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Tomato Production Using Magnetized Agriculture Drainage Water

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ABSTRACT

Maximizing use of water unit is one of the most important approach of sustainable agricultural development from agricultural policy-makers view around the world in the past and the future. Also, agriculture sector actively consumes large amounts of fresh water share in Egypt. Agricultural drainage water represents a significant percentage of water if it is reused again by raising its quality. So, this could be obtained by using magnetic technology (water/filed) as a means of mitigation lack of water by reusing agriculture drainage water in vegetable crops irrigation like tomato and studied plant productivity under these conditions. The objectives of this research were to evaluate the efficiency of magnetized drainage water and some anti-stressors on tomato plants behavior under Delta region conditions. The data presented in this paper are the results of two field experiments and it was observed that irrigation magnetic agriculture drainage water superior untreated plants in their effects on most of studied parameters. Concerning anti-stressors treatments, melatonin followed by glycine betaine recorded the best effects on plant growth, chemical composition, enzymes activity as well as yield and fruit quality parameters in both seasons. However, plants irrigated with drainage water only achieved the lowest values of all parameters as a result of salinity stress except fruit quality. The most concluded treatment of the superior positive effect on tomato plant productivity was irrigation with magnetized drainage water with foliar spray with melatonin, also it may be considered as the best option to save water under its scarcity and limited sources.

Keywords: anti-stressors – magnetized water – irrigation – tomato

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is the second widely cultivated and extensively consumed vegetable crop after potatoes worldwide (Pandey *et al.*, 2011). It is a natural medicine with multiple health benefits for human because of containing a significant proportion of essential amino acids, vitamins, sugars, minerals, antioxidants and dietary fibers that reduce or prevent cancer diseases opportunities (Bhowmik *et al.*, 2012). Egypt, the arid country, faces more challenges because both disorders of water balance and limited water resources (Nasr and Zahran, 2015). To fill the gap between demand and supply, reusing the agricultural drainage water should be practiced. Drainage water (DW) in Egypt reused in three ways; *i.e.* naturally, officially and unofficially. Natural reusing DW occurred when canals or rivers act as a drain for hydrologic basin aquifer systems (El Gamal *et al.*, 2005). Official reusing occurred by lifting amounts of DW from drainage canals and mixing them with the main irrigation canals. Unofficial reusing practiced by individual farmers without any pre-permissions from the ministry of water resources and irrigation (Allam and Negm, 2013). Egypt water quality regulations were developed to control types of reusing (El-Kady and Elshibiny, 1999) because the agricultural sector is the highest consumer of the available freshwater (about 85%). In addition to increasing water use efficiency, DW reusing is the most promising immediate and economic attractive solution for making water available for cultivating (Fleifle *et a.l*, 2013). Irrigation water quality for agriculture based on both the impact on crops production and soil physio-chemical properties (FAO, 1985). Using water with low quality in irrigation is the main reason of most soil problems (e.g., sodicity, salinity, restricted infiltration and contamination) (USA Salinity Laboratory, 1954). Low irrigation Water quality is characterized by lower transparency, reduction of dissolved oxygen, high electric conductivity, high levels of total dissolved solids, high alkalinity and water temperature increase (Al Hadrami, 2013).

Magnetized water treatment is considered one of magnetic field application techniques, so irrigation with the mentioned techniques can generally enhance agricultural production through developing plants growth, accelerating seedlings growth, enhancing seed germination, improving both seeds and fruits mineral contents. The effects of magnetic water (MW) depend on the type of magnetization as well as water ion-content and quality (Morimitsu *et al.*, 2000).

Great efforts have been made to mitigate the harmful effects of a biotic stress on plants productivity by using different types of plant growth stimulants. Among these substances melatonin (ML) (Zahedi *et al.*, 2020), glycine betaine (GB) (Yang and Lu, 2005), Sorbitol, and Glutathione (GSH). ML (N-acetyl-5-methoxytryptamine), found through both animals and plants kingdom. ML regulate root regeneration, plant physiology (Bose and Howlader, 2020), photosynthesis (Bahcesular *et al.*, 2020), leaves senescence (Wang *et al.*, 2012), antioxidant activity (Yang *et al.*, 2020) and immunological enhancement (Calvo *et al.*, 2013). Also, ML may boost the anti-oxidative capacity to protect plants from abiotic stresses as salinity (Kamiab, 2020), chemicals and disease (Yin *et al.*, 2013), drought (Nawaz *et al.*, 2016), low temperature (Zhang *et al.*, 2017) and heat stress (Hardeland *et al.*, 2012). ML was reported to enhance resistance against salinity stress in cucumber (Zhang *et al.*, 2014) and soybean (Wei *et al.*, 2015).

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Glycine betaine (GB) extracted from sugar beet molasses during sugar processing (Makela *et al*., 1998). Its application significantly increased yield and quality of various crops under abiotic stress conditions (Khattab and Afifi, 2009). The vital role of GB in plants under stress condition is protecting plant cells against osmotic effects *via* osmotic adjustment (Gadallah, 1999), photosynthetic apparatus protection (Allakhverdiev *et al*. 2003), protein stabilization (Makela *et al.*, 2000) and reduction of oxygen radical (Heuer, 2003).

Sorbitol (six carbon sugar alcohol), mostly found in plants, is a direct product of photosynthesis in mature leaves. Under salt-stress, sorbitol promoted the tolerance of spinach crop by improving photosynthetic pigments, carbohydrates and proteins (Gul *et al.*, 2017). Therefore, its exogenous application could be highly efficient as a method to counteract the adverse effects of salinity.

Glutathione (GSH) is a low molecular weight thiol tripeptide constituted by glutamate, cysteine and glycine. The presence of cysteine in the chemical reactivity and high water solubility of the thiol and glycine make it an important metabolite to boost plant performance including both growth and development as well as modulating plant responses under various environmental stresses (Noctor *et al.*, 2012). GSH is widely used as a marker of oxidative stress to plants, although its part in plant metabolism is a multi- faceted one (Grill *et al.*, 2001). As it is a non-protein sulphur-containing tripeptide, GSH acts as a storage and transport form of reduced sulphur. GSH is related to the sequestration of heavy metals and is also an essential component of the cellular anti-oxidative defence system, which keeps reactive oxygen species (ROS) under control (Noctor and Foyer, 1998). Anti-oxidative defence and redox reactions play a central role in the acclimation of plants to their environment, which made glutathione a suitable candidate as a stress protective component. The physiological significances of GSH may be because it regulates sulfur uptake at root level and plays a crucial role in controlling and maintaining the intracellular redox state. Under salt stress conditions, GSH is a key role through scavenging active oxygen species under salt stress ameliorate salt alterations of the plasma membrane which may enhance salt tolerance in plants (Jui-Hung et *al.*, 2012).

The present work aimed to achieve new approach in tomato irrigation for overcoming problems of water scarcity and limited water resources using magnetized agriculture drainage water (MDW) in tomato irrigation with application of some supportive foliar spray treatments. All to improve MDW qualities (that reflects on tomato productivity), enhancing different performances of tomato plants, greatly saving irrigation fresh water, meanwhile obtaining commercial tomato productivity.

MATERIALS AND METHODS

The experiment was conducted at a private farm at Sahragt El-Soghra near Mansoura, Dakahlia Governorate, Egypt, during the two successive summer seasons of 2017 and 2018 to evaluate the effect of irrigation with agricultural drainage water treatments, some foliar applications their interactions on vegetative growth attributes, leaf chemical constituents, yield and fruit quality of tomato plants (*Solanum lycopersicum* L) "6112" hybrid in Delta region under drip irrigation system.

Tomato seedlings were transplanted on 15th March in both growing seasons. Experimental layout was split plot system in a randomized complete block design with three replicates. Irrigation water treatments (magnetized drainage water and non-magnetized drainage water) were conducted in main plots and the chemical properties of drainage water were illustrated in Table 1. In the sub plots, foliar application with anti-stressors treatments (melatonin, sorbitol, glycine betaine and glutathione) plus control were randomly distributed. The experimental plot area was 24 m^2 including 3 drip lines × 10 m long × 1.6 m width. The seedlings were transplanted on one side of drip line at 50 cm apart.

Main treatments (irrigation water treatments):

1- Magnetized drainage water.

2- Non-magnetized drainage water.

Sub treatments (foliar application treatments):

1) **Melatonin**: $C_{13}H_{16}N_2O_2$ with molecular weight (232.28 g/mol), was applied at concentration of 50 µM.
2) **Glutathione**: $C_{10}H_{17}N_3O_6S$ with molecular weight (307.32 g/mol), (tri S-peptide, containing 3 amino acids) (γ-L-Glutamyl-L-cysteinyl-glycine, L-Glutathione reduced) was applied at the concentration of 50 ppm.
3) **Glycinebetaine**: $(CH_3)_3N^+$-CH^2-Coo^- with molecular weight (117.148 g/mol), was supplied by Sigma Chemical Co., U.S.A. and applied at the concentration of 50 ppm.
4) **Sorbitole:** $C_6H_{14}O_6$ with molecular weight (182.17 g/mol), was applied at concentration of 50 ppm.
5) **Control**.

All mentioned foliar substances were applied three times within 15 days' intervals started after 30 days from transplanting.

Experimental soil analysis was determined before transplanting and after magnetic treatment according to Black, 1965 and Page *et al.*, 1982 (Table 2). The experimental soil preparation, fertigation and pest control were applied as recommended by Egyptian Ministry of Agriculture and land reclamation during the two growing seasons.

Plant Sampling and Measurements: After 75 days from transplanting three plants were randomly taken from each treatment and the following characteristics were recorded

Measurements of Plant Growth Characteristics:

- Plant height (cm),
- Total fresh weight of plant (g/plant),
- Total dry weight of plant (g/plant),
- Total leaf area/plant (m^2): Calculated according to Koller, 1972.

Measurements of leaf mineral and photosynthetic pigment contents:

- Nitrogen content (N %): According to Piper, 1947.
- Phosphorus content (P %): According to Sandell, 1950.
- Potassium content (K %): According to Horneck and Hanson, 1998.
- Magnesium (%): According to Jackson, 1967.
- Zinc and manganese (ppm): As described by AOAC, 1990.
- Total chlorophyll (a+b): As described by Arnon, 1949.
- Carotenoids: As described by Arnon, 1949.

Measurements of Antioxidant Enzyme Activity:

Superoxide dismutase, catalase and peroxidase activities were determined according to Cao *et al.*, 2005 and calculated according to Kong *et al.*, 1999.

Measurements of yield: Five pickings with 10 days' intervals were done started after 90 days from transplanting to calculate:

- Early yield (ton/fed.): Fruit fresh weight of the first two pickings from plants.
- Total fruit yield (ton/fed): Plot total yield (kg) used to calculate total fruit yield (ton/fed).
- Marketable yield (ton/fed): Healthy fruits (which are not infected by any disease and free from physiological defects; i.e., suitable for consumption and conforms to the hybrid specifications (color and size) and is free from physiological defects.

Measurements of fruits quality:

- Vitamin C (mg/g fresh weight) and titratable acidity (%): As described by AOAC, 1990.
- Total soluble solids (TSS %): Was measured in fruits juice using the hand refractometer.
- Lycopene: As described by Ranganna, 1976.

Statistical analysis: The obtained data were subjected to statistical analysis of variance according to Snedecor and Cochran, 1967. Treatment means were compared using Duncan's Multiple Range Test (Duncan, 1965).

Table 1. Some chemical properties of agriculture drainage water during 2017 and 2018 seasons.

		Na^+	K^+	Ca^{++}	Mg^{++}	$CO3^-$	Cl^-	HCO_3^-
Drainage water	pH	143.4	9.99	22.0	49.0	0.01	2.8	6.62
season 2017	7.68	Fe^{++}	Zn^{++}	Mn^{++}	Cd^{++}	Cu^{++}	Ni^{++}	Pb^{++}
		0.313	0.276	0.337	0.033	0.051	0.600	0.433
		Na^+	K^+	Ca^{++}	Mg^{++}	$CO3^-$	Cl^-	HCO_3^-
Drainage water	pH	154.1	9.88	22.1	48.5	0.02	2.7	6.69
season 2018	7.55	Fe^{++}	Zn^{++}	Mn^{++}	Cd^{++}	Cu^{++}	Ni^{++}	Pb^{++}
		0.351	0.288	0.349	0.039	0.71	0.579	0.424

Table 2. Some chemical and physical properties of soil sample before and after irrigated with magnetic drainage water.

	Soil texture	Organic matter	pH	EC dsm^{-1}	Na^+	K^+	Ca^{++}	Mg^{++}	$CO3^-$	Cl^-	SO_4^{2-}
Soil irrigated with drainage water	Clay loam	1.21 %	7.68	0.895	3.87	0.13	12.41	11.23	1.58	4.26	0.89
Soil irrigated with magnetic drainage water	Soil texture	Organic matter	pH	EC dsm^{-1}	Na^+	K^+	Ca^{++}	Mg^{++}	$CO3^-$	Cl^-	SO_4^{2-}
	Clay loam	1.22 %	7.55	0.712	2.14	0.10	12.12	10.01	1.47	3.87	0.64

RESULTS AND DISCUSSION

1. Vegetative growth characteristics:

Effect of drainage water treatments:

The obtained data from Table 3 show that irrigation with magnetized drainage water (MDW) significantly achieved the best results of all recorded parameters as compared with those irrigated with drainage water (DW) in both growing seasons. MW enhances the activation of both phyto-hormones and bio-enzyme systems in plants (Taia *et al.,* 2007). In addition, MW caused some changes in properties (physical and chemical) in both soil and water i.e. reducing pH (Maheshwari and Grewal, 2009), stimulating phyto-availability on nutrients (macro and micro) in soil solution and reduced EC values (Sadeghipour and Aghaei, 2013), increasing soil micro-organisms population as well as its activity (Swelam, 2018) which expected to stimulate growth performance and productivity of plants. Similar influencing effects were indicated by Abo El-Yazied *et al.*, 2012 and Yusuf and Ogunlela, 2017.

Table 3. Vegetative growth characteristics of tomato plants as affected by irrigation with drainage water treatments, some anti-stressors and their interactions during summer seasons of 2017 and 2018.

Treatments		Plant height (cm) 2017	Plant height (cm) 2018	Total fresh weight (gm/plant) 2017	Total fresh weight (gm/plant) 2018	Total dry weight (gm/plant) 2017	Total dry weight (gm/plant) 2018	Leaf area (m^2/plant) 2017	Leaf area (m^2/plant) 2018
Drainage water treatments:									
Magnetized		70.4 a	78.7 a	835.3 a	884.1 a	97.3 a	101.2 a	26.05 a	28.20 a
Non-magnetized		48.8 b	56.7 b	468.8 b	514.9 b	52.5 b	57.4 b	11.51 b	13.17 b
Anti-stressors treatments:									
Melatonin		66.4 a	75.9 a	765.7 a	824.5 a	90.8 a	96.7 a	24.85 a	26.62 a
Sorbatole		59.9 c	67.7 c	608.6 d	644.9 d	68.8 c	69.8 c	16.65 d	19.43 d
Glycinebetaine		64.3 ab	72.1 b	697.1 b	745.5 b	81.9 b	86.9 b	20.98 b	23.17 b
Glutatione		62.0 bc	70.0 bc	660.8 c	711.2 c	81.6 b	86.7 b	19.48 c	20.88 c
Control		45.5 d	52.8 d	528.2 e	571.3 e	51.4 d	56.4 d	11.93 e	13.33 e
Interaction between drainage water and anti-stressors treatments									
Magnetized	Melatonin	80.0 a	91.1 a	981.3 a	1048.6 a	117.9 a	124.7 a	35.51 a	36.45 a
	Sorbatole	69.3 c	77.2 c	815.9 c	855.2 c	92.7 c	89.9 c	24.97 c	28.18 c
	Glycinebetaine	76.2 b	83.7 b	885.8 b	932.3 b	101.4 b	106.5 b	28.36 b	30.60 b
	Glutatione	71.3 c	79.3 c	821.1 c	871.4 c	102.0 b	107.2 b	26.28 c	28.49 c
	Control	55.5 d	62.1 d	672.6 d	712.8 d	72.5 d	77.5 d	15.11 d	17.26 d
Non-magnetized	Melatonin	52.8 de	60.8 de	550.1 e	600.4 e	63.7 e	68.7 e	14.18 de	16.79 de
	Sorbatole	50.4 e	58.3 e	401.3 g	434.5 g	44.9 f	49.6 f	8.33 g	10.68 g
	Glycinebetaine	52.4 de	60.4 de	508.4 f	558.7 f	62.4 e	67.3 e	13.60 ef	15.73 e
	Glutatione	52.8 de	60.8 de	500.5 f	550.9 f	61.3 e	66.2 e	12.69 f	13.27 f
	Control	35.5 f	43.5 f	383.8 g	429.9 g	30.4 g	35.2 g	8.76 g	9.39 g

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.

Concerning the control plants, using agricultural drainage water in direct irrigation decreased growth and development of plants because increasing EC of irrigation water (Table 1) applied to tomato (El-Zawily *et al.,* 2019). Also, the harmful impacts of irrigation with saline water decreased plant biomass (Romero-Aranda *et al.,* 2001), have direct toxic effect on plant tissues (Morales *et al.,* 2008), decreased nutrients and water absorption (Hussein *et al.,*

2012) and activity of both hormones and enzymes (Hussein and Oraby 2008 and Kaya *et al.*, 2009). Likewise, combination between magnetic technology and saline water increased productivity parameters compared with untreated saline water on tomato (Selim *et al.,* 2013).

Effect of anti-stressors treatments:

Data in Table 3 show that all applied ant-stressors significantly superior the control in their effects on all vegetative growth characteristics of tomato plants in both growing seasons. The most effective ones were ML followed by GB and the check was the last treatments.

The protective role of MT on tomato plants may be related to its role in osmotic adjustment and in plant defence system (Wang *et al.,* 2020). MT is an amphipathic molecule that can easily diffuse throughout the cell membranes into cytoplasm and enter subcellular compartments in plants (Ahmed *et al.*, 2020). In addition, MT has great roles in many aspects of both growth and development and the most basic roles related with abiotic stress i.e.; salinity, drought and heat stress (Zhang *et al.*, 2020 and Fig. 1). Exogenous application of MT decrease salt inhibition for plants growth as well as increase biomass accumulation (Jiang *et al.,* 2016). In addition, MT application increased growth attributes, accumulation of biomass and improved assimilation of carbon in plant tissues due to increase the photosynthetic rate and pigments content under stress conditions (Hernández-Ruiz *et al.,* 2005 and Yan *et al*., 2020).

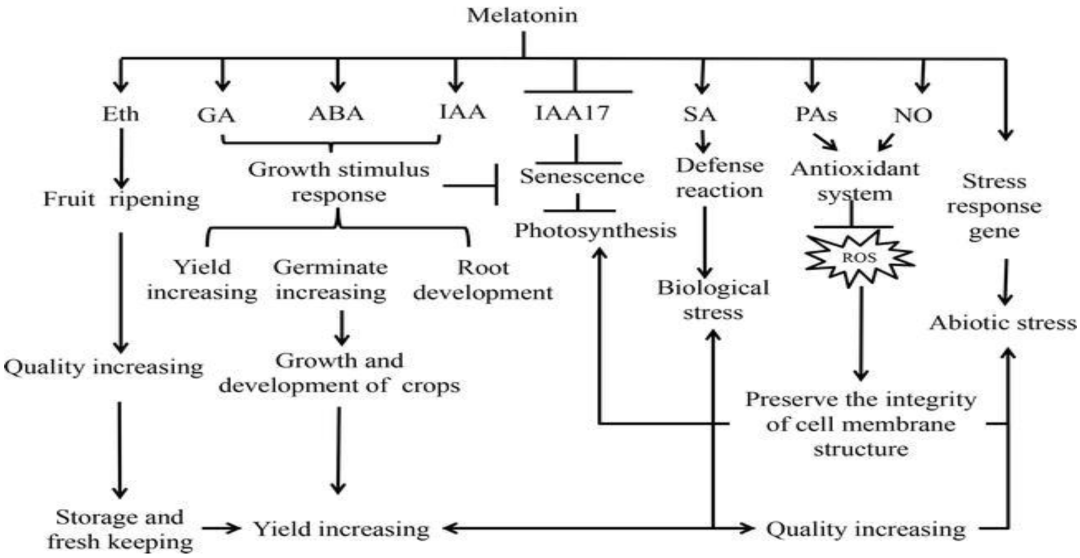

Figure 1. The signal transduction network of melatonin in plant growth, development and stress tolerance (Yan *et al.*, 2020).

Effect of interaction between drainage water and anti-stressors treatments:

Data in Table 3 show that the interaction between the applied anti-stressors and MDW was more favourable in most cases for vegetative performance than un-magnetized drainage water plus anti-stressors in both seasons. The same data indicated that plants irrigated with MDW plus ML recorded the highest values of vegetative growth attributes compared with all other interactions in both seasons followed by the interaction between MDW plus GB.

On the other hand, control plants which irrigated only with DW gave the lowest mean values of all studied parameters in both two seasons. Such response of un treated plants indicated that plants of this interaction were not protected against saline water (DW) and its adverse effects on tomato plant growth and developments (Selim *et al.,* 2013).

2. Leaf mineral and photosynthetic pigments contents:

Effect of drainage water treatments:

Irrigated tomato plants with magnetic drainage water achieved the highest recorded data (Table 4) of all measurements of both chemical and photosynthetic contents in both seasons compared to irrigation with untreated water (DW). The positive effect of MDW may be due to changing in water/soil properties (chemical or physical Table 2) in response to magnetic field. Also, MW increased the availability and absorption of nutrients in soil solution causing higher accumulation/content of these elements in different plant tissues and decreased them in soil (Swelam, 2018).

Concerning photosynthetic pigments content, MW stimulate chlorophylls contents in leaves due to its role in increasing proline in plants tissues, which reflect on increasing Mg^{+2} and K^{+1} ions which are needed for chlorophylls synthesis process, in end lead to stimulate photosynthetic efficiency (Garcia-Reina and Pascual, 2001 and Selim and El-Nady, 2011) on tomato plants.

Effect of anti-stressors treatments:

The same data show that, the foliar anti-stressors treatments significantly increase minerals and photosynthetic pigments content in tomato leaves in both seasons. In this respect, ML gave the best values followed by GB (with significant differences between them), while negative respond was observed in the control plants in both summer seasons. The improvement in nutrient uptake efficiency and enhancement in N metabolism was perceived in response to the exogenous application of ML, particularly under salt stress conditions (Zhang *et al.,* 2017). In the present study, the obtained results are in agreemrnt with Jiang *et al.*, 2016 indicating that ML application enabled tomato plants to maintain higher K^+ concentrations in leaves, increased chlorophylls concentration in leaves (Arnao and Hernández, 2010) and down-regulated the expression of chlorophylls which is a light-regulated enzyme involved in chlorophyll degradation processes (Weeda *et al.,* 2014).

Photosynthetic efficiency (chlorophylls pigment content) is considered a vital physiological processes to mitigate several plant activities, absorption and transmission of sun energy (Arnao and Hernández, 2010). In our study, drainage water (saline stress) negatively affected photosynthesis process and the accumulation of biomass in tomato plants. Also under salinity stress conditions one of the basic responses of plants is to close stomata in order to decrease water loss (leaf relative water content) which is accompanied by a reduction in gases and consequently stomatal limitation of photosynthesis rate (Meloni *et al*., 2003). Therefore, ML improved stomata functions by enabling plants to reopen their stomata under different stress conditions (Ye *et al.*, 2016).

Table 4. Minerals and photosynthetic pigments content of tomato leaves as affected by irrigation with drainage water treatments, some anti-stressors and their interactions during summer seasons of 2017 and 2018.

Treatments		N (%) 2017	N (%) 2018	P (%) 2017	P (%) 2018	K (%) 2017	K (%) 2018	Mg (%) 2017	Mg (%) 2018
Drainage water treatments:									
Magnetized		3.91 a	4.33 a	0.59 a	0.64 a	3.20 a	2.69 a	0.55 a	0.54 a
Non-magnetized		2.29 b	2.72 b	0.24 b	0.29 b	1.58 b	1.07 b	0.17 b	0.15 b
Anti-stressors treatments:									
Melatonin 50 ppm		4.24 a	4.65 a	0.62 a	0.67 a	2.95 a	2.44 a	0.49 a	0.48 a
Sorbatole		2.77 c	3.19 c	0.36 d	0.40 d	2.37 c	1.87 c	0.35 c	0.34 c
Glycinebetaine		3.27 b	3.69 b	0.49 b	0.53 b	2.68 b	2.17 b	0.40 b	0.39 b
Glutatione		3.20 b	3.65 b	0.41 c	0.45 c	2.62 b	2.11 b	0.39 bc	0.38 bc
Control		2.01 d	2.47 d	0.22 e	0.26 e	1.33 d	0.82 d	0.17 d	0.16 d
Interaction between drainage water and anti-stressors treatments									
Magnetized	Melatonin	5.67 a	6.07 a	0.96 a	1.00 a	3.85 a	3.34 a	0.79 a	0.78 a
	Sorbatole	3.22 c	3.65 c	0.48 c	0.52 c	3.29 b	2.78 b	0.53 c	0.52 c
	Glycinebetaine	3.94 b	4.32 b	0.69 b	0.74 b	3.41 b	2.91 b	0.61 b	0.60 b
	Glutatione	3.76 b	4.22 b	0.53 c	0.58 c	3.37 b	2.86 b	0.60 bc	0.59 bc
	Control	2.95 cd	3.40 cd	0.30 d	0.34 d	2.07 c	1.56 c	0.24 d	0.23 d
Non-magnetized	Melatonin	2.81 de	3.23 de	0.29 d	0.33 d	2.05 c	1.54 c	0.20 d	0.18 d
	Sorbatole	2.32 f	2.73 g	0.24 d	0.28 d	1.46 d	0.95 d	0.17 d	0.16 d
	Glycinebetaine	2.60 ef	3.05 e	0.29 d	0.33 d	1.94 c	1.43 d	0.19 d	0.18 d
	Glutatione	2.63 e	3.07 e	0.28 d	0.32 d	1.87 c	1.36 d	0.18 d	0.16 d
	Control	1.08 g	1.53 g	0.13 e	0.17 e	0.59 e	0.09 e	0.10 e	0.08 e

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.

Table 4. Cont. Minerals and photosynthetic pigments content of tomato leaves as affected by irrigation with drainage water treatments, some anti-stressors and their interactions during summer seasons of 2017 and 2018.

Treatments		Zn (ppm) 2017	Zn (ppm) 2018	Mn (ppm) 2017	Mn (ppm) 2018	Total chl. (a + b) (mg/gm F. Wt.) 2017	Total chl. (a + b) (mg/gm F. Wt.) 2018	Carotenoids (mg/gm F. Wt.) 2017	Carotenoids (mg/gm F. Wt.) 2018
Drainage water treatments:									
Magnetized		12.709 a	13.893 a	206.173 a	196.073 a	2.004 a	2.046 a	0.700 a	0.704 a
Non-magnetized		7.785 b	9.055 b	108.226 b	98.146 b	1.165 b	1.232 b	0.510 b	0.507 b
Anti-stressors applications:									
Melatonin		13.280 a	14.620 a	187.116 a	177.016 a	2.012 a	2.076 a	0.710 a	0.697 a
Sorbatole		8.901 c	10.242 c	145.816 d	135.716 d	1.432 d	1.476 d	0.561 b	0.573 c
Glycinebetaine		11.756 b	12.930 b	178.633 b	168.533 b	1.733 b	1.771 b	0.665 a	0.666 ab
Glutatione		9.775 c	11.115 c	170.033 c	159.983 c	1.599 c	1.686 c	0.605 b	0.622 bc
Control		7.523 d	8.687 d	104.400 e	94.300 e	1.146 e	1.187 e	0.482 c	0.470 d
Interaction between drainage water and anti-stressors treatments									
Magnetized	Melatonin	17.191 a	18.529 a	244.200 a	234.100 a	2.388 a	2.466 a	0.848 a	0.837 a
	Sorbatole	10.728 cd	12.069 cd	194.200 d	184.100 d	1.815 c	1.851 d	0.620 bc	0.630 cd
	Glycinebetaine	14.270 b	15.278 b	231.600 b	221.500 b	2.106 b	2.131 b	0.773 a	0.786 ab
	Glutatione	11.492 c	12.833 c	214.633 c	204.533 c	1.990 b	1.998 c	0.687 b	0.709 bc
	Control	9.864 de	11.205 de	146.233 e	136.133 e	1.720 cd	1.786 de	0.571 cd	0.559 de
Non-magnetized	Melatonin	9.369 ef	10.710 def	130.033 f	119.933 f	1.637 d	1.687 e	0.572 cd	0.558 de
	Sorbatole	7.075 g	8.416 g	97.433 h	87.333 g	1.048 g	1.101 g	0.503 d	0.517 e
	Glycinebetaine	9.241 ef	10.582 ef	125.666 fg	115.566 f	1.360 e	1.412 f	0.558 cd	0.546 de
	Glutatione	8.057 fg	9.398 fg	125.433 g	115.433 f	1.209 f	1.375 f	0.523 d	0.536 e
	Control	5.182 h	6.169 h	62.566 i	52.466 h	0.572 h	0.587 h	0.394 e	0.381 f

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.

Additionally, carotenoids are important pigments in plants which serves as photo-protection/adjustment functions as safety substances that release the excess energy before damaging different plant cells (Szafranska *et al.,* 2016).

Effect of interaction between drainage water and anti-stressors treatments:

Data indicate that the interaction between MDW and all anti-stressors are superior in all studied parameters in both seasons of research. It was evident that, the interaction between MDW and melatonin gave the highest values of minerals, total chlorophylls and carotenoids content, whereas DW plus control maintained the lowest values of the previous parameters, in two seasons of study.

3. Antioxidant enzymatic activity:

Effect of drainage water treatments:

Data (Table 5) revealed that, tomato plants irrigated with MDW possess more mitigation efficiency against saline water than plants which irrigated with DW, since MDW plants achieved best activity of catalase (CAT), superoxide dismutase (SOD) and peroxidase (PX) in two summer seasons. Under various environmental stress conditions i.e., salinity the activity of anti-oxidants enzymes (CAT, SOD and PX) increased in plants tissues to stimulate plant tolerance system to mitigate/adaption with stress actions. These results are in harmony with Swelam, 2018 on tomato plants.

Table 5. Enzymes activity of tomato leaves as affected by irrigation with drainage water treatments, some anti-stressors and their interactions during summer seasons of 2017 and 2018.

Treatments		Peroxidase activity (/g F. Wt./h)		Superoxide dismutase activity (/g F. Wt./h)		Catalase activity (/g F. Wt./h)	
		2017	2018	2017	2018	2017	2018
Drainage water treatments:							
Magnetized		221.11 a	220.18 a	210.75 a	220.81 a	106.25 a	106.15 a
Non-magnetized		175.76 b	174.70 b	163.93 b	173.71 b	73.91 b	73.81 b
Anti-stressors treatments:							
Melatonin		239.10 a	238.15 a	216.10 a	226.46 a	104.96 a	104.87 a
Sorbatole		188.89 c	187.97 c	189.19 b	199.47 b	89.13 c	89.05 c
Glycinebetaine		186.41 c	185.26 c	214.81 a	225.07 a	86.64 d	86.52 d
Glutatione		204.88 b	203.91 b	166.76 c	177.09 c	96.15 b	96.06 b
Control		172.91 d	171.92 d	149.85 c	158.20 d	73.52 e	73.41 e
Interaction between drainage water and anti-stressors treatments							
Magnetized	Melatonin	286.5 a	285.61 a	233.72 a	244.16 a	111.65 a	11.55 a
	Sorbatole	201.71 c	200.81 c	204.95 b	215.23 b	104.65 c	104.58 c
	Glycinebetaine	198.96 cd	197.87 cd	233.72 a	244.00 a	102.65 d	102.52 d
	Glutatione	224.38 b	223.48 b	202.35 bc	212.73 b	109.65 b	109.54 b
	Control	194.02 de	193.12 de	179.01 cd	187.93 c	102.65 d	102.55 d
Non-magnetized	Melatonin	191.71 ef	190.69 ef	198.48 bc	208.76 b	98.28 e	98.19 e
	Sorbatole	176.08 g	175.12 g	173.43 d	183.71 c	73.61 g	73.52 g
	Glycinebetaine	173.86 g	172.65 g	195.90 bcd	206.15 b	70.64 h	70.51 h
	Glutatione	185.38 f	184.34 f	131.18 e	141.46 d	82.65 f	82.57 f
	Control	151.80 h	150.72 h	120.68 e	128.46 d	44.39 i	44.26 i

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.

Effect of anti-stressors treatments:

Same data mostly illustrated that different anti-stressors treatments increased the activity of PX, AT and SOD enzymes as compared with those of the untreated plants during two growing seasons. Tomato plants which treated with ML recorded significantly the highest values of peroxidase and catalase activity followed by GSH treatments in both seasons of study. On the other hand, ML and GB gave the best recorded values of superoxide dismutase activity without significant differences in the two seasons.

Mitochondria is considered the basic producer of energy in plants through the aerobic respiration and played as a key role in both plant growth and development (Robles and Quesada, 2017). Additionally, chloroplast and mitochondria are referred to be the original site of ML in plants (Tan *et al.,* 2013). Also, mitochondria were indicated as a major generation site for ROS (Igamberdiev and Hill, 2018), playing vital role in mitigating stresses and regulating ROS (Mur *et al.,* 2013). As a result, mitochondria can be damaged due to the over production of ROS molecules under environmental stress (a biotic and biotic) (Igamberdiev and Hill, 2018).

Evidence confirms that ML application recovers the damage occurs to mitochondria that occurred in response to stress (Franco *et al.,* 2018), scavenges ROS with high efficiency (Tan *et al.,* 2013), scavenges H_2O_2 and induction of antioxidant enzymes activates (Li *et al.,* 2017) and improves antioxidant substances and capacity (Ibrahim *et al.,* 2020). Numerous rehearse reported that, MT application directly improved the activity of antioxidant enzymes (POD, CAT and SOD) under abiotic stress conditions (Jiang *et al.,* 2016 and Zhou *et al.,* 2020). These enzymes have evolved effective antioxidant defense enzymes activities and play the dominant role in the defense mechanisms (Cui *et al.,* 2017).

Effect of interaction between drainage water and anti-stressors treatments:

Data show that the interaction between MDW and anti-stressors treatments superior the interactions between DW plus anti-stressors (in most cases) in both seasons of this study. Same data showed that, irrigated tomato plants with MDW plus ML gave the best recoded values of PX and CAT, while tomato plants which irrigated with DW in the absence of foliar substances gave the lowest values of above recorded data in both seasons.

4. Yield parameters:

Effect of drainage water treatments:

Data of (Table 6) cleared that, irrigating tomato plants with magnetic drainage water treatment gave the highest values of all fruits yield parameters compared with irrigation with drainage water in the two seasons of study. Irrigation with untreated (saline) water negatively reflected on tomato yield components parameters. Our results are in agreement with Zayton *et al.,* 2009 and Whab-Allah and Al-Omran, 2012.

The increment in tomato fruit yield parameters as a result of magnetic treatment may be due to the enhanced vegetative growth, the enhanced photosynthetic pigments, minerals content as well as the accelerated enzymes obtained in the present study (Tables 3, 4 and 5) which finally lead to increment in yield attributes. Presented results are in harmony with Abou El-Yazied *et al.,* 2012 and Swelam, 2018 on tomato plants.

Effect of anti-stressors treatments:

Concerning the effects of applied anti-stressors substances, same data confirmed the positive relationship between the tomato yield and its components with anti-stressors applications compared with untreated plants, in both growing seasons. On contrast, untreated plants achieved the lowest values of all aforementioned yield parameters in both summer seasons. Also, melatonin foliar application is the superior treatment in enhancing both early and total yield of tomato plants followed by glycine betaine or glutathione (whit out significant differences between them in most cases).

ML also had a key role in regulating both plant biological and physiological processes (Farag *et al.,* 2020). Once again, ML is considered a biological plant growth regulator to improve plants production capacity and a nontoxic biodegradable molecule used in organic farming (Janas and Posmyk, 2013).

Table 6. Yield parameters of tomato plants as affected by irrigation with drainage water treatments, some anti-stressors and their interactions during summer seasons of 2017 and 2018.

Treatments		Early yield (ton/fed.)		Total yield (ton/fed.)		Marketable yield (ton/fed.)	
		2017	2018	2017	2018	2017	2018
Drainage water treatments:							
Magnetized		9.002 a	8.390 a	35.575 a	36.009 a	32.407 a	33.417 a
Non-magnetized		6.569 b	7.267 b	28.953 b	29.383 b	26.342 b	27.198 b
Anti-stressors treatments:							
Melatonin		8.520 a	8.501 a	35.491 a	35.923 a	32.307 a	33.256 a
Sorbatole		7.585 c	7.639 b	31.123 c	31.555 c	28.389 c	29.296 c
Glycinebetaine		7.863 b	7.934 b	32.483 b	32.915 b	29.601 b	30.614 b
Glutatione		7.766 bc	7.937 b	33.211 b	33.643 b	30.392 b	31.216 b
Control		7.194 d	7.133 c	29.012 d	29.443 d	26.183 d	27.156 d
Interaction between drainage water and anti-stressors treatments							
Magnetized	Melatonin	10.428 a	9.469 a	41.278 a	41.711 a	37.629 a	38.582 a
	Sorbatole	8.511 c	8.012 bc	33.611 c	34.044 c	30.532 c	31.615 c
	Glycinebetaine	9.302 b	8.462 b	35.773 b	36.206 b	32.870 b	34.052 b
	Glutatione	9.051 b	8.354 b	36.775 b	37.208 b	33.652 b	34.370 b
	Control	7.718 d	7.654 cd	30.441 d	30.874 d	27.352 d	28.464 d
Non-magnetized	Melatonin	6.612 e	7.534 cd	29.705 de	30.136 de	26.985 d	27.931 de
	Sorbatole	6.660 e	7.266 d	28.635 ef	29.065 ef	26.245 de	26.977 ef
	Glycinebetaine	6.425 e	7.406 d	29.194 de	29.624 de	26.332 de	27.176 def
	Glutatione	6.480 e	7.519 cd	29.648 de	30.078 de	27.133 d	28.061 de
	Control	6.669 e	6.613 e	27.584 f	28.012 f	25.014 e	25.848 f

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.

Effect of interaction between drainage water and anti-stressors treatments:

Data in Table 6 illustrated that the interaction between irrigation with magnetic drainage water and anti-stressors foliar treatments gave the best recorded data as compared with interaction between drainage water plus anti-stressors substances in both seasons. Generally, it was noticed that plants irrigated with MDW and sprayed with ML recorded the highest values of all data as compared with the other studied treatments in both seasons of research.

5. Fruits quality:

Effect of drainage water treatments:

Results of Table 7 indicated that irrigation with poor quality water (non-magnetized) produce increment of fruits chemical contents such as vitamin C, T.S.S and acidity except lycopene content of tomato fruits compared with MDW treatment in both seasons. The increment of this properties may be due to accumulation of sugars molecules and free amino acids as a result of irrigation with saline water. These results are in the same line with Feizi *et al.*, 2013 and El-Zawily *et al.*, 2019.

Table 7. Fruits quality parameters of tomato plants as affected by irrigation with drainage water treatments, some anti-stressors and their interactions during summer seasons of 2017 and 2018.

Treatments		Total soluble solids (%)		Vitamin C (mg/100g)		Lycopene (mg/100g)		Acidity (%)	
		2017	2018	2017	2018	2017	2018	2017	2018
Drainage water treatments:									
Magnetized		4.05 b	4.07 b	11.34 b	11.99 b	11.60 a	11.45 a	0.34 b	0.45 b
Non-magnetized		5.13 a	5.15 a	15.20 a	15.77 a	8.68 b	8.53 b	0.45 a	0.57 a
Anti-stressors treatments:									
Melatonin		5.25 a	5.28 a	15.03 a	15.59 a	11.10 a	10.94 a	0.45 a	0.57 a
Sorbatole		4.26 d	4.29 d	13.37 c	13.99 b	9.85 b	9.70 b	0.38 c	0.50 b
Glycinebetaine		4.58 c	4.61 c	13.65 bc	14.21 b	10.07 b	9.93 b	0.42 b	0.55 a
Glutatione		4.84 b	4.87 b	13.83 b	14.43 b	10.83 a	10.68 a	0.39 c	0.51 b
Control		4.01 e	3.99 e	10.46 d	11.17 c	8.86 c	8.71 c	0.33 d	0.44 c
Interaction between drainage water and anti-stressors treatments									
Magnetized	Melatonin	5.97 a	6.00 a	17.94 a	18.47 a	12.62 a	12.47 a	0.51 a	0.63 a
	Sorbatole	5.00 c	5.03 c	15.11 b	15.67 b	11.52 c	11.37 b	0.44 c	0.56 c
	Glycinebetaine	4.83 c	4.86 c	15.22 b	15.77 b	11.27 c	11.14 b	0.48 b	0.60 ab
	Glutatione	5.24 b	5.28 b	15.58 b	16.18 b	12.14 b	12.00 a	0.45 bc	0.58 bc
	Control	4.60 d	4.57 d	12.13 c	12.75 c	10.46 d	10.30 c	0.39 d	0.50 d
Non-magnetized	Melatonin	4.53 de	4.56 d	12.11 c	12.71 c	9.58 e	9.42 d	0.39 d	0.51 d
	Sorbatole	3.53 f	3.55 f	11.62 c	12.32 c	8.18 g	8.04 f	0.32 e	0.44 e
	Glycinebetaine	4.33e	4.36 e	12.09 c	12.65 c	8.86 f	8.71 e	0.37 d	0.49 d
	Glutatione	4.44 de	4.47 de	12.09 c	12.68 c	9.52 e	9.35 d	0.33 e	0.45 e
	Control	3.43 f	3.42 f	8.79 d	9.59 d	7.26 h	7.13 g	0.28 f	0.39 f

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.

Effect of anti-stressors treatments:

It was noticed from the same data that all anti-stressors treatments significantly improved tomato fruits quality attributes in both growing seasons compared with check treatments. Similarly, ML gave significantly the best values of all recorded parameters followed by GB and GSH (within significant difference among them) respectively in the two seasons of research. On the other hands, control treatment (absence of anti-stressors applications) gave the lowest recorded values of previous parameters in both grown seasons.

In our study, the data suggested that MT application increased total soluble sugars content which play a vital role in maintaining osmotic balance (Ali *et al.*, 2020), regulating all cellular metabolism (Sivakumar *et al.,* 2002), acting as H_2O_2 and ROS scavengers and contributing in the protection of macromolecules and membranes (Mahajan and Tuteja, 2005).

Concerning lycopene pigment (a highly characteristic phytonutrient), is considered an important component of soluble solids and directly affects tomato fruits quality. This ROS-scavenging compound accounts for approximately 80% of all carotenoids present in tomato fruits (Rao *et al.*, 1998). Furthermore, it is fundamental to the final nutritional quality and commercial value of tomato fruit (Dumas *et al.,* 2003).

Effect of interaction between drainage water and anti-stressors treatments:

Data demonstrate that total soluble solids, acidity, vitamin C and lycopene responded positively to the interaction. Tomato plants irrigated with MDW and sprayed with all applied anti-stressors recorded the best values of only lycopene content, while irrigation with drainage water in the presence of foliar substances recorded the best ones of total soluble solids, acidity, vitamin C parameters in both studying seasons.

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إنتاج الطماطم بإستخدام مياه الصرف الزراعى الممغنط

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قسم بحوث محاصيل الخضر الذاتية التلقيح - معهد بحوث البساتين - مركز البحوث الزراعية - جيزة – مصر

تعظيم الاستفادة من وحدة المياه أحد أهم مبادئ (محاور) التنمية الزراعية المستدامة من وجهة نظر صانعي السياسات الزراعية حول العالم في الماضي والمستقبل. كما أن قطاع الزراعة يستهلك كميات كبيرة من المياه العذبة في مصر. تمثل مياه الصرف الزراعي نسبة ملموسة من المياه إذا أعيد استخدامها مرة أخرى عن طريق رفع جودتها. لذلك استخدام التكنولوجيا المغناطيسية لمعالجة المياه أو التربة كوسيلة لرفع الانتاجية من وحدة المياه عن طريق إعادة استخدام مياه الصرف الزراعي في ري محاصيل الخضر مثل الطماطم ورفع إنتاجيتها في ظل هذه الظروف. يهدف هذا البحث لتقييم كفاءة استخدام التقنية المغناطيسية في معاملة مياه الصرف الزراعي وبعض مضادات الاجهاد على سلوك نباتات الطماطم تحت ظروف منطقة الدلتا. البيانات المقدمة في هذا البحث هي نتائج تجربتين حقليتين في موسم الصيف ولوحظ أن مياه الصرف الزراعي المعالجة بالمجال المغناطيسي تتفوق على النباتات غير المعالجة في معظم الصفات المدروسة. فيما يتعلق بمعاملات مضادات الاجهادات، سجل الميلاتونين يليه الجليسين بيتاين أعلي صفات لنمو النبات ، والنشاط الكيميائي ، ونشاط الإنزيمات وكذلك المحصول ومعايير الجودة في كلا الموسمين. النباتات المروية بمياه الصرف حققت أدنى قيم لجميع المعايير المدروسة نتيجة إجهاد الملوحة بينما سجلت أعلى القيم لصفات جودة الثمار ماعدا الليكوبين. لذا توصي هذه الدراسة بمعاملة مياه الصرف الزراعي بالتقنية المغناطيسية مع الرش بمضادات الاجهاد مثل الميلاتونين أو الجليسين بيتاين لرفع انتاجية نباتات الطماطم تحت الظروف المشابهة للدراسة.

الكلمات الدالة: مضادات الاجهاد – الماء الممغنط – الرى – الطماطم.