.59	2.51	10.74
Chitosan	16.73	4.71	1.57	2.94	83.87	2.12	13.03
Glycerol	15.99	4.36	1.80	3.83	82.54	2.32	12.38
$MgCO_3$	15.75	4.37	2.15	4.13	81.49	2.44	12.13
$LSD_{0.05}$	0.42	0.68	0.40	0.86	0.46	0.18	0.67

α-a N: Alpha-amino nitrogen, SLM%: Sugar lost to molasses%, ES%: Extracted sugar% and QI: Quality index

Interaction effects of anti-transpirants and irrigation levels

The interaction effects of anti-transpirants and irrigation levels on sugar beet crop development and yield characteristics were cleared in tables 7 and 8 and figures 1 and 2. The combination between anti-transpirants and irrigation levels in both seasons had a substantial impact on all features, according to the results in Tables 7 and 8. The highest values for chlorophyll, root length, root diameter, top yield, and root yield were obtained

Table 7. Effects of the interactions between foliar application and levels of water stress on sugar beet growth and yield parameters during in 2019/2020 and 2020/2021 seasons

Irri. level	Treats	Traits							
		Chl. (SPAD Un.)	RWC (%)	MSI (%)	POX µmol/g fw.min	Proline mg/g d.wt	Root length (cm)	Root diameter (cm)	Top yield (ton/fed)
		2019/2020 season							
100%	Control	47.90	79.57	85.57	9.33	7.33	33.67	8.50	8.43
	Chitosan	53.93	82.03	89.05	5.88	4.21	32.33	9.20	9.30
	Glycerol	48.07	82.41	89.98	8.07	5.09	31.33	9.03	9.07
	$MgCO_3$	48.07	81.14	88.78	4.84	4.71	30.00	9.03	8.76
80%	Control	47.90	80.23	86.04	18.23	7.56	30.00	8.07	7.68
	Chitosan	50.00	83.57	88.35	8.71	4.38	32.33	8.40	8.69
	Glycerol	53.23	86.84	86.72	14.33	5.10	32.00	8.03	8.40
	$MgCO_3$	47.20	81.84	88.04	7.94	5.17	31.00	7.93	8.01
60%	Control	43.50	76.76	77.00	25.46	8.53	32.00	7.50	6.68
	Chitosan	43.83	79.86	80.84	12.68	6.25	33.00	7.90	7.46
	Glycerol	42.73	80.50	79.97	24.42	7.62	33.00	7.53	6.90
	$MgCO_3$	42.30	78.50	78.80	23.66	6.90	31.00	7.50	6.60
	$LSD_{0.05}$	2.82	1.61	2.47	3.06	2.41	2.61	0.31	0.26
		2020/2021 season							
100%	Control	49.17	78.57	84.66	11.70	8.28	26.67	8.90	8.85
	Chitosan	56.07	80.70	88.81	6.05	5.25	27.67	9.50	9.67
	Glycerol	52.90	81.75	90.03	6.78	6.57	27.33	9.40	9.38
	$MgCO_3$	51.43	79.91	90.43	5.85	6.10	25.67	9.43	9.24
80%	Control	49.23	80.74	85.73	22.32	6.43	26.00	8.40	7.96
	Chitosan	52.03	83.57	88.20	7.73	3.71	28.33	8.80	9.18
	Glycerol	52.53	87.27	86.68	12.27	4.21	28.33	8.50	8.84
	$MgCO_3$	51.27	79.97	87.17	12.87	5.08	27.33	8.40	8.57
60%	Control	48.00	76.28	75.94	20.52	9.41	29.00	8.10	7.44
	Chitosan	46.80	79.58	80.42	16.54	6.28	30.00	8.50	7.78
	Glycerol	44.53	79.25	79.85	20.64	6.72	29.67	8.27	7.33
	$MgCO_3$	44.43	77.64	78.57	18.76	7.25	28.67	8.13	7.03
	$LSD_{0.05}$	3.03	1.72	1.97	2.36	3.08	1.49	0.25	0.30

Chl: chlorophyll, RWC: Relative water content, MSI: Membrane stability index, POX: Peroxidase activity by spraying chitosan at the recommended irrigation level (100%), in both seasons, higher values for MSI were obtained by applying chitosan and glycerol at the recommended irrigation level (100%) and by chitosan at 80% of the recommended irrigation level, in both seasons. It is clear from the data in Table 7 that spraying the glycerol as anti-transpirant was significantly effective in enhancing the chlorophyll, RWC, and sugar yield for the sugar beet plant under an 80% tested irrigation regime. The addition of chitosan or glycerol at an irrigation level of 100% or 80% gives the lowest values of proline in both seasons and the lower value of POX given by spraying of chitosan with water irrigation level of 100% in both seasons (Table 7).

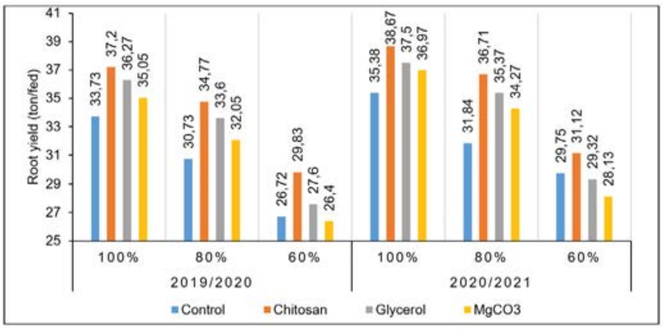

Figure 1. Effects of the interactions between foliar application and levels of water stress on root yield of sugar beet crop during in 2019/2020 and 2020/2021 seasons

The lowest values for all yield traits were obtained under 60% in both seasons, indicating that deficit irrigation or drought stress limits agricultural production, resulting in a variety of deleterious impacts on plant health, including the production of reactive oxygen species (ROS), which causes membrane lipid peroxidation and interactions with the other macromolecules, resulting in reduced plant growth and yield (Yang et al., 2009; Bistgani et al., 2017). Drought stress also inhibits chlorophyll production by impairing photosynthetic capacity. The decrement of chlorophyll content during drought stress might be due to the destruction of chlorophyll pigment complexes (Farouk and Amany, 2012). In comparison to control plants, anti-transpirant lowers vapor (water movement) and photosynthesis, as well as leaf permeability to carbon dioxide exchange.

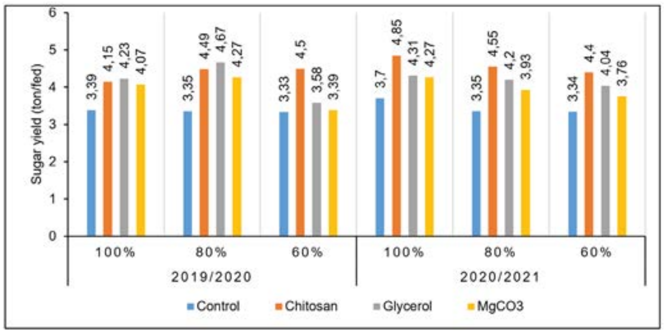

Figure 2. Effects of the interactions between foliar application and levels of water stress on sugar yield of sugar beet crop during in 2019/2020 and 2020/2021 seasons

The same results were found by Khan et al. (2002) and Sheikha and Al-Malki (2011) who said that an increased photosynthesis level was observed when maize, soybean, and bean were treated with chitin oligosaccharides, this may be due to an increase in nitrogen and potassium content in plant shoot which helps photosynthetic pigments under drought (Hidangmayum et al., 2019). Chitosan foliar application under drought stress reduced the negative impact of drought conditions, able to alleviate these effects in most crops and increased plant development (Bistgani et al., 2017), while other anti-transpirants such as glycerol which formed a thin film on the leaves and $MgCO_3$ which reflecting sun radiation) and did not affect the stomatal opening which suggests that photosynthetic activity and stomatal conductance changes proportionally, thus reducing assimilated carbon as water consumption decreases.

Data in Table 8 expresses that the interaction between anti-transpirants and irrigation levels caused a significant increase in sucrose percentage and quality index under three water levels in the 2020 seasons and with the application of chitosan under 60% in 1st season.

The same results were found by Farouk and Amany (2012) who decided that total carbohydrates increased when sprayed with chitosan under drought stress. This could be because the breakdown of polysaccharides, which aid in the maintenance of turgor, causes an increase in total soluble sugar buildup under drought conditions (Nazarli et al., 2011). Peas, sugar beets, and black poplars all benefit from soluble sugars, which help them withstand drought (Liu et al., 2011).

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Table 8. Effects of the interactions between foliar application and levels of water stress on sugar beet growth and yield parameters during in 2019/2020 and 2020/2021 seasons

Irri. level	Treats	Traits						
		Sucrose (%)	K (%)	Na (%)	α-a N	QI (%)	SLM (%)	ES (%)
		2019/2020 season						
100%	Control	15.44	4.09	2.47	5.31	80.33	2.75	10.02
	Chitosan	15.75	2.98	1.76	4.94	83.47	2.40	11.16
	Glycerol	15.72	3.54	2.44	4.68	82.30	2.51	11.66
	$MgCO_3$	15.68	3.66	2.48	5.09	81.70	2.63	11.61
80%	Control	15.14	4.37	2.09	4.48	80.70	2.52	10.89
	Chitosan	16.83	4.14	1.37	3.97	84.83	2.26	12.90
	Glycerol	17.34	4.81	1.60	3.20	83.90	2.20	13.89
	$MgCO_3$	16.50	3.71	1.54	4.10	84.30	2.26	13.32
60%	Control	16.11	4.47	1.96	3.84	82.20	2.36	12.49
	Chitosan	18.93	4.28	0.90	3.58	86.80	2.15	15.13
	Glycerol	16.90	4.07	1.00	3.84	85.87	2.17	12.96
	$MgCO_3$	16.55	4.15	1.41	3.35	84.80	2.11	12.82
	$LSD_{0.05}$	1.96	1.30	0.51	1.29	1.71	0.24	2.20
		2020/2021 season						
100%	Control	14.95	5.46	1.77	4.18	78.83	2.56	10.46
	Chitosan	16.37	4.93	1.54	2.08	83.73	1.93	12.54
	Glycerol	15.95	4.75	1.85	3.61	81.83	2.33	11.48
	$MgCO_3$	15.57	4.98	2.00	3.55	80.60	2.36	11.54
80%	Control	15.37	5.28	2.14	3.98	79.50	2.38	10.54
	Chitosan	16.73	4.22	1.81	3.39	83.67	2.34	12.41
	Glycerol	15.97	4.47	1.90	3.84	82.47	2.35	11.87
	$MgCO_3$	15.79	4.37	2.21	4.14	81.40	2.46	11.46
60%	Control	15.60	4.44	2.36	4.58	80.43	2.60	11.22
	Chitosan	17.07	4.93	1.36	2.77	84.20	2.08	14.15
	Glycerol	16.05	3.85	1.66	4.03	83.33	2.28	13.78
	$MgCO_3$	15.88	3.76	2.24	4.69	82.47	2.51	13.37
	$LSD_{0.05}$	0.72	1.17	0.70	1.49	0.79	0.31	1.15

α-a N: Alpha-amino nitrogen, SLM%: Sugar lost to molasses%, ES%: Extracted sugar% and QI: Quality index

Sugars like glucose and fructose aid drought tolerance by modulating plant growth, development, and stress responses through signal transduction (Rolland et al., 2006). These carbohydrates boost glucose, fructose, mannose, trehalose, sorbitol, and myoinositol in chitosan-treated plants (Li et al., 2017). Increased osmotic adjustment and carbon balance maintenance in response to dehydration stress may contribute to increased drought resistance. Also, data showed that the application of chitosan or glycerol with 100% of water level decreased potassium percentage, while with 60% gave lower values for potassium, sodium, and α-amino nitrogen, also, chitosan under 80% significantly decreased them. This indicates that the interactions between the factors evaluated had a substantial effect.

Water consumptive use (WCU)

According to Figure 3, sugar beet water consumption increased by 531.3 and 1090.5 m^3 of water when irrigation was applied at 100% recommended days versus 80 and/or 60% in the first season, corresponding to 492.5 and 1091.2 m^3 of water in the second season, respectively. Prolonging the period of irrigation at 60% recommended irrigation leads to a gradual decrease in the values of water consumptive use of sugar beet plants in both seasons. Foliar sprayings were applied. Chitosan gradually decreased as in the values of water consumptive use of sugar beet plants in both seasons. It was noticed that the maximum values of water consumptive (3250 and 3320 m^3/fed) were recorded at 100% of the recommended days compared with that irrigated at 80 and/or 60% in both seasons.

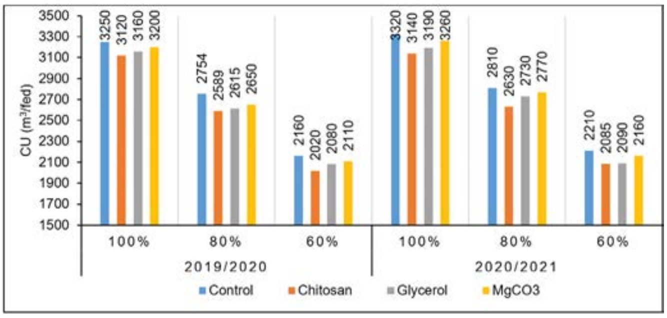

Figure 3. Effect of irrigation levels, anti-transpirant treatments, and their interaction on water consumptive use (m^3/fed) in 2019/2020 and 2020/2021 seasons

Water use efficiency (WUE)

Data in figures 4 and 5 indicate that the values of WUE calculated either as roots or sugar (kg/m^3 water). Water use efficiency increased gradually as irrigation decreased from 100 to 60% of the recommended irrigation and reached its maximum value when irrigation was given to sugar beet at 60% of the recommended compared days intervals, followed by that applied at 80 and 100 of the recommended days.

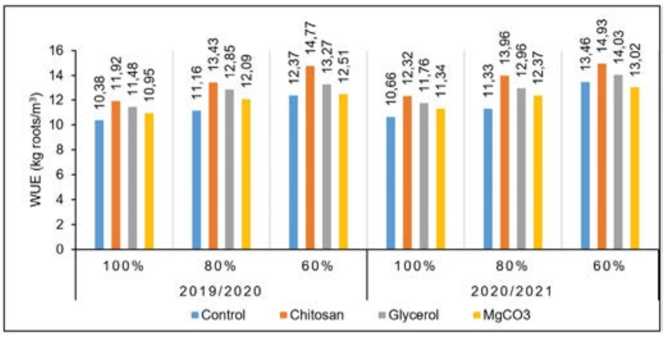

Figure 4. Effect of irrigation levels, anti-transpirants treatments, and their interaction on water use efficiency for roots (kg/m^3), in 2019/2020 and 2020/2021 seasons

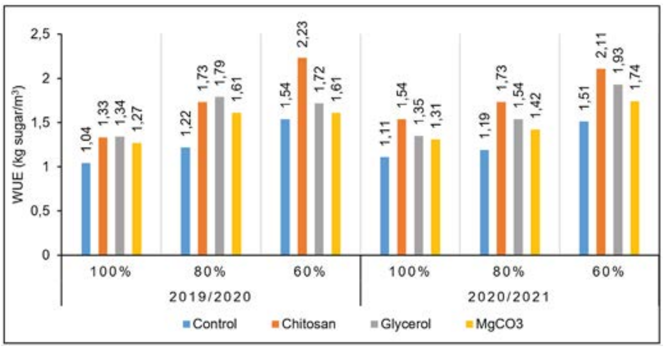

Figure 5. Effect of irrigation levels, anti-transpirants treatments, and their interaction on water use efficiency for sugar yields (kg sugar/m^3 water consumed) in 2019/2020 and 2020/2021 seasons

Foliar sprays were applied Chitosan gradually increased the values of the WUE of sugar beet plants in both seasons. It was noticed that the maximum values of WUE consumptive kg roots (13.17 and 13.56 kg/m^3 water) and kg sugar (1.33 and 1.76 kg/m^3 water) were recorded by foliar sprayings with chitosan in both seasons.

CONCLUSIONS

Anti-transpirant applications to plants in high evaporative demand conditions reduced water use while slightly improving chlorophyll, RWC, and MSI of leaves and increasing quality parameters of beet crop.In addition, anti-transpirant treatment reduced water requirements, allowing irrigation water to be conserved for a longer time, allowing irrigation frequency to be reduced without significant production reductions when compared to control plants. As a consequence, WUE increased while maintaining root quality parameters. The use of chitosan as an anti-transpirant agent will be appropriate for crops subject to drought, heat, thirst, or lack of water. Under study conditions, chitosan-treated plants allow their natural physiological mechanisms to quickly restore optimal carbon uptake while sustaining biomass and yield in these conditions. Thus, under conditions of the present investigation, planting sugar beet varieties with spraying chitosan or glycerol as anti-transpirant under irrigation at the recommended level can be recommended to obtain the highest root and sugar yield/fed.

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