Impact of Water Stress on Growth, Productivity and Powdery Mildew Disease of Ten Sugar beet Varieties

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ABSTRACT

Powdery mildew is a fungal disease that causes a serious reduction in both root and sugar yields in sugar beet areas in Egypt. This study aimed to determine the effect of three water stress treatments namely, IR_1 (recommended irrigation times), IR_2 (3 withholding irrigation times), and IR_3 (4withholding irrigation times) on powdery mildew infection severity and yield components of ten sugar beet varieties. The experimental design was a split-plot design with three replications at Al-Fayoum Governorate, (29°17 ` N; 30°53 ` E), Egypt, during 2017/2018 and 2018/2019 growing seasons. Results showed that disease severity varied significantly under the three water stress treatments, which were about 21.02, 18.71, and 16.60 %, respectively. Meanwhile, IR_3 (4 withholding irrigation times) is more effective in the control of powdery mildew disease, but it is the lowest one in yield components traits. Varieties i.e. Heba, Pleno, Beta 382 and Sibel registered the lowest values of disease severity percentage (11.77, 13.64, 14.90, and 16.40%, respectively). Withholding of irrigation had a significant effect ($P< 0.05$) on sugar and root yields so that IR_3 water stress treatment registered lower yield (2.78 and 18.53 ton/fed) than IR_2 water stress treatment (3.17 and 22.60 ton/fed). As a result, growing sugar beet under IR_2 water stress produced higher sugar content and less amino-N and Na accumulation in the root, as compared to IR_3 water stress. The lowest disease severity percentage (11.77%) along with the best root yield (22.20 ton/fed) was observed in Heba variety. Sugar beet varieties i.e. Heba, Beta382, and Sibel registered the highest value of oxidative enzymes (catalase, peroxidase, polyphenol oxidase), and we can be recommended these as tolerant disease varieties. Skipping one or more irrigation to reduce the powdery mildew disease was recommended. According to the results, the stress tolerance index (STI) and of geometric mean productivity (GMP) appears to be a suitable selection index to distinguish tolerant sugar beet varieties for water stress. Breeders should focus on the performance of varieties with high root yield in diverse environments and high extractable sugar.

Keywords: Sugar beet, powdery mildew, disease severity, water stress, stress tolerance index.

INTRODUCTION

Sugar beet (*Beta vulgaris* L.) is considered as one of the two important sugar crops worldwide. Total sugar beet cultivated area reached 208.33 thousand hectares in Egypt. Recently sugar beet surpassed sugar cane in sugar productivity and became the first source of sugar production in Egypt compared to sugar cane. Sugar beet is suffering from infection with many important plant diseases in various stages of development. Fungal diseases are the most important diseases that affect beet in terms of economic importance and spread.

Powdery mildew is considered one of the most dangerous fungal diseases affecting sugar beet in several sugar beet growing countries. Powdery mildew caused by *Erysiphe betae* (Vanha) is a serious fungal foliar disease resulting in sugar yield losses of up to 30% and reduced the root yield by 20-25% and responsible for low production of sugar (Francis, 2002). In recent years, sugar beet powdery mildew disease began to spread in Egypt and became economically worthwhile. The disease appears first on lower and older leaves and gradually spreads towards the upper and younger leaves and infection is more common on upper surface of leaves than the lower ones (Srivastava, 2004), and caused declining rates of net photosynthesis as it directly affect the composition of sugar and other materials needed by the plant to supplement its life cycle (Hills *et al.*, 1980). Disease damage varies in different regions, the disease spread and severity is largely dependent on weather condition in last winter and the summer of planting year (Draycott, 2006). Climatic elements affected a lot the growth and spread of this disease, as the incidence of this disease intensifies in humid weather, as humidity ranges from 30 to 50% accompanied by a moderate temperature (22 to 32 °C).

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The relationship between water stress, powdery mildew, and productivity traits of sugar beet has been studied before. Most studies showed that water stress has a remarkable impact on disease control (Asher and Dewar, 2001). Irrigation regimes are more effective in controlling sugar beet powdery mildew disease (Basati *et al.,* 2015). The timing, frequency, amount, and mode of irrigation may affect both yield and physiological traits responses (Abu-Ellail *et al.,* 2016) and sensitivity to pathogenic agents (Pivonia *et al.,* 2004), thus altering disease incidence and severity. As Rotem and Palti (1969) have suggested, irrigation influences disease development not only via an impact on conditions that favor host infection but also in terms of pathogen sporulation and subsequent spore dispersal. Flooding irrigation may increase the risk of foliar diseases compared to water stress.

Water stress is a major limiting factor that affects crop productivity in semi-arid regions. Because the quantity and distribution of rainfall are unpredictable in most arid regions, crop varieties must be produced under a wide range of moisture conditions. Drought tolerance should be considered an essential breeding objective in areas where the sugar beet crop is likely to encounter a water deficit (Sadeghian *et al.,* 1999). Varieties with high productivity in both stress and non-stress conditions are useful for breeding purposes. Indicators of stress tolerance are useful in choosing adapted varieties like the drought sensitivity index (DSI), geometric mean productivity (GMP) and the stress tolerance index (STI) for screening drought tolerant genotypes in stress and non-stress conditions. (Hesadi *et al.,* 2015, Sadeghian *et al.,* 2000, and Mohamdian, 2010). The aims of this study were to evaluate the effect of water stress on yield, quality, and control of powdery mildew disease of ten sugar beet varieties, as well as to determine the efficiency of tolerance indices to identify drought-tolerant sugar beet varieties.

MATERIALS AND METHODS

The experiments were carried out at Al-Fayoum Governorate, (29°17 ` N; 30°53 ` E), Egypt, to study the effect of three water stress treatments namely, IR_1(recommended irrigation times), IR_2 (3 withholding irrigation times), and IR_3 (4 withholding irrigation times) (Table 1) on powdery mildew disease of ten sugar beet varieties during the two successive growing seasons 2017-2018 and 2018-2019. This study was conducted under heavily natural infection conditions with powdery mildew disease. The fertilizers and all other agronomic practices were applied as recommended by the Ministry of Agriculture and Land Reclamation, Egypt.

The surface soil sample taken from the experimental site at a depth of (30-40 cm) before planting to identify some physical and chemical properties of the experimental soil as shown in (Table 2). The present study was arranged in a split-plot design with three replications. The water stress treatments were allocated in main plots, separated from each other by 1meter distance to prevent water leakage during water treatment, meanwhile, varieties were occupied the subplot was randomly distributed in the subplot. Each experimental basic unit included 5 rows, 60 cm apart, 5 m long, and 20 cm between plants, comprising an area of 15 m^2. Experiments were sown on November 25*th* and 21*th* in the first and second seasons, respectively. Monthly weather data at Fayoum, Egypt as an average for the two growing seasons of study are presented in Table 3.

Assessment of powdery mildew disease:

When the severity of the disease reached its maximum, the recording was conducted to determine the extent of disease infection. For the determination of infection percentage and selection of healthy plants, the index suggested by Paulus *et al.,* (2001) was used which is the latest index used for powdery mildew damage. Determination of disease assessment after four months from sowing, powdery mildew leaf spot was counted on 50 plants and disease severity was calculated according to the scale of Whitney *et al.,* (1983). For each treatment in each replication, 100 leaves were recorded and the infection score was attributed.

Table 1. Water stress treatments followed in this experiment

Weeks	4 w	7 w	10 w	13 w	16 w	19 w	22 w	25 w	28 w
IR_1	+	+	+	+	+	+	+	+	+
IR_2	+	-	+	+	-	+	+	-	+
IR_3	+	-	+	-	+	-	+	-	+

IR_1= normal irrigation , IR_2= 3withholding irrigation and IR_3= 4 withholding irrigation

(-) = Skipping or withholding irrigation , (+) = Irrigation

Table 2. Chemical and physical properties of the experimental soil

	Mechanical analysis		Chemical analysis		
Properties	**2017-18**	**2018-19**	**Properties**	**2017-18**	**2018-19**
Sand %	21.9	23.6	Ca^{++}	9.8	11.34
Silt %	39.9	29.9	Mg^{++}	5.55	5.64
Clay %	38.2	46.5	Na^{+}	18.3	19.7
Soil texture	Silty clay		K^{+}	0.65	0.42
EC (dSm-1)	1.43	1.71	HCO_3^{-}	2.5	2.8
Ph (1:2.5)	7.31	7.29	Cl^{-}	26.1	29.2
*Sp%	70	60	SO_4^{-}	5.7	5.1

*SP= Saturation percentage.

Table 3. Monthly temperature and relative humidity

Months	Temperature °C		Relative Humidity %	Temperature °C		Relative Humidity %
	Maximum	Minimum		Maximum	Minimum	
	2017-2018			2018-2019		
Nov.	25.96	12.84	47.93	23.95	10.29	46.59
Dec.	21.49	9.90	43. 54	20.40	6.60	52.82
Jan.	17.68	4.72	50.01	18.46	4.75	53.31
Feb.	20.32	5.16	44.35	24.29	9.94	37.47
Mar.	26.85	13.17	34.58	25.20	14.20	44.00
Apr.	31.10	13.40	35.00	29.00	11.80	36.21
May	36.80	19.50	33.00	33.60	16.30	35.12
Mean	25.74	11.56	41.20	24.99	10.55	43.65

Source: Meteorological Department, Agricultural Research Center, Ministry of Agriculture.

Scale ranged from 0-5, categories whereas 0= no mildew colonies observed 1= 1-10%, 2= 11- 35%, 3 = 36-65%, 4 = 65-90% and 5 = 91-100%, respectively of matured leaf area covered by mildew and the average disease rating per treatment was calculated.

Disease severity (%) =

$$\frac{\{\sum(\text{rating no.})\times(\text{no. leaves in rating category})\times(100)\}}{(\text{Total no. leaves})\times(\text{highest rating value})}$$

Biochemical changes determination:

This study was carried out to determine some biochemical changes associated with the different treatments. Thus, total chlorophyll content, phenolic compounds, as well as the activity of oxidative enzymes, were determined in the leaves of ten sugar beet plants collected randomly from the second row of each sub plot from each sugar beet variety grown under different water stress treatments as follow:

1. **Total chlorophyll content of leaves:** was measured as optical density (OD) using Chlorophyll meter Model (SPAD-502) according to Uddling *et al.*, (2007).
2. **Total phenolic compounds:** was determined using UV/Vis. Spectrophotometer, Jenway England at wavelength 750 nm as described by Singleton *et al.*,(1999) determined England (Folin and Ciocalteau phenol reagent).
3. **Activities of oxidative enzymes:** Sample preparation: 0.5 g leaf was homogenized at 4 ° C with a 2 ml sodium phosphate buffer of 0.1 M (pH 6.5). The homogeneous material was centrifuged at 10,000 rpm for 2 min and the supernatant is used as an enzyme source for plant defense enzymes estimation. Peroxidase activity (POD) was determined by measuring the oxidation of guaiacol in the presence of hydrogen peroxide into the water at 470 nm as described by Hammerschmidt *et al.*, (1982). The activity was expressed as the increase in absorbance at 470 nm in $min^{-1}mg^{-1}$ of protein. Polyphenol oxidase (PPO) activity was measured as per the procedure given by Mayer *et al.*, (1965). Oxidation of the substrate catechol to yellow color benzoquinone was measured at 495nm. The activity was expressed as a change in absorbance at 495 nm in $min^{-1}mg^{-1}$ of protein. Catalase (CAT) activity was measured as mentioned by (Maxweell and Bateman, 1967). Results were calculated taking control as

100% to find increase or decrease in activities of enzymes.

At harvest 210 days from planting, the three guarded central rows of each sub- plot per each variety under the three water stress treatments were harvested to estimate yield and its attributes, as well as the following growth traits were estimated from random five plants:

Growth traits

Root length (cm), Root diameter (cm), and Root fresh weight/plant (kg).

Productivity traits

1. Root yield (ton/fed): Calculated from root weight of experimental unit then converted to ton/fed.
2. Top yield (ton/fed): calculated from top weight of experimental unit then converted to ton/fed.
3. Sugar yield (ton/fed): calculated according to the following equation: Sugar yield (ton/fed)= extractable sugar% x root yield (ton/fed)/100

Quality traits

Quality traits were determined in Al-Fayoum sugar company laboratories.

1. Impurities of juice, (K and Na) and Alpha-amino-N concentrations were estimated according to Brown and Lilliand (1964)
2. Sucrose% was estimated in fresh root samples using (Saccharometer) according to the method described by A.O.A.C. (2005).
3. Sucrose loss to molasses (SLM %) was determined according to (Devillers, 1988).
4. Extractable Sugar % =Sucrose % – SLM% - 0.6 (Dexter *et al.*, 1967).

Statistical analysis

Data collected from each season was statistically analyzed according to Gomez and Gomez (1984) by using SAS computer software package. The separate analysis of variance for different treatments and the combined analysis of variance for different characters were performed on plot mean basis. Revised L.S.D at 5% level was used to compare the means according to Waller and Duncan (1969). Three selection indices, drought susceptibility index (DSI), stress tolerance index (STI) and geometric mean productivity (GMP), were estimated for each variety based on root yield and sugar yield under stress (Ys) and non-stress (Yp) conditions. Drought resistance indices were calculated using the following equations:

(1)

$$DSI = \frac{1-(\frac{Ys}{Yp})}{1-(\frac{\overline{Ys}}{\overline{Yp}})}$$ (Fischer and Maurer, 1978)

(2)

$$STI = \frac{Yp \times Ys}{(\overline{Yp})^2}$$ (Fernandez, 1993)

(3)

$$GMP = \sqrt{Yp \times Ys}$$ (Fernandez,1993)

Where Ys is the yield of variety under stress, Yp the yield of variety under irrigated condition, $\overline{Ys}$ and $\overline{Yp}$ are the mean yields of all varieties under stress and non-stress conditions, respectively, and $1 - (\overline{Ys}/\overline{Yp})$ is the stress intensity. The irrigated experiment was considered to be non-stress conditions in order to have a better estimation of the optimum environment.

RESULTS AND DISCUSSION

Effect of water stress and varieties on powdery mildew disease:

According to the climatic data of El-Fayoum district in Table (3), show that mean of relative humidity % for two growing seasons (2017-2018 and 2018-2019) is 41.20 and 43.65 %, respectively, as well as, the mean minimum and maximum temperatures for two growing seasons are (11.56 and 25.74 °C) and (10.55 and 24.99°C), respectively, therefore it is suitability to spread powdery mildew disease. Data in harmony with (Neher and Gallian, 2013) who reported that the optimal temperature range for infection and colony development is (15°–30°C), infection occurs when daily temperatures fluctuate by up to (15°C) between daytime and nighttime and under conditions at a very low relative humidity (30–40%), as well as, (Hills *et al.*, 1980) found the disease score rate increased with increasing relative humidity up to 100%, in fact, decreasing moisture in soil inhibited disease infection and colony development. In the conditions of the absence of control measures, the disease severity of powdery mildew increased (Gado, 2013), the control of disease is mainly achieved by applications of increased plant spacing, used tolerant sugar beet varieties, and avoid excess nitrogen and irrigation (Francis, 2002).

1. Disease severity (%):

Results in Table (4) indicated that powdery mildew disease severity (DS %) was significantly decreased with increasing water stress during the two successive seasons. Average disease severity was decreased to 18.71 and 16.60% by withholding (3 and 4 times of irrigation, respectively) compared with normal treatment (21.02%). A significant difference in disease severity % was also observed among varieties. Heba cv. recorded the lowest disease severity (11.77%) followed by Pleno cv. (13.64%) and Beta382 (14.90%)

compared to the other treated varieties. Otherwise, Oscarpoly cv. recorded the highest value of D.S % (25.66%). A significant difference ($P < 0.05$) was also observed among varieties for the infection score. Concerning the evaluated sugar beet varieties, data indicated that powdery mildew disease severity% was significantly varied among the ten sugar beet varieties in the two growing seasons. It could be noticed that varieties (Oscarpoly, Pyramide and Univers) were most sensitive in the two growing seasons. The significance of water stress × varieties interaction ($P < 0.05$) showed that cultivars did not have the uniform performance for disease severity%. This result might be due to the gene make-up, which plays an important role in plant structure and morphology. These findings are in the same line with those reported by Pivonia *et al.*, (2004) indicated that less frequent and reduced irrigation postponed the onset of plant collapse and lowered disease incidence.

2. Total chlorophyll:

Total chlorophyll in leaves decreased significantly by increasing water stress (Table 4). Meanwhile, the highest total chlorophyll was produced by using moderate stress compared with normal irrigation treatment. This might be due to increasing disease severity and reducing the photosynthetic area as well as toxicity from toxins produced by the powdery mildew which prompts the plant to produce new leaves to compensate this loss of leaves and thus lead to a shortage in root crop and sugar (Barry *et al.*, 2000 and Gary *et al.*, 2011). A significant difference ($P < 0.05$) was also observed among varieties for the chlorophyll content. Resistant varieties (Heba, Pleno, Beta382 and Sibel) showed low infection under an increased number of furrow irrigation the rate was lower than susceptible varieties (Oscarpoly, Univers and Pyramide) which were held less chlorophyll (49.18, 51.25 and 53.16%, respectively). The decreasing number of irrigation led to increasing chlorophyll under RI_2 (withholding of 3 irrigation times), but with increasing withholding to 4 times, it was decreased. High moisture is not favorable for mildew and control disease (Yarwood, 1978), meanwhile chlorophyll content increased by increasing irrigation (Bhattacharya and Shukla 2002).

Table 4. Effect of water stress treatments on disease severity%, total phenols%, and chlorophyll% of ten sugar beet varieties during the combined of two growing seasons 2017/2018 and 2018/2019.

Varieties	Disease severity%			Mean	Total Phenols%			Mean	Chlorophyll %			Mean
	IR_1	IR_2	IR3		IR_1	IR_2	IR3		IR_1	IR_2	IR3	
Beta382	16.61	15.31	12.79	14.90	98.44	113.38	115.34	109.05	56.76	66.99	65.48	63.08
Gazelle	23.78	20.40	18.96	21.05	49.37	53.31	55.32	52.67	50.69	61.03	59.57	57.10
Heba	13.37	12.02	9.93	11.77	95.87	105.81	108.82	103.50	60.78	71.03	69.74	67.18
Nancy	19.84	17.55	15.28	17.56	71.31	75.23	77.47	74.67	52.62	62.95	57.82	57.80
Oscarpoly	29.38	25.08	22.51	25.66	48.03	51.86	53.87	51.25	42.85	53.09	51.61	49.18
Pleno	15.21	13.91	11.79	13.64	97.53	103.36	105.37	102.09	58.77	69.01	66.88	64.89
Pyramide	25.31	24.11	22.32	23.91	46.79	50.73	52.81	50.11	46.78	57.02	55.68	53.16
Rona	21.85	20.55	18.15	20.18	66.34	70.28	76.36	70.99	48.81	59.05	63.88	57.25
Sibel	18.11	16.77	14.33	16.40	85.89	89.83	95.91	90.54	54.78	65.03	62.69	60.83
Univers	26.78	21.43	19.96	22.72	45.32	49.27	51.38	48.66	44.88	55.14	53.73	51.25
Mean	21.02	18.71	16.6	18.78	70.49	76.31	79.27	75.35	51.77	62.03	60.71	58.17
L.S.D at 0.05												
Water stress (S)				1.26				1.49				1.61
Varieties (V)				2.32				1.36				1.22
S × V				4.64				2.93				2.22

NS= Non-significant, IR_1 (recommended irrigation times), IR_2 (3 withholding irrigation times), and IR_3 (4 withholding irrigation times)

3. Total phenolic compounds (g/100g. fresh weight):

Increasing water stress significantly increased the total phenolic content as a result of decreasing powdery mildew infection (Table 4). In this respect, the highest phenol contents were recorded under IR_3 (4 withholding irrigation times) compared with RI_1 (recommended irrigation times). In this study, resistant varieties, Beta382 (109.05%), Heba (103.50%), and Pleno (102.09%), and Sibel (90.54%), showed the highest percentage of total phenol obtained under water stress treatments than the other susceptible varieties, Univers (48.66%), and Pyramide (50.11%) Oscarpoly (51.25%). However, under normal irrigation treatment, both susceptible and resistant varieties did not show much difference in infection rate and the total phenols. Concerning the effect of interaction between water stress and varieties, it showed a significant effect on the total phenolic components. This result may be due to decrease in disease severity% which occurred after 4 withholding irrigation times, according to Matern and Kneusal (1988) and Khan and Smith (2005), the first step of the defense mechanism in plants involves a rapid accumulation of phenols at the infection site, which act as mobilized defense system can be translocated by plants and enzymatically converted into defensive substance.

4. Biochemical changes (Oxidative enzymes activities)

Data in (Fig. 1) revealed that significant effects under water stress treatments and powdery mildew disease on catalase (CAT), polyphenol oxidase (PPO) and peroxidase (POD) activities in ten sugar beet varieties. Under IR_2 (withholding 3 irrigation times), and under IR_3 (withholding 4 irrigation times), the activities of the enzymes were significantly increased in all varieties compared to IR_1 (recommended irrigation). Enzyme activity played an important role in plant disease tolerance through increasing plant defense mechanisms that are considered the main tool of varietal resistance (Takuo *et al*., 1993 and El-Habbak, 2003). Sugar beet varieties (Heba, Pleno, Beta382, and Sibel) were recorded the highest percentage of CAT, PPO, and POD activities) under IR_2 and IR_3, compared with $IR_{1,}$ normal irrigation. These varieties are mentioned above as the most tolerant to water stress and powdery mildew disease. The increase in enzyme activity increased the induced resistance closely associated with active resistance to powdery mildew biosynthesis, such as phytoalexins, phenols, lignins (Alkahtani *et al.*, 2011).

According to data presented in (Fig. 1), there was a significant induction for oxidative enzymes, catalase (CAT), peroxidase (POD), and polyphenol oxidase (PPO) in sugar beet plants under IR_2 and IR_3 water stress treatments. The highest increasing levels of oxidative enzymes were induced by IR_3 water stress. Significant responses among the tested sugar beet varieties to water stress, as well as CAT, PPO, and POD enzymes induction rates were higher in the tolerant varieties than the susceptible varieties. According to the obtained results, reduction of disease severity values was positively correlated with the induction of CAT, POD, and PPO enzymes. These results are in line with the findings of Harrier and Watson (2004) and Avdiushko *et al.*, (1993) indicated that many plant enzymes are involved in defense reaction against plant pathogens and drought stress, such as POD and PPO which CAT the formation of lignin and other oxidative phenols that contribute to the formation of defense barriers for reinforcing the cell structure.

Effect of water stress and varieties on growth traits

Results in Table (5) showed that water stress had a significant effect on root length, diameter, and fresh weight at 5% probability level. Root length increased by increasing withholding irrigation times, while root diameter and root fresh weight decreased. Means comparison revealed that increase water stress up to (4 withholding irrigation times), which increased root length by 14.34%, however, decreased root diameter and root weight by 27.91 and 32.26 %, respectively, as compared with $IR_{1,}$ normal conditions.

Regarding the varieties effects, it was noticed that Nancy variety surpassed the other varieties in all growth traits where it recorded 29.5 cm, 11.15 cm and 0.92 kg for root length, diameter, and fresh weight traits. While the lowest mean value was obtained from Univers and Oscarpoly varieties, moreover, the interaction effect of water stress × varieties was significant on all investigated traits of sugar beet varieties. The difference among sugar beet varieties in this trait may be referred to their gene make-up effect. Similar results were obtained by (Abu-Ellail *et al.*, 2019 and El-Mansuob and Mohamed 2014).

Effect of water stress and varieties on yield traits

Data in Table (6) showed that water stress had a significant effect on top, root and sugar yields in growing seasons. It could be noticed that growing sugar beet under IR_3 (4 withholding irrigation times), scored the lowest values of top and root and sugar yields. Root yield was decreased by 22.27% under IR_3, water stress compared with $IR_{1,}$ normal irrigation. Results showed that sugar yield under IR_2 stress (3.17 ton/fed) was higher than under IR_1 irrigation (3.04 ton/fed).

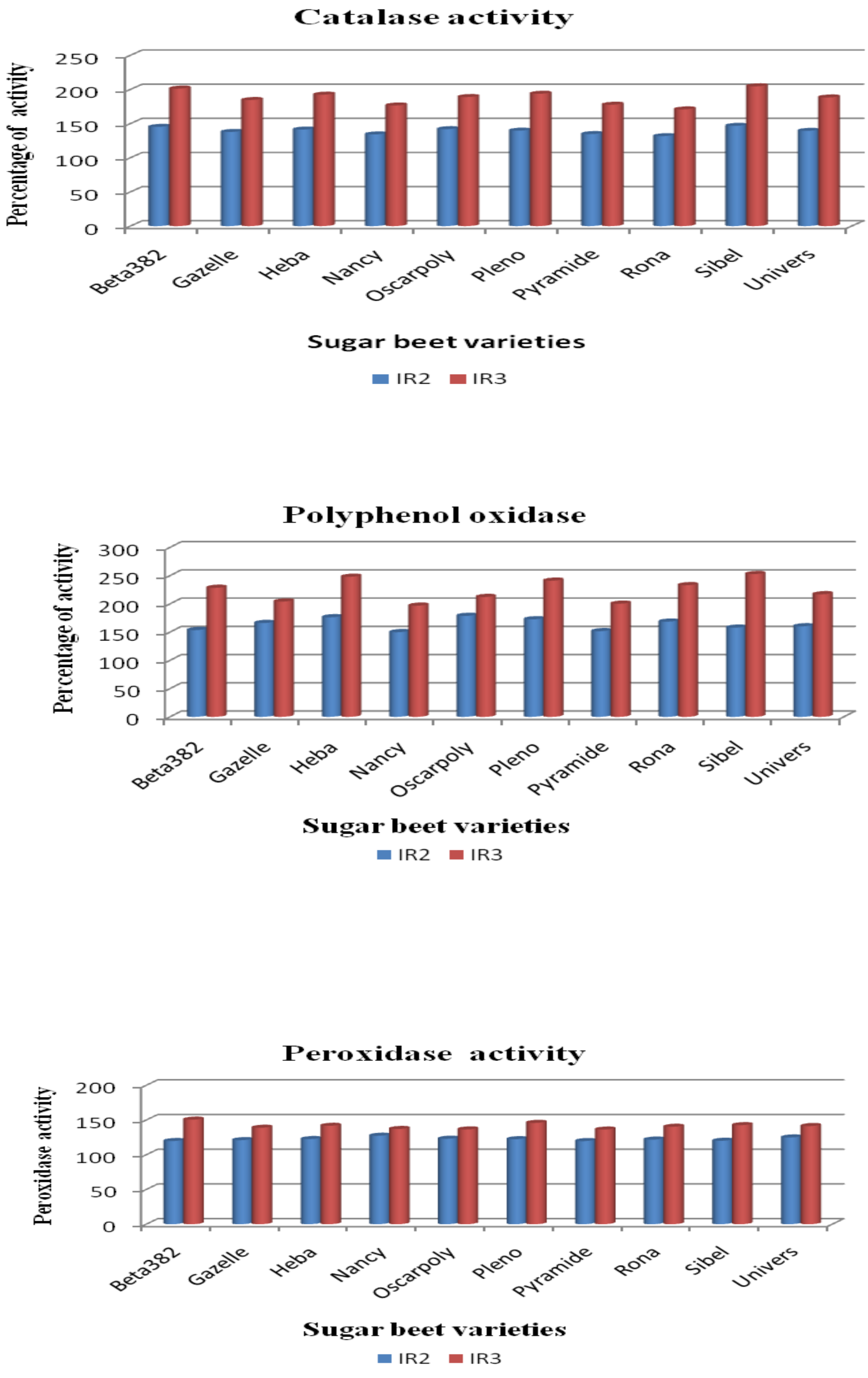

Fig. 1. Percentage of enzymes activities in ten sugar beet varieties affected by water stress treatments and powdery mildew disease

Table 5. Effect of water stress treatments on root length, diameter, and weight of ten sugar beet varieties during the combined of two growing seasons 2017/2018 and 2018/2019

Varieties	Root length (cm)			Mean	Root diameter (cm)			Mean	Root weight (kg)			Mean
	IR_1	IR_2	IR3		IR_1	IR_2	IR3		IR_1	IR_2	IR3	
Beta382	27.23	29.23	29.65	28.70	13.08	10.55	9.74	11.12	0.96	0.88	0.68	0.84
Gazelle	25.93	27.93	28.44	27.43	11.14	9.57	8.66	9.79	0.92	0.83	0.65	0.80
Heba	26.23	28.23	28.75	27.74	13.41	9.83	6.69	9.98	0.86	0.79	0.58	0.74
Nancy	28.10	30.10	30.31	29.50	12.81	11.24	9.41	11.15	1.12	0.93	0.72	0.92
Oscarpoly	23.89	25.89	26.21	25.33	10.14	8.57	7.62	8.78	0.84	0.76	0.55	0.72
Pleno	26.17	28.16	30.14	28.16	12.33	10.76	9.88	10.99	0.98	0.89	0.69	0.85
Pyramide	24.85	26.85	27.28	26.33	10.78	9.21	8.27	9.42	0.88	0.71	0.59	0.73
Rona	25.41	27.41	27.91	26.91	10.99	9.41	7.48	9.29	0.89	0.72	0.60	0.74
Sibel	27.00	29.00	29.41	28.47	12.80	10.22	9.32	10.78	0.94	0.87	0.65	0.82
Univers	24.51	26.51	26.76	25.93	10.39	8.82	7.91	9.04	0.92	0.65	0.54	0.70
Mean	25.93	27.93	29.65	27.84	11.79	9.82	8.50	10.04	0.93	0.80	0.63	0.79
L.S.D at 0.05												
Water stress (S)				1.40				0.33				0.10
Varieties (V)				0.97				1.06				0.11
S × V				1.71				1.08				0.22

NS= Non-significant, IR_1 (recommended irrigation times), IR_2 (3 withholding irrigation times), and IR_3 (4 withholding irrigation times).

Table 6. Effect of water stress treatments on top yield, root yield, and sugar yield of ten sugar beet varieties during the combined of two growing seasons 2017/2018 and 2018/2019

Varieties	Top yield (ton/fed)			Mean	Root yield (ton/fed)			Mean	Sugar yield (ton/fed)			Mean
	IR_1	IR_2	IR3		IR_1	IR_2	IR3		IR_1	IR_2	IR3	
Beta382	7.34	8.34	6.13	7.27	24.78	23.57	19.14	22.50	3.24	3.52	3.09	3.29
Gazelle	6.45	7.45	5.16	6.35	24.73	23.52	18.08	22.11	3.26	3.32	2.66	3.08
Heba	5.71	6.71	4.38	5.60	24.18	23.97	18.45	22.20	2.66	3.31	2.64	2.87
Nancy	6.76	8.76	6.40	7.31	25.43	24.22	19.72	23.12	3.65	3.66	3.09	3.46
Oscarpoly	5.51	6.51	4.14	5.39	23.57	22.36	16.96	20.96	2.98	3.01	2.55	2.85
Pleno	7.53	8.53	6.18	7.41	25.18	23.97	19.38	22.84	3.45	3.58	3.18	3.40
Pyramide	6.04	7.04	4.68	5.92	21.35	20.14	17.66	19.72	2.60	2.64	2.55	2.59
Rona	5.21	6.21	4.87	5.43	21.56	18.35	17.86	19.26	2.50	2.20	2.42	2.37
Sibel	6.12	7.12	5.77	6.34	23.61	22.19	19.7	21.83	3.02	3.06	2.99	3.02
Univers	5.09	6.69	5.37	5.72	23.96	23.75	18.31	22.01	3.13	3.55	2.70	3.13
Mean	6.18	7.34	5.31	6.27	23.84	22.60	18.53	21.66	3.04	3.17	2.78	3.00
L.S.D at 0.05												
Water stress (S)				0.56				0.13				0.21
Varieties (V)				0.44				1.07				0.28
S × V				1.05				1.00				NS

NS= Non-significant, RI_1 (recommended irrigation times), IR_2 (3 withholding irrigation times), and IR_3 (4 withholding irrigation times)

This result may be expected due to the positive effect of withholding 4 irrigation times on decreasing disease severity, meanwhile, it had a negative effect on reducing root diameter and root weight as shown previously in Tables 4 and 5, respectively. Similarly, Davidoff and Hanks (1989) reported that by decreasing the amount of water, the sugar content increased in the root. Numerous studies have shown that exposing beets to water stress leads to an increase in sugar content while causing a decrease in weight and root yield (Fotohi *et al.*, 2008). Sugar beet varieties differed significantly in top, root and sugar yields, varieties (Pleno, Nancy, and Beta382) had the highest values under treatments, while the lowest values recorded by varieties (Rona, Pyramide and Oscarpoly). The interaction effect of water stress × varieties was significant for top yield and root yield whereas sugar yield was not significantly affected by the interaction between water stress and varieties; this showed that water stress treatments and varieties under this study act independently on sugar yield; this result could be attributed to the genetic background differences among varieties. There exists a large variation in sugar beet yield and quality due to water stress tolerance among sugar beet varieties (Pigeon *et al.*, 2006). In the conditions of high disease pressure, the reduction of root yield may exceed 22% and root sucrose content may exceed 13% (Magyarosy, 1979; Karaoglanidis and Karadimos, 2006).

Effect of water stress and varieties on quality traits

Data illustrated in Table (7) showed that water stress had a significant effect on sucrose%, extractable sugar%, and sugar loss to molasses ($P < 0.05$). Results showed that mean values of sucrose% and extractable sugar% under IR_3 (4 withholding irrigation times) was (17.84 and 15.03 %, respectively) higher than IR_1 (recommended irrigation times), (15.45 and 12.76 %, respectively), while the sugar loss to molasses was decreased to 1.61% compared by normal irrigation (2.53%). These results are in agreement with those obtained by Hang and Miller, (986), who reported that the concentration of sugar in water-stressed crops rises more quickly throughout the growing season, averaging between 20 and 23 percent before harvest (g sugar per 100 g fresh roots), compared by unstressed crops under normal irrigation conditions. Deficit water in the root led to increases in the percentage of sucrose reported by Roberts *et al.,* (1980).

Table 7. Effect of water stress treatments on sucrose%, extractable sugar%, and sugar loss to molasses of ten sugar beet varieties during the combined of two growing seasons 2017/2018 and 2018/2019

Varieties	Sucrose%			Mean	Extractable sugar%			Mean	Sugar loss to molasses			Mean
	IR_1	IR_2	IR3		IR_1	IR_2	IR3		IR_1	IR_2	IR3	
Beta382	16.46	17.23	18.46	17.38	13.09	14.94	16.15	14.73	2.77	1.69	1.71	2.06
Gazelle	15.71	16.48	16.91	16.37	13.19	14.1	14.73	14.01	1.92	1.78	1.58	1.76
Heba	14.49	16.26	17.49	16.08	11.01	13.79	14.32	13.04	2.88	1.87	1.57	2.11
Nancy	16.80	17.57	18.82	17.73	14.34	15.1	15.65	15.03	1.86	1.87	1.57	1.77
Oscarpoly	15.20	15.97	17.29	16.15	12.64	13.45	15.05	13.71	1.96	1.92	1.64	1.84
Pleno	15.62	17.41	18.65	17.23	13.7	14.92	16.43	15.02	2.32	1.89	1.62	1.94
Pyramide	14.70	16.46	17.74	16.30	12.16	13.1	14.44	13.23	2.94	1.76	1.70	2.13
Rona	14.67	16.46	17.74	16.29	11.58	12.01	13.57	12.39	2.89	1.85	1.57	2.10
Sibel	14.20	17.99	18.32	16.84	12.79	13.78	15.19	13.92	2.81	1.61	1.53	1.98
Univers	16.60	17.35	16.95	16.97	13.07	14.96	14.74	14.26	2.93	1.79	1.61	2.11
Mean	15.45	16.92	17.84	16.73	12.76	14.02	15.03	13.93	2.53	1.80	1.61	1.98
L.S.D at 0.05												
Water stress (S)				0.38				0.25				0.36
Varieties (V)				0.31				0.14				0.31
S × V				0.47				0.19				0.46

NS= Non-significant, IR_1 (recommended irrigation times), IR_2 (3 withholding irrigation times), and IR_3 (4 withholding irrigation times)

Results showed that significant differences among sugar beet varieties on all juice quality traits in both seasons. Sugar beet Nancy variety recorded the highest value of sucrose% and extractable sugar% (17.73 and 15.03 %); while the value of the lowest of sugar lost in molasses (1.76 and 1.77 %) recorded by variety Gazelle and Nancy, respectively. The differences between studied varieties in juice quality traits may be due to the differences in growth, yield, and reaction to the surrounding environmental conditions prevailing during the formation of soluble solids in plants. The interaction effect between water stress and varieties was significant for quality traits with increasing withholding irrigation times. Sugar beet varieties i.e., Nancy follows by Pleno, and Beta382, which recorded the highest value of sucrose% extractable sugar% compared with other varieties. Also, sugar lost to molasses% for most varieties was reduced when withholding irrigation increased compared to normal irrigation. The results are in line with those obtained by Mahmoodi *et al*., (2008), who found that irrigation regimes treatments had a significant effect on sugar beet yield and quality traits. Abd El-Aal *et al.,* (2010) and Davidoff and Hanks (1989) reported that water stress led to increased sugar content in the plant, also there were significant differences in overall yield potential and in the sucrose yield response to water stress among sugar beet genotypes (Tarkalson *et al.,* 2014).

Effects of water stress and varieties on impurities (meq/100 g beet)

Data in Table (8) pointed out that water stress had a significant effect on Na %, and alpha-amino N in the combined of two growing seasons. It could be noticed that increasing withholding of irrigation up to 4 times increased all impurities, but the differences between treatment were not great enough to reach the five percent level of significant for k% and the difference between IR_2 (3 withholding irrigation times), and IR_3 (4 withholding irrigation times)**.** There was a significant variation among varieties for Na% and α-N % traits. Varieties, Sibel and Nancy registered the lowest value of Na% and α-N % compared the other varieties. Otherwise, potassium % was insignificantly affected by withholding irrigation and varieties, the differences between studied varieties in impurities traits may be due to the variation in growth, and reaction to the surrounding environmental conditions prevailing during the formation of soluble solids in plants. Different studies showed that plants accumulate more α-N and Na under stress and the impurities decrease under normal irrigation (Fotohi *et al.,* 2008; Abu-Ellail *et al.,* 2019; Ebrahimipak, 2010 and Noorjo and Bagaeekia, 2004).

Table 8. Effect of water stress beet varieties treatments on Na%, K%, and α-amino N% of ten sugar during the combined of two growing seasons 2017/2018 and 2018/2019

Varieties	Na%			Mean	K%			Mean	α-amino N%			Mean
	IR_1	IR_2	IR3		IR_1	IR_2	IR3		IR_1	IR_2	IR3	
Beta382	2.01	2.48	2.5	2.33	2.99	3.67	3.67	3.45	2.02	2.52	2.79	2.44
Gazelle	1.96	2.53	2.75	2.41	2.74	3.42	3.42	3.14	1.69	2.19	2.3	2.06
Heba	1.82	2.39	2.4	2.20	2.53	3.20	3.2	2.93	1.86	2.35	2.46	2.22
Nancy	1.74	2.30	2.35	2.13	2.91	3.58	3.58	3.31	1.68	2.17	1.95	1.93
Oscarpoly	2.12	2.59	2.89	2.53	2.58	3.24	3.24	2.96	1.93	2.42	2.52	2.29
Pleno	2.08	2.55	2.54	2.39	2.82	3.49	3.49	3.16	2.05	2.44	2.4	2.30
Pyramide	2.18	2.66	3.21	2.68	3.01	3.56	3.56	3.33	1.58	2.07	2.35	2.00
Rona	1.83	2.30	2.56	2.23	2.67	3.33	3.33	3.06	1.74	2.23	2.35	2.11
Sibel	1.59	2.06	2.03	1.89	2.77	3.44	3.44	3.19	1.68	2.17	2.21	2.02
Univers	2.03	2.50	2.89	2.47	2.75	3.42	3.42	3.15	1.76	2.25	2.27	2.09
Mean	1.94	2.44	2.61	2.33	2.78	3.44	3.44	3.17	1.8	2.28	2.36	2.15
L.S.D at 0.05												
Water stress (S)				0.34				NS				0.15
Varieties (V)				0.49				0.20				0.34
S × V				0.60				NS				0.48

NS= Non-significant, RI_1 (recommended irrigation times), IR_2 (3 withholding irrigation times), and IR_3 (4 withholding irrigation times)

In this study, the α-N, as well as Na accumulation was lower under normal irrigation times than water stress treatments. The interaction effect between water stress and varieties was significant for Na%, K%, and α-amino N% during the combined two growing seasons 2017/2018 and 2018/2019. However, by growing sugar beet plant under IR_1(recommended irrigation times), results demonstrated that Sibel variety recorded the lowest value of Na% (1.59), and the lowest value of α-amino N% (1.68%) under IR_1 treatment, in addition Heba variety recorded the lowest value of K% (2.53%). These showed that water stress treatments and varieties act dependently on the previous studied characters (Table 8). Similar results were reported by Abd El-All and Makhlouf (2017) and Hosseinpour *et al*., (2006), who found that impurities% decreased by increased water stress in the first and second seasons, respectively.

Identification of stress tolerant varieties by using selection indexes

1. Drought susceptibility index (DSI)

According to the drought susceptibility index (Fig. 2), Pleno variety followed by Sibel and Rona had the lowest (DSI) values less than unit, which were considered as varieties with low drought susceptibility and high root and sugar yields in stress and non-stress conditions, whereas Oscarpoly variety followed by Gazelle and Univers varieties with DSI values higher than the unit can be identified as high drought sensitivity and low root and sugar yields. It is concluded that the effectiveness of selection indices depends on the stress severity supporting the idea that only under moderate stress conditions, potential yield greatly influences yield under stress (Blum, 1997). Drought susceptibility index (DSI) is an effective identifier for varieties with high yield in both stressed and non-stressed environments (Sadeghian *et al.*, 2000 and Tarkalson *et al.,* 2014).

2. Stress tolerance index (STI)

Based on the stress tolerance index for root yield (Fig. 3), all varieties had STI high than the unit was considered to be tolerant genotypes and high root yield under non-stress and less reduction under stress conditions. However, there are varied significantly among varieties in the STI for sugar yield, Nancy variety followed by Beta382 and Sibel with the highest values were considered to be tolerant genotypes, whereas the Oscarpoly variety followed by Rona with the lowest STI were intolerant, results indicated that varsities with high STI usually have a high difference in yield in two different conditions. These results are in line with (Sadeghian *et al.*, 1999; Rover and Buttner, 1999) who indicated that STI was the only index, which had a positive correlation with mean sugar yield under both limited and continuous stress, as well as adequate water conditions. This confirms the advantage of STI as selection criteria for identifying high yielding, stress-tolerant sugar beet varieties.

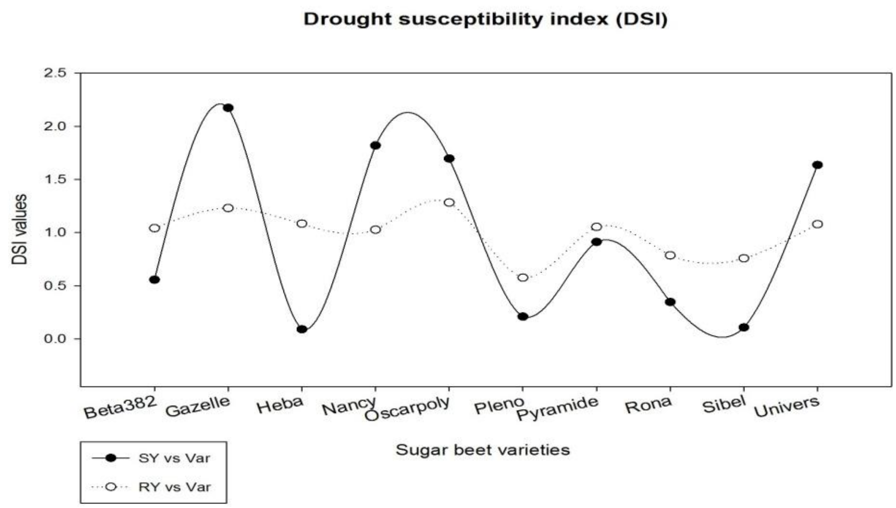

Fig. 2. Values of drought susceptibility index (DSI) for root yield (RY) and sugar yield (SY) under non-stress and stress conditions (over two years).

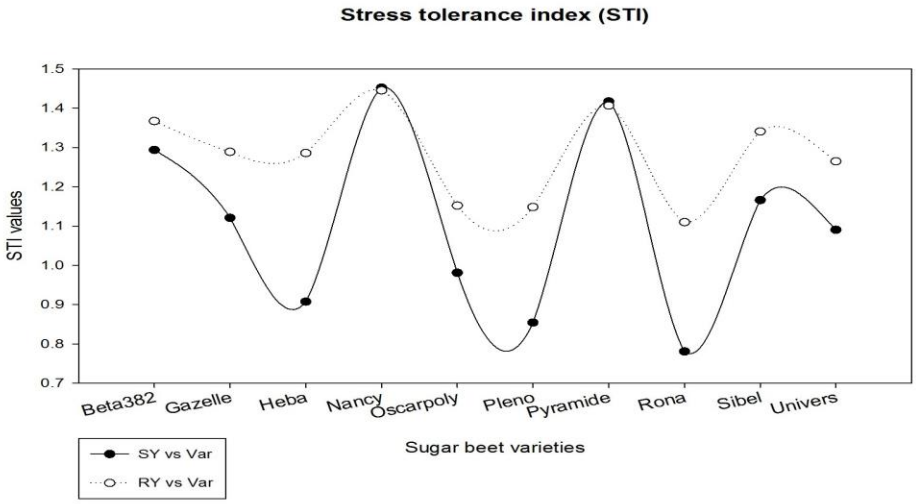

Fig. 3. Values of stress tolerance index (DSI) for root yield (RY) and sugar yield (SY) under non-stress and stress conditions (over two years).

3. Geometric mean productivity (GMP)

Results in Figure (4) indicted that geometric mean productivity (GMP) varied significant aomg sugar beet varieties for root and sugar yield. In general, similar ranks for the varieties were observed by GMP and STI indices, which suggested that these two indices were equal for selecting genotypes. Selecting high yielding varieties based on GMP index would not necessarily produce varieties that were productive in diverse environments. The difference between the highest and lowest root yielding variety was about 2.76 and 4.08 tons /fed in IR_3, stress, and IR_1, non-stress conditions, respectively (Table 6). Results suggest that indirect selection in a water stress environment would improve yield in a water stress environment better than a selection from a non-water stress environment. Selecting high yielding varieties' based on DSI, or STI indexes would not necessarily identify varieties that produce a high yield, indicated that GMP can identify genotypes with high yield potential under both stress and well-watered conditions. The index GMP exhibited a strong correlation with YS and YP, therefore, it can discriminate drought-tolerant genotypes with high white sugar yield in under stress and non-stress conditions (Hesadi *et al.,* 2015).

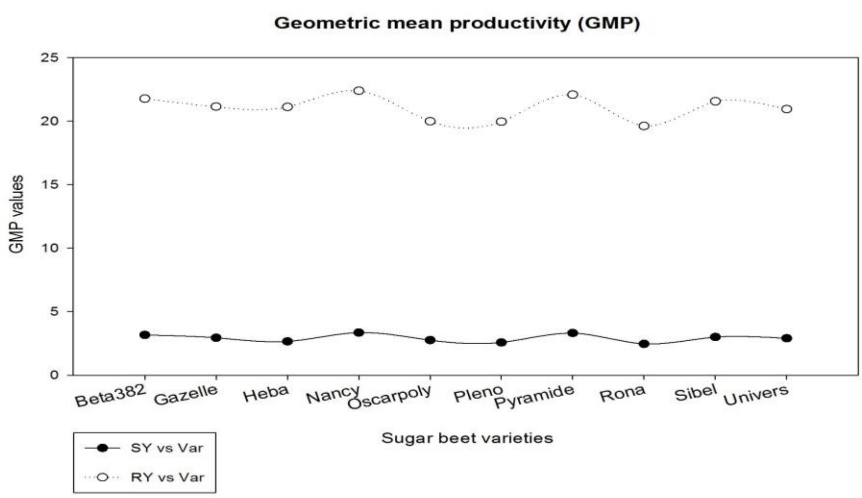

Fig. 4. Values of geometric mean productivity (GMP) for root yield (RY) and sugar yield (SY) under non-stress and stress conditions (over two years).

CONCLUSION

The present study concluded that powdery mildew disease in sugar beet plant was significantly reduced by applied the tested water stress treatments i.e. four and three withholding irrigation times compared to the normal irrigation. Three withholding irrigation times was the best treatment for reducing powdery mildew disease and gave the highest content of phenols and antioxidant enzymes. Sugar beet varieties i.e. Heba, Beta382, and Sibel recorded the highest value of oxidative enzyme activity, which is an important role defense in that are considered the main tool of varietal resistance. Sugar beet breeders should take into account the stress severity of the environment when choosing an index. DSI, STI, and GMP were able to identify varieties producing high yield in stress and non-stress conditions.

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الملخص العربي

تأثير الإجهاد المائي على النمو والإنتاجية ومرض البياض الدقيقي لعشرة أصناف من بنجر السكر

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البياض الدقيقي هو مرض فطري يسبب انخفاضًا في إنتاجية الجذور والسكر في مناطق زراعة بنجر السكر في مصر. تهدف هذه الدراسة إلى تحديد تأثير ثلاثة معاملات من الإجهاد المائى وهى كالأتى IR_1 (الري الموصى به)، IR_2(منع 3 ريات) و IR_3 (منع 4 ريات) على شدة عدوى مرض البياض الدقيقي ومكونات المحصول لعشرة أصناف من بنجر السكر. كان التصميم التجريبي عبارة عن قطع منشقة مرة واحدة بثلاث مكررات في محافظة الفيوم، (29 ° 17 ` شمالا؛ 30 ° 53 ` شرقا)، مصر، خلال مواسم 2018/2017 و2019/2018. أوضحت النتائج أن شدة المرض اختلفت بشكل كبير تحت معاملات الإجهاد المائى الثلاثة حيث بلغت 21.02، 18.71 و16.60٪ على التوالي. وفي الوقت نفسه، فإن حجب 4 ريات كان أكثر فعالية في السيطرة على مرض البياض الدقيقي ولكن نتج عنه إنخفاض في المحصول ومكوناتة. سجلت الأصناف، مثل (Heba ، Pleno ، Beta 382 ، Sibel) أدنى قيم لنسبة شدة المرض (11.77 و13.64 و14.90 و16.40٪ على التوالي). كان لمنع الرى تأثير معنوي ($P < 0.05$) على محصول السكر والجذور بحيث سجلت معاملة الإجهاد المائى (منع 4 ريات) محصولاً أقل (2.78 و18.53 طن/ فدان) من معاملة الإجهاد المائى (منع 3 ريات) (3.17 و22.60 طن/فدان). ونتيجة لذلك، أدى منع 3 فترات من الري إلى زيادة نسبة السكر وقلة تراكم الأمونيا والنيتروجين والصوديوم في الجذر، مقارنة بـ منع 4 ريات. لقد سجل الصنف (هبة) أقل نسبة شدة إصابة بالمرض (11.77٪) مع محصول جذري مناسب (22.20 طن/فدان). سجلت أصناف بنجر السكر (هبة وبيتا 382 وسيبل) أعلى قيمة للأنزيمات المؤكسدة (الكاتالاز، البيروكسيديز، بوليفينول أوكسيديز)، ويمكن التوصية بها كأصناف متحملة للبياض الدقيقى.أوصي بتخطي رية واحدة أو أكثر لتقليل مرض البياض الدقيقي.وفقًا للنتائج، يتضح أن مؤشرات تحمل الإجهاد (STI) ومتوسط الإنتاجية الهندسية (GMP) مؤشرات اختيار مناسبة لتحديد أصناف بنجر السكر المتحملة للإجهاد المائي. يجب على المربين التركيز على أداء الأصناف ذات المحصول العالي والسكر القابل للإ ستخلاص في البيئات المتنوعة.

الكلمات المفتاحية: بنجر السكر، البياض الدقيقي، شدة المرض، الإجهاد المائي، مؤشر تحمل الإجهاد.