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Effect of Normal and Magnetized Greywater on Growth, Mineral Hemostasis and Antioxidant Content in Zucchini (*Cucurbita pepo* L.)

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EGYPT is recently facing the challenge of water scarcity due to the increase in population and limitation of water resources. Therefore, researchers should investigate the usage of non-conventional water sources, for example, greywater to increase water budget which is available to overcome this problem. Since quantities of water are consumed in the ablution process, and this water is less polluted, this research aims to collect greywater and study its quality for reuse in irrigating zucchini plants. Three treatments were carried out for irrigation: 1- Tap water (TP: control), 2- Greywater (GW), and 3- Magnetized greywater (MGW). To investigate how well these treatments worked, some measurements were made on zucchini plants and soil properties. The tenth (10^{th}) and twentieth (20^{th}) day following the agriculture produced the maximum chlorophyll a (Chl-a), chlorophyll b (Chl-b) and carotenoid (Car) levels as compared to control when plants were watered with MGW. Additionally, the activity of antioxidant enzymes raised when GW is used, whereas it diminishes when MGW is used, compared to control on the 10^{th} and 20^{th} day after agriculture .The outcomes data demonstrated that MGW irrigation of zucchini plants produced the greatest NPK values. Among different irrigation water used (TP, GW and MGW), MGW recorded the most significant values of soil chemical properties as well as seed germination. The data showed that the EC value of soil irrigated by MGW significantly decreased compared to the EC values of the soil before irrigation or soil irrigated by GW or TP. Also, the germination percentage was recorded 100% after 12 days with MAW compared with TP and AW which recorded 80% for the two qualities, respectively.

Keywords: Antioxidant enzymes, C. pepo irrigation, greywater, magnetization, pigments, water quality.

1. Introduction

Water scarcity is a major problem in many countries of the world, especially in dry regions. Egypt suffers from a water shortage, and this problem increases with the construction of the El-NAHDA Dam. Maintaining the life of living organisms is one of the most important reasons for water consumption with other uses such as household requirements, food production and other needs related to progress. (Hardinge et al., 2018).

In many parts of the world, water overuse occurs in addition to freshwater pollution caused by human factors. At the moment, it is estimated that over 800 million people are living in areas where they are subject to a certain level of water stress, and it is anticipated that this figure will rise to 3 billion in the year 2025 (Kaya et al., 2011; Oteng-Peprah et al., 2018). The term "greywater" refers to wastewater that does not contain any trace of sewage (toilet

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water) (Casanova et al., 2001; Ledin, 2004). Fixtures, lifestyle, and weather all play a role in determining the unique chemical makeup of each person's greywater, and water-scarce regions often recycle this resource especially in locations experiencing a severe water shortage or in dry climates(Abedin & Rakib, 2013; Carvalho et al., 2013; Kaya et al., 2011).

Issues with public health attitudes and unsuitable technology for the reuse option have been the primary difficulties with greywater reuse (Hardinge et al., 2018). A model has been created to evaluate the merits of several strategies for reusing household water considering performance goals and associated costs. When compared to the baseline need, the findings revealed that the suggested method might save up to 75% of freshwater (Khor et al., 2020).

Several types of edible crops and the effect of household greywater on them were studied (Finley, 2009). According to the results, there were no significant differences in pollution levels between crops watered with fresh water, treated greywater, and untreated greywater. The levels of pollution were low across the board, posing no significant risk to human health. Gray water's low nutrient, phosphorus, and potassium (NPK) levels mean it has little effect on plant development and yield. When generating a static magnetic field (MF), normal water is passed through a magnetic field of a predetermined intensity. Water that had been subjected to magnetic treatment had its chemical and physical characteristics altered, which in turn boosted plant biological activity and had knock-on effects on plant growth (Chibowski & Szcześ, 2018).

It has been noted by several authors utilizing magnetically treated water to water crops in agriculture is a highly regarded ecologically benign approach (Abd El-Hady et al., 2024; Alattar et al., 2019, 2021; Chou, 2007; Talat 2022). Several studies have shown that pretreatment with a static magnetic field (MF) improves photosynthetic performance and raises NO content, which may protect plants from the deleterious effects of oxidative stress, such as decreased surface tension, pH, boiling point, total soluble solids (TSS), and electrical conductivity (EC) (El-Mesery, 2015; Kataria et al., 2015, 2021; Sokolov et al., 2022). In addition, the lettuce had more leaves and weighed more when watered with magnetically treated water as compared to ordinary water. The plant's oxidative damage was reduced by catalase (CAT), superoxide dismutase (SOD), polyphenol oxidase (PPO), and peroxidase (POD) (Fakhri et al., 2018; Liu et al., 2019, 2020a; Sarraf et al., 2020). The use of magnetization has a role in reducing the electrical conductivity values of water compared to non-magnetized water. Moreover, the leaching of soluble salts from the soil profile increased under the salinity of magnetically treated irrigation water. Available macro and micronutrients in soil as affected with magnetic irrigation water were higher than untreated water (Abd-Elrahman and Shalaby, 2017; Sary, 2021). Nutrient content and quality of potato tubers recorded the highest values under soaking the tubers in magnetic water before planting and using 75% of the recommended doses of NPK + fulvic acid. In the other words, reducing the chemical fertilizers and production costs can be achieved through subjected plant materials such as tubers to magnetized water (Abd El-Hady et al., 2023)

It is known that environmental stress increases plant production of Reactive Oxygen Species (ROS) responsible for plant cell damage (Elsherpiny & Helmythat, 2022) found that plants grown under alternative furrow irrigation technique had the highest values of enzymatic antioxidants i.e., SOD, POD, and CAT, Plants protect themselves from various environmental stresses using a variety of mechanisms (Chang et al., 2020). The proper irrigation interval increases the plant water stress tolerance by increasing the water use efficiency and the nutrient concentrations of plant (Ali & Ahmed, 2020).

An annual herbaceous plant belonging to the Cucurbitaceae family is called *Cucurbita pepo L.* (*C. pepo*). One of the world's oldest cultivars, *C. pepo* was developed between 7,000 and 5,500 BC. Traditionally, C. pepo has been cultivated at elevations ranging from relatively low, in semi-arid areas, to over 2,000 metres, in alpine environments (Kadhim et al., 2020). The seeds of this plant contain advantageous active substances that aid in the treatment of atherosclerosis, urinary tract inflammation, and prostate gland inflammation. Seeds bolster the body's immunity to illnesses. The oil from C. pepo seeds, which is high in fatty acids and free of cholesterol, can effectively treat joint discomfort. More than 40% of it is oleic acid, followed by 33.1% of linoleic acid and 14.7% of palmitic acid (Medjakovic et al., 2016; Neđeral et al., 2012; Richter et al., 2013).

The research aims to collect ablution water and study its quality for reuse in irrigating zucchini plants. As well as studying the effect of magnetization of greywater on soil properties.

2. Material and Methods

2.1. Sampling and soil analysis

The current investigation aims to study the possibility of using untraditional irrigation water greywater (GW), magnetized greywater (MGW) as well as tap water (TP) on plant growth, antioxidant enzymes, nutrient uptake by zucchini plant (*Cucurbita pepo* L. *cv pepo*) grown on a sandy loam soil at Al-Azhar University, Faculty of Agricultural Engineering (Latitude: 30° 3'14.70"N Longitude: 31°19'15.49"E), Cairo, Egypt during the summer season of 2021. Sandy loam soil samples were therefore collected prior to the experimental study air dried, crushed and sieved through a 2.0 mm sieve. Some physical and chemical analysis of soil were assessed according to the methods described by (Estefan, 2013; Klute, 1986; Page, 1982) and the results are presented in Table 1. After completing the soil analysis, plastic pots of diameter = 25 cm and a height of 28 cm were filled with 10 kg of sandy loam soil. Also, soil sampling was taken at the end of the experiment to investigate the effect of different water treatments on some soil's physical and chemical properties.

2.2. Sampling and water analyses

The study included two types of unconventional irrigation water, the first one is greywater include (ablution water (AW) and body wash without soap) and the second one is magnetized greywater (MGW), as well as tap water (TP) as a control treatment. The water samples were analyzed at Science Center for Detection & Remediation of Environmental Hazards (SCDREH), Faculty of Science, Al-Azhar University, Cairo, Egypt. The physical-chemical characteristics of water samples were measured according to the method described by (Estefan, 2013) as follows: total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand at five days (BOD5), alkalinity, nitrate ($N\text{-}NO_3^-$), turbidity, electrical conductivity (EC), pH, total dissolved solids (TDS), calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^+), potassium (K^+), chloride (Cl^-), carbonate (CO_3^{-2}), bicarbonate (HCO_3^-), ammonium ($N\text{-}NH_4^+$), sulphate (SO_4^{-2}), aluminum (Al), copper (Cu), boron (B), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), iron (Fe), manganese (Mn), molybdenum (Mo), phosphorus (PO), lead (Pb), strontium (Sr), vanadium (V) nickel (Ni) and zinc (Zn). Moreover, microbiological analyses were carried out in the collected samples as follows: *pseudomonas, alcaligenes, Escherichia coli, Citrobacter, salmonella, klebsiella, proteus, Enterobacter* and *coli* forms count.

2.3. Collection and amounts of GW

GW quantities were collected from a collection pipe for ablution and washing water from the building of the Faculty of Agricultural Engineering, Al-Azhar University in two tanks, and the tank capacity is 120 liters. The water of the first tank (GW) was used for irrigation directly, and the water of the second tank was magnetized before irrigation (MGW), to compare these treatments with irrigation by TP. The amounts of GW were collected for a group of people of different categories (students, faculty members, employees and workers).

2.4. Magnetization of GW and flux density

Magnetization of GW was performed on a closed system for one hour by passing the GW on fixed magnets on the outer surface for stainless steel pipe connected of the collection tank. The magnets were calibrated with Gauss/Tesla meter (Model 4048 and made in USA). The magnetic flux density ranged from 0.151 to 1.903 KG, respectively.

2.5. Germination percentage of zucchini seeds

Ten zucchini seeds were soaked for 12 hours in different irrigation treatments (TP, GW and MGW) and continued irrigated by TP, GW and MGW for 6, 9 and 12 days. Seeds of zucchini were grown in box (50X30 cm) with a mixture of perlite and peat moss (1:1 v/v) as a substrate.

2.6. Plant materials and source of nutrients

Zucchini seeds (*C. pepo*) were obtained from the Horticulture Department, faculty of agriculture, Cairo, Egypt. Two seeds of zucchini plant were sown in a plastic pot (capacity of 10 kg sandy loam soil, diameter of 25 cm and 30 cm of depth). Half ionic strength of Hoagland nutrient solution was prepared from calcium nitrate, potassium nitrate, potassium mono-phosphate and magnesium sulphate as the source for macro and micronutrients during Zucchini pot experiment, according to (Hoagland & Arnon, 1950). The concentration of essential nutrients in 0.25 Hoagland nutrient solutions used is shown in Table (2).

After full germination, the zucchini plants were thinned to one plant per pot to start the experimental treatments of irrigation water as the following:

1- Plants irrigated by tap water (TP, control)
2- Plants irrigated by greywater (GW)
3- Plants irrigated by magnetized greywater (MGW)

Under different irrigation water treatments, soil moisture content was kept at field capacity. Each treatment was replicated three times (**Figure 1**).

2.7. Data recorded

Chlorophyll a (Chl-a) and Chlorophyll b (Chl-b) content, , carotenoids (Car) content, antioxidant enzymes activity (catalase (CAT), peroxidase (POD), polyphenol oxidase (PPO)), Nitrogen, phosphorus and potassium (NPK) content as well as physical and chemical analysis of soil and water were recorded.

Determination of Chl-a, Chl-b and Car contents

(Chl-a**)**, (Chl-b) and (Car) levels (Methanol solvent) were determined using Lichtenthaler and Wellburn (1983) formulas**:**

Chl-a = 15.65 A666- 7.340 A653
Chl-b =27.05 A653- 11.21 A666
Car = 1000 A470- 2.860 Ca- 129.2 Cb*1/245.

Determination of antioxidant enzymes activity

Fresh leaves samples (0.2 g) were crushed in liquid N_2 and then homogenized in an ice bath with a 4 ml homogenizing solution containing 50 mM potassium phosphate buffer and 1% (w/v) polyvinylpyrrolidone. This procedure was done to prepare the tissue for enzymatic antioxidants (pH 7.8). The supernatant obtained after centrifuging the homogenate at 14000 rpm for 10 minutes at 4 °C was utilized for enzyme tests. The spectrophotometer (Jenway 6305 UV/Visible) was then used to measure the absorbance for 60 s.

Determination of Catalase (CAT)

According to (Aebi, 1984), "BLANK" was created by combining 0.03 mL of enzyme solution (supernatant) with 1.5 mL of 100 mM potassium phosphate classes buffer (pH = 7.2). Up to 3 mL of pure water was added to the mixture. 0.5 ml of 75 mM hydrogen peroxide solution (H_2O_2) (El-Gomhouria Co. For Trading Drugs, Chemicals & Medical Supplies) is added to the reaction to start it. At 240 nm, a decline in absorbance was seen for 60 s. Calculating the amount of degraded H_2O_2 is used for the accounting of the enzyme function.

Determination of Peroxidase (POD)

The "BLANK" was made by combining 0.06 ml of enzyme solution with 1.07 ml of 100 mM potassium phosphate buffer (pH = 6.0 at 25°C), 0.3 ml of 5% (w/v) pyrogallol (Riedel-De Haen AG, Seelze-Hannover, Germany) solution, 0.1 ml of 0.5% (w/w) H_2O_2 and 0.70 ml water for the measurement of POD activity at 420 nm. POD activity was assessed using Chance and Maehly's technique (Chance & Maehly, 1955).

Determination of Polyphenol Oxidase (PPO)

According to Duckworth & Coleman, (1970). polyphenol oxidase (PPO) activity was measured at 420 nm at 25°C The "BLANK" was made by combining 1.70 ml of 20 mM Catechol (BDH Chemicals Ltd., Poole, England) solution with 0.06 ml of enzyme solution, which was made of a 50 mM potassium phosphate buffer with a pH of 6.8 at 25°C. Antioxidant enzymes activity was calculated according to: ± of control = (Value of trait / Value of control) × 100

Determination of nitrogen, phosphorus and potassium

Plant samples were dried at 70 °C ground in a stainless-steel mill and then kept for chemical analysis. After that, 0.5 g of dried plant materials were wet digested using a solution of perchloric and sulphuric acids ($HClO_4$ + H_2SO_4) at the ratio of 3:1. Acid digested solution was left to cool and then diluted with redistilled water to a final volume of 100 mL. Micro-Kjeldahl technique was used to calculate total nitrogen (%) in accordance with (AOAC, 1995). A colourimetric technique using the ascorbic acid method and spectrophotometer (JENWAY-Models 670S UV/VIS - UK) was used to calculate phosphorus concentration (%) in accordance with (Page, 1982). A flam-photometric technique using a Flame photometer (JENWAY- Models PFP7- UK) was used to measure the potassium concentration (%) following (Chapman & Pratt, 1962).

2.8. Statistical analyses

Using the (CoStat, 2005) package tool, an analysis of variance was performed on all data. At a significance level of 0.05, Duncan multiple range test was used to compare the differences between the means.

Table 1. Some physical and chemical analysis of the soil used before the cultivation of zucchini plant.

Practical size distribution				
Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture class
46.10	29.05	14.85	10.00	Sandy loam

Moisture content (%) at:			BD	RD	pH_s	ECs	CEC	OC	OM	$CaCO_3$
FC	PWP	Av.W	(g cm^{-3})	(g cm^{-3})	(1:2.5)	(dS m^{-1})	(cmolc kg^{-1})	(%)	(%)	(%)
9.62	4.57	5.05	1.42	2.73	8.14	1.58	2.75	0.28	0.48	3.55

Soluble ions (mmolc l^{-1})							
Cations				Anions			
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$
2.09	1.35	11.75	0.61	0.00	2.95	10.80	2.05

Available macronutrients (mg kg^{-1})		
N	P	K
8.00	2.00	8.75

Available micronutrients (mg kg^{-1})			
Fe	Zn	Mn	Cu
35	20	23	2.50

FC: Field capacity; PWP: Permanent wilting point; Av. W: Available water; BD: Bulk density; RD: Real density; pHs: 1:2.5 w/v soil water suspension; ECs: 1:2.5 w/v soil paste extract; CEC: Cation exchange capacity; OC: organic carbon and OM: organic matter.

Table 2. Chemical composition of Hoagland nutrient solution used.

Macronutrients (mg l^{-1})						Micronutrients (mg l^{-1})					
N	P	K	Ca	Mg	S	Fe	Zn	Mn	Cu	B	Mo
52	8	54	50	12	32	1	0.25	0.25	0.02	0.25	0.01

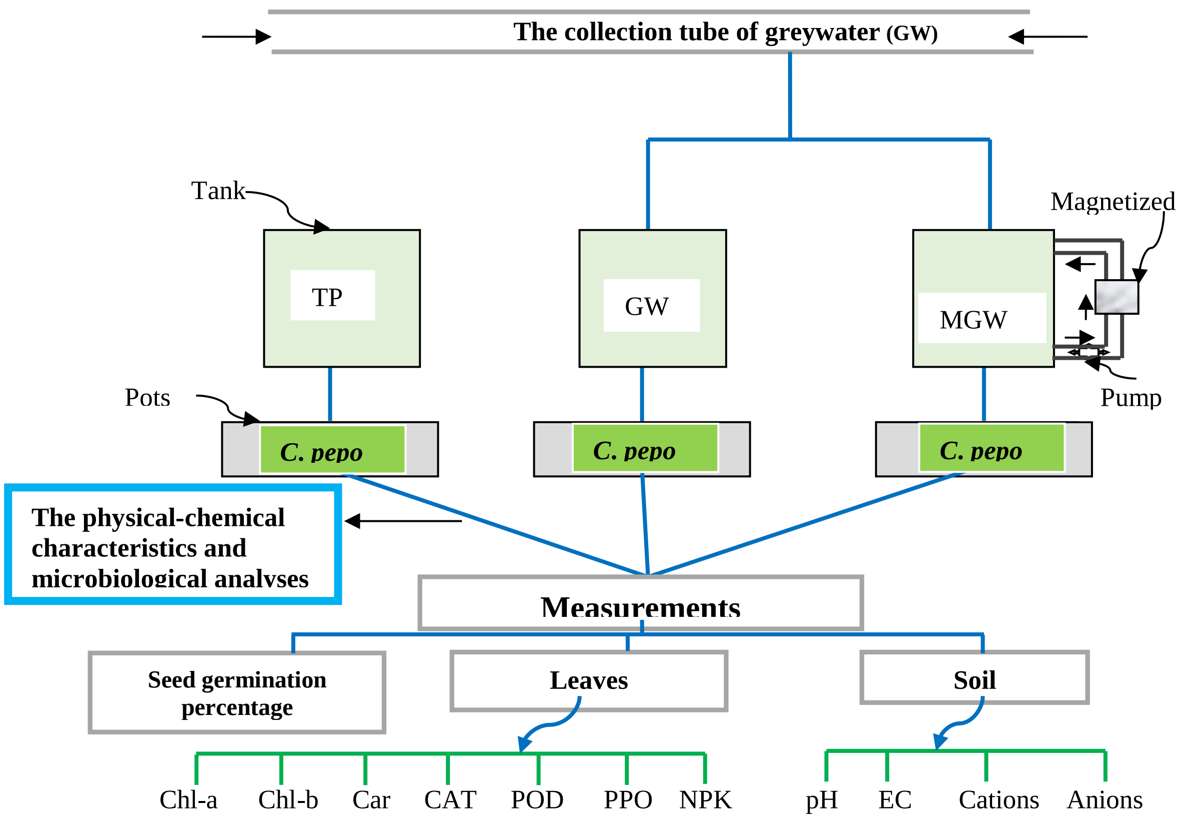

Fig. 1. Layout of the experimental treatments and measurements.

3. Results

3.1. Effect of TP, GW and MGW on seed germination percentage of zucchini plant

Data illustrated in **Fig. 2** showed the germination percentage of seeds zucchini that were soaked for 12 hours in different irrigation treatments (TP (control), GW and MGW) and continued irrigation by TP, GW and MGW for 6, 9 and 12 days. Results indicate that magnetization of zucchini seeds and greywater (GW) caused a significant increase in the germination percentage compared with the non-magnetization of zucchini seeds or water at GW and TP. At different germination periods (6, 9, and 12 days), magnetized seeds irrigated by (MGW) exhibited superiority in the number of zucchini seedlings compared with TP and GW. The germination percentage was recorded 100% after 12 days with MGW compared with TP and GW which recorded 80% for the two qualities, respectively. These results supported by those obtained of (Shahin et al., 2016) who found that the magnetization of water and tomato, eggplant, cucumber, and zucchini seeds caused a significant increase in germination percentage at all germination periods (7, 10 and 15 days from sowing) compared to non- magnetized water or seeds. In addition, the germination percentage of seedlings of tomato, eggplant, cucumbers and squash with magnetized seeds irrigated with magnetized water was recorded 100% after 15 days compared to the germination percentage of 80, 77, 88 and 87%, respectively, with non-magnetized seeds irrigated with non-magnetized water. In this concern, (Hilal & Hilal, 2000), recorded full germination of magnetized wheat grains irrigated by magnetized water after six days of iirigation or planting??? compared with germination percentages of 83% after nine days for non-magnetized either seeds or water. (Hachicha et al., 2018) found that a significant increase in seeds germination rate of corn irrigated by magnetized saline water. (Martínez et al., 2009), and (Shahin et al., 2016) provided an acceptable explanation for the beneficial effects of magnetic treatments that was related to the paramagnetic properties of some atoms in plant cells and pigments, i.e. chloroplasts. Moreover, the magnetic properties of molecules determine their ability to absorb the energy of the magnetic field, then transform it into other kinds of energy and transfer this energy later to other structures in plant cells, thus activating them.

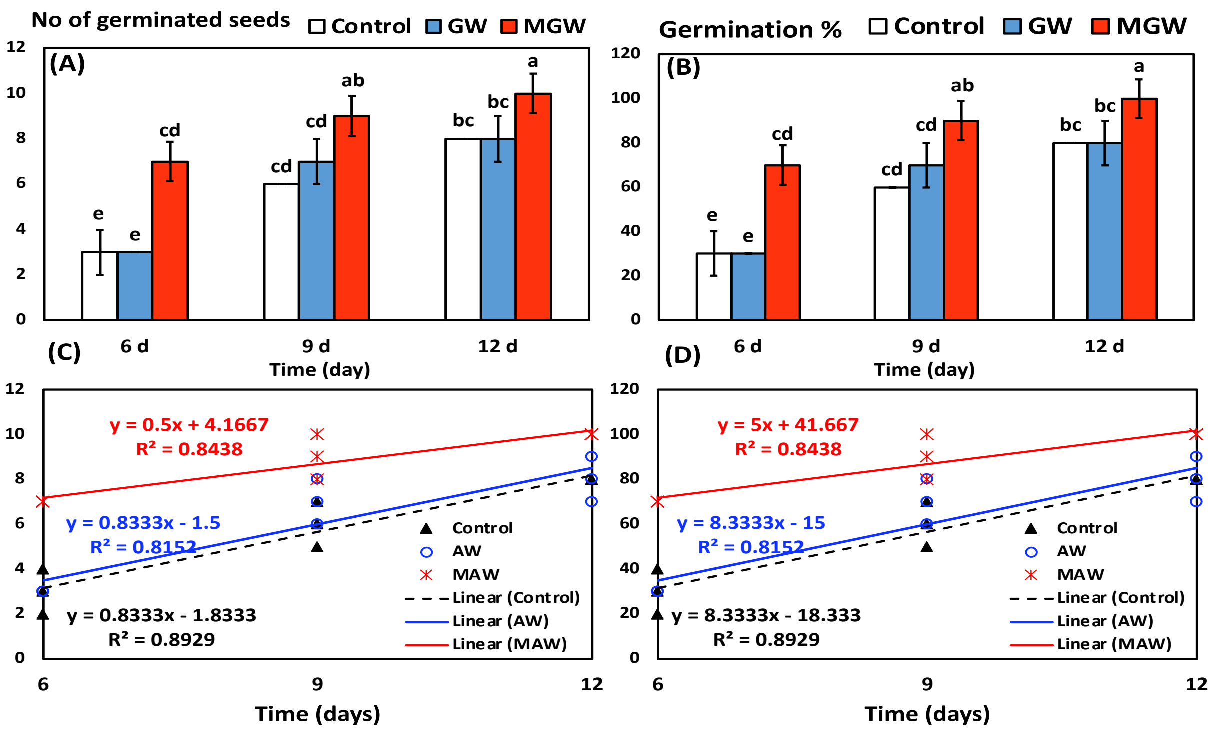

Fig. 2. A,C number of germinated seeds, B,D, germination (%) of plant at different treatment groups, Control (C), greywater (GW), and magnetic greywater (MGW), data presented as mean and standard deviation. The relationship between time (days) and germination was presented in term of regression trendline.

3.2. Effect of TP, GW and MGW on soil properties

Table 3 shows effect of TP, GW and MGW on some chemical and physical properties of soil. The results revealed that cations (Ca^{++}, Mg^{++}, and Na^{+}) were significantly lower in soil that had been irrigated with MGW as compared to irrigated soil TP or GW. K^{+} values were not affected by magnetized greywater. The results show that using MGW significantly reduced the values of Na^{+} and

Cl^- from 11.75 and 10.80 mmol/L to 8.20 and 7.90 mmol/L, respectively. Soil physical properties are not impacted by using TP, GW, or MGW for irrigation. Soils irrigated with MGW increased pH from 8.14 to 8.22 while EC decreased from 1.58 to 1.22 ds/m.

3.3. Water samples analysis

Tables 4 and 5 show the physical-chemical parameters and microbiological analysis of samples of water; control, GW and MGW. The results revealed that the amount of total suspended solids rose following the ablution and body wash procedure, while the percentages of dissolved oxygen (DO) fell. The data show that values of nitrogen in the form of ammonia decreased, while it increased in the form nitrate after ablution and body wash procedure. Also, Turbidity increased significantly after use. The results show that EC and TDS values of decreased in MGW when compared to TP and GW. Also notice that all cations in magnetized water (MGW) decreased compared to TP and GW. Additionally, anions (HCO_3^-, Cl^-, and SO_4^{--}) decreased in magnetized water (MGW) as compared to TP and GW. Trace elements and heavy metals were unaffected by the use of ablution and body wash procedure. Additionally, according to the microbiological analysis, all treatments were negative with the exception of the Coli form counts, which rose by 7% after the use compared to before the use.

3.4. Effect of GW and MGW on Chl-a, Chl-b and Car contents

Figure 3 shows effect of GW and MGW on Chl-a, Chl-b and Car contents in *C. pepo* leaves. The results demonstrated that when watering C. pepo with GW and MGW, their contents of Chl-a, Chl-b, and Car increased. watering C. pepo with MGW resulted in the highest Chl-a, Ch-b, and Car contents at the 10th and 20th days from the cultivation compared to control.

3.5. Effect of GW and MGW on antioxidant enzymes activity

Figure 4 shows effect of GW and MGW on antioxidant enzymes activity in *C. pepo* leaves. The results showed that the activity of the POD enzyme increases in the leaves of the zucchini plant after 20 days of planting with irrigation with GW and MGW, while the activity of the PPO enzyme decreases. Concerning CAT activity, it did not show any activity through measurements at the tenth day and the twentieth day from the cultivation.

3.6. Effect of GW and MGW on N, P and K contents in shoot zucchini plant

Figure 5 shows effect of GW and MGW on N, P and K contents in shoot zucchini plant**.** Results show that when magnetic water was used for irrigation, nitrogen, phosphorus, and potassium percentages increased significantly.

Table 3. Some chemical and physical analysis of soil properties used before and after irrigated by TP, GW and MGW.

Treatments		Soil before irrigation	Soil irrigated by TP	Soil irrigated by GW	Soil irrigated by MGW
pH 1:2.5		8.14	8.15	8.16	8.22
EC (dS m^{-1})		1.58 c	1.62 b	1.67 a	1.22 d
Soluble cations (mmolc l^{-1})	**Ca^{++}**	2.09 b	2.16 ab	2.22 a	2.02 c
	Mg^{++}	1.35 b	1.45 a	1.49 a	1.25 c
	Na^+	11.75 c	11.99 b	12.21 a	8.2 d
	K^+	0.61 b	0.62 b	0.75 a	0.75 a
Soluble anions (mmolc l^{-1})	**$CO_3^=$**	0	0	0	0
	HCO_3^-	2.95 b	3.00 a	3.02 a	2.35 c
	Cl^-	10.80 c	11.13 b	11.54 a	7.90 d
	$SO_4^=$	2.05 b	2.09 ab	2.11 a	1.95 c
BD		1.42 a	1.41 a	1.40 a	1.43 a
RD		2.73 a	2.75 a	2.71 a	2.70 a
Particle Size distribution (%)	**Sand**	75.15 a	75.17 a	75.25 a	75.30 a
	Silt	14.85 a	14.88 a	14.85 a	14.65 a
	Clay	10.00 a	9.95 a	9.90 a	10.05 a
Texture class		Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam

Table 4. Values of physic-chemical parameters of water samples; TP (control), GW and MGW.

Parameter	TP (control)	GW	MGW
Total suspended solids (mg l^{-1})	15.82	23.67	23.67
DO (mg l^{-1})	8.79	8.07	8.05
BOD_5 (mg l^{-1})	Nil	Nil	Nil
pH	6.10	6.10	6.12
EC (dS cm^{-1})	0.41	0.41	0.31
TDS (mg l^{-1})	262.00	262.00	198.00
N-NH_4 (mg l^{-1})	5.10	3.00	3.00
N-NO_3 (mg l^{-1})	5.20	7.20	7.20
Turbidity (NTU)	1.47	13.16	13.16
Cations and anions (mg l^{-1})			
Calcium	57.89	57.89	50.10
Magnesium	66.70	66.70	51.00
Sodium	126.00	126.00	87.00
Potassium	5.00	5.00	5.00
Carbonate	0.00	0.00	0.00
Bicarbonate	60.30	60.30	50.00
Sulphate	68.22	68.22	54.00
Chloride	127.00	127.00	89.00
Trace and heavy metals (mg l^{-1})			
Aluminium	0.2041	0.2041	0.2041
Boron	<0.0040	<0.0040	<0.0040
Barium	0.03940	0.03940	0.03940
Cadmium	<0.0006	<0.0006	<0.0006
Cobalt	<0.0010	<0.0010	<0.0010
Chromium	<0.0100	<0.0100	<0.0100
Copper	<0.0060	<0.0060	<0.0060
Iron	0.04090	0.0409	0.0409
Manganese	<0.0020	<0.0020	<0.0020
Molybdenum	0.0079	0.0079	0.0079
Nickel	0.0573	0.0573	0.0573
Lead	<0.0080	<0.0080	<0.0080
Strontium	0.4680	0.4680	0.4680
Vanadium	<0.0100	<0.0100	<0.0100
Zinc	<0.0006	<0.0006	<0.0006

Table 5. Microbiological analysis for water samples of TP (control), GW, and MGW.

Media Used For Isolation	Organism	Occurrence			Sign
		TP (Control)	AW	MAW	
MacConky	*Pseudomonas sp.*	- ve	- ve	- ve	*>0.05 ns*
XLD	*Alcaligenes sp.*	- ve	- ve	- ve	*>0.05 ns*
S.S	*Escherichia coli*	- ve	- ve	- ve	*>0.05 ns*
	Citrobacter sp.	- ve	- ve	- ve	*>0.05 ns*
	Salmonella sp.	- ve	- ve	- ve	*>0.05 ns*
	Shigella sp.	- ve	- ve	- ve	*>0.05 ns*
	Klebsiella sp.	- ve	- ve	- ve	*>0.05 ns*
Biochemical test media					
	Proteus	- ve	- ve	- ve	*>0.05 ns*
TSI				- ve	*>0.05 ns*
MIU	Enterobacter	- ve	- ve	- ve	*>0.05 ns*
MR					
VP					
C (Simmons Citrate Agar)					
Coli forms counts	CFU/100ml				
Total microbial count	CFU/ml	280	> 300	> 300	>0.05 ns

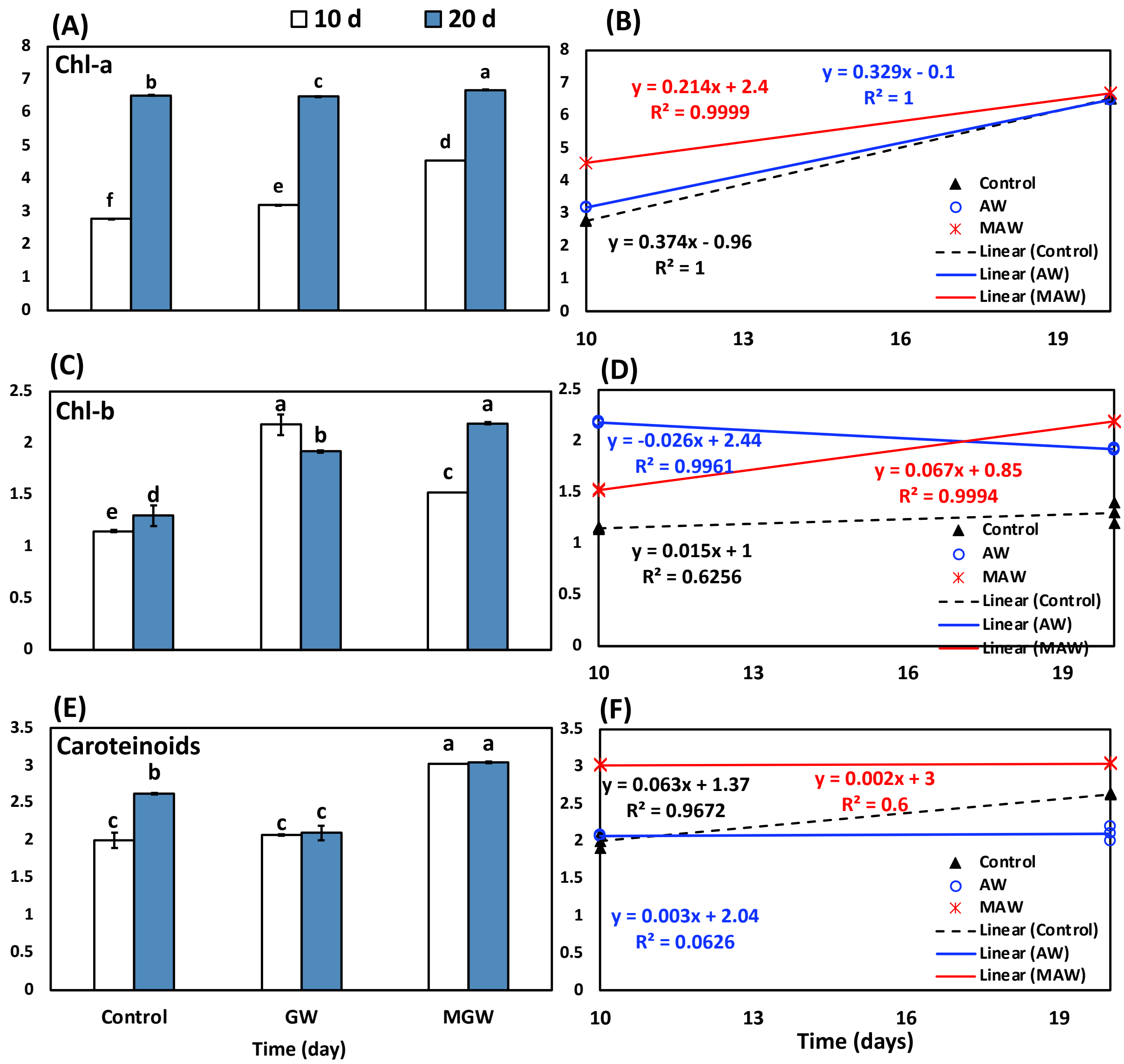

Fig. 3. Effect of GW and MGW on contents of Chl-a, Chl-b and Car in C. pepo leaves.

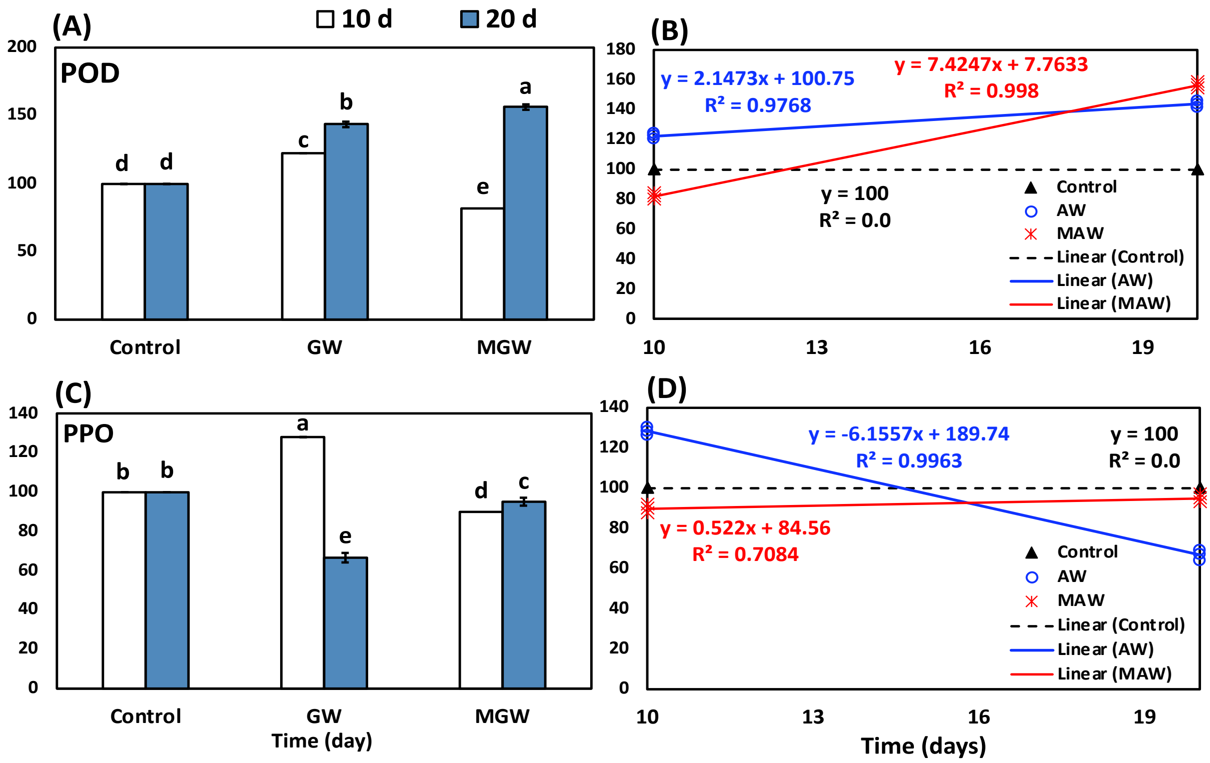

Fig. 4. shows the effect of GW and MGW on antioxidant enzyme activity in zucchini plant leaves.

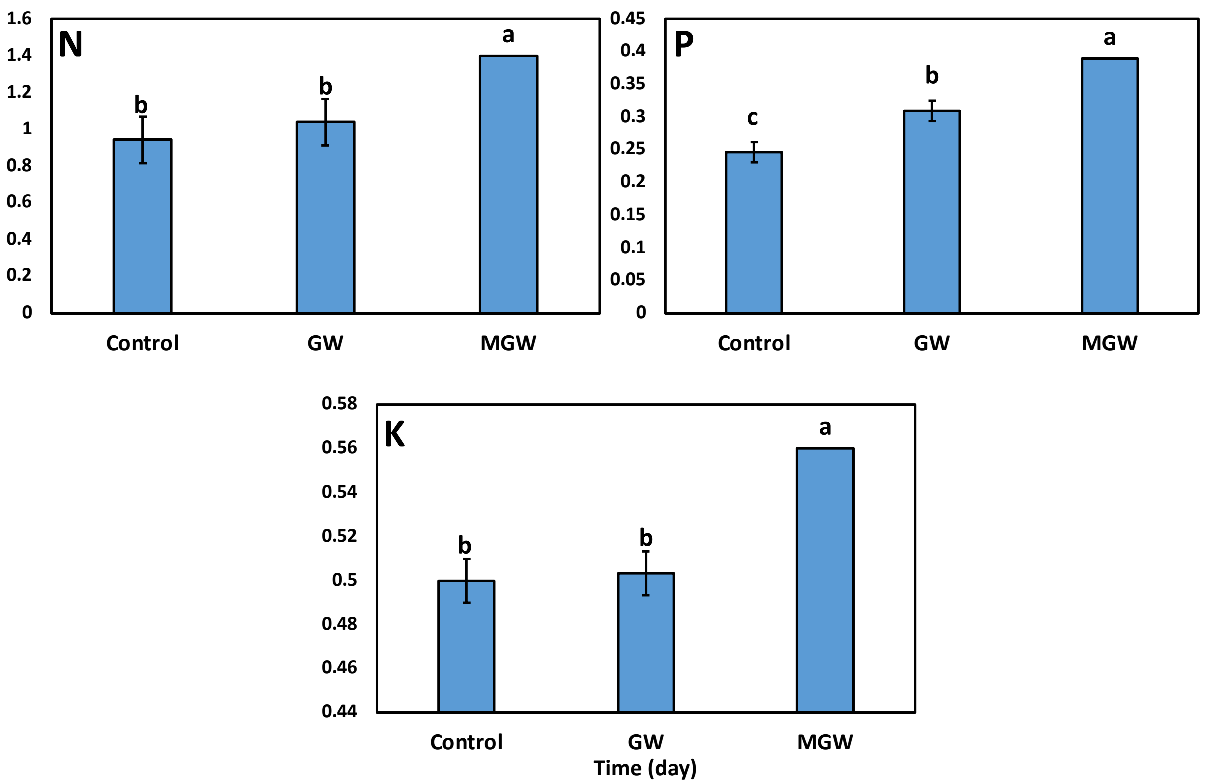

Fig. 5. Effect of TP, GW, and MGW on N, P, and K contents in shoot zucchini plant. Bars followed by different letters are significantly different according to DMRTs at 0.05.

In Table 6, MANOVA multivariate analysis of variance presenting the effect of different treatment groups and time on different study variables. We concluded that all measurements increased significantly with the corrected model and all the Treatments of the different measurement periods and treatment x time, except for the NPK measurements, as there was no significant increase with time and treatment x time. The highest significant increase was with Chl-a, followed by POD, PPO, and then Chl-b.

Table 6. MANOVA multivariate analysis of variance presenting the effect of different treatment groups and time on different study variables.

	Corrected Model		Treatments		Time		Treatment x time	
	F	*p*-value	F	*p*-value	F	*p*-value	F	*p*-value
Germ No.	32.1	***<0.001****	43.8	***<0.001****	79.8	***<0.001****	2.4	***0.088ns***
Germ %	32.1	***<0.001****	43.8	**<0.001***	79.8	**<0.001***	2.4	**0.088ns**
Chl-a	94399.7	***<0.001****	15564.5	***<0.001****	420444.5	<.001	10212.5	***<0.001****
Chl-b	347.4	***<0.001****	637.5	***<0.001****	89.6	<.001	186.2	***<0.001****
Carot.	206.6	***<0.001****	428.6	***<0.001****	68.0	<.001	53.8	***<0.001****
POD	896.9	***<0.001****	601.7	***<0.001****	1677.5	<.001	801.8	***<0.001****
PPO	374.3	***<0.001****	28.5	***<0.001****	503.0	<.001	655.7	***<0.001****
N	7.4	***0.001****	18.6	***<0.001****	N/A	N/A	N/A	N/A
P	50.7	***<0.001****	126.6	***<0.001****	N/A	N/A	N/A	N/A
K	35.1	***<0.001****	87.7	***<0.001****	N/A	N/A	N/A	N/A

Data of heat map analysis (**Figure 6**) showed that all the treatments and time significantly enhanced most of the measurements as Chl-a, Chl-b, Carot, POD, and NPK. While PPO significantly decreased as compared with the control.

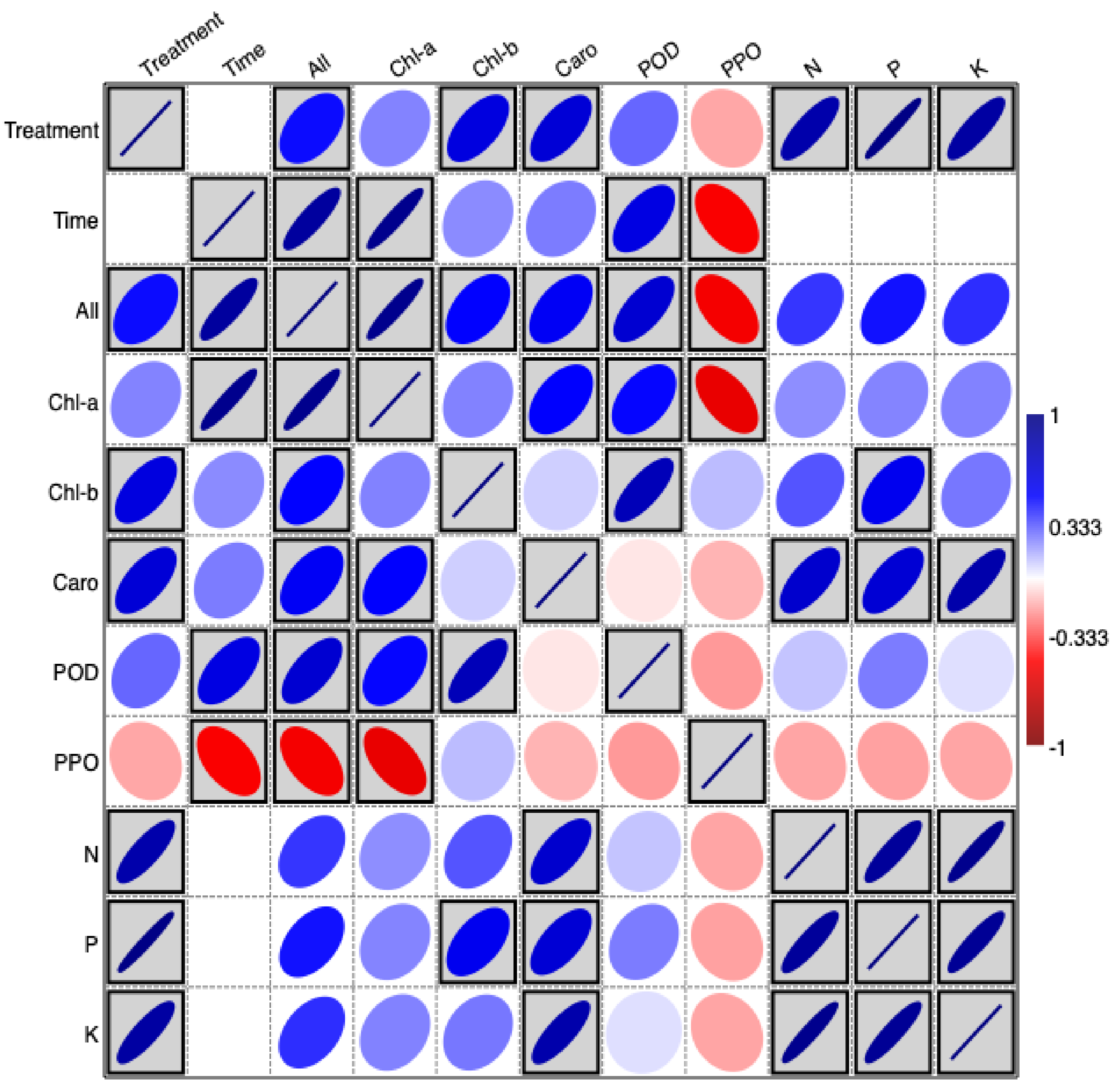

Fig. 6. Heatmap presenting the interrelationship between study variables.

4. Discussion

Magnetized greywater (MGW) enhanced the ability of zucchini seeds to germinate (Fig. 2). and this finding was confirmed by (Shahin et al., 2016) They discovered that, compared to non-magnetized water or seeds, magnetized water and tomato, eggplant, cucumber, and zucchini seeds significantly recorded higher germination percentages at all periods (7, 10, and 15 days from sowing).

They also noted that after 15 days, the germination percentage of tomato, eggplant, cucumber, and zucchini seedlings was recorded 100% when the seeds and water were magnetized, as opposed for non-magnetized seeds and water were 80, 77, 88, and 87%, respectively. In this regard, (Hilal & Hilal, 2000) found that magnetized wheat grains fully germinated after six days when irrigated with magnetized water, compared to germination percentages of 83% after nine days for non-magnetized seeds or water.

According to (Hachicha et al., 2018), magnetized saline water irrigation significantly increased the rate at which corn seeds germinated.

(Martínez et al., 2009; Shahin et al., 2016)explained that water molecules absorb magnetic field energy, convert it into other types of energy, and then transfer this energy to other structures in plant cells, thus activating them. Greywater, which has low levels of pathogens, organic matter, and nutrients, makes up the majority of domestic wastewater that comes from the kitchen, bathroom, and laundry (Noutsopoulos et al., 2018) **.** The MW increased the rate of seed germination (Sronsri et al., 2022)**.** Other studies (Garland, 2000; Lubbe et al., 2016; Misra et al., 2010) found no significant effects for irrigation with greywater irrigation seed germination compared to tap water.

The use of grey water for irrigation has become crucial for water management programmes in a number of arid and semi-arid regions. Meanwhile, irrigation with greywater and/or waste water alters the soil's physicochemical and microbial composition, which has a significant impact on plant growth and yield. In this experiment, tomatoes were watered with greywater (from laundry and dishes) that had been treated in a wetland mini reactor. One of the most significant abiotic factors affecting seed germination and seedling establishment is soil moisture content. Other important abiotic factors include electrical conductivity and pH. (Mudgal et al., 2011; Yazdi et al., 2013).

The findings of (Hachicha et al., 2018; Shahin et al., 2016), indicated that the EC, Na, and Cl values of soil irrigated with magnetized saline water significantly decreased compared to the values of soil untreated with non-magnetized saline water as in the initial state of the soil, could be used to support these findings. They also attributed the rise in pH values to the effects of irrigation water magnetization on the soil. When soluble cations (Ca^{++}, Mg^{++}, and Na^{+}) were measured in 1:2.5 soil water extract, the results revealed that they were significantly lower in soil that had been irrigated with the magnetized irrigation water (MGW) as compared to irrigated soil with non-magnetized water (TP or GW). It is clear that at MGW, where there was no discernible difference in the values of soluble K^{+} extracted from soil irrigated by GW or MAW, therefore the magnetization of water has no effect on soluble K^{+} values.

It is noteworthy that using MGW significantly reduced the values of Na^{+} and Cl^{-} from 11.75 and 10.80 mmolc L^{-1} before soil irrigation to 8.20 and 7.90 mmol/l, respectively. These outcomes were also confirmed by other researchers (Mohamed & Ebead, 2013)**,** who discovered that the use of magnetized irrigation water decreased the soluble values of Na^{+} and Cl^{-} in soil water extract.

The measured soil physical properties are not impacted by using TP, GW, or MGW for irrigation, according to research on the impact of various irrigation water treatments (TP, GW, and MGW). Numerous properties of soil, such as pH, phosphorus content, and extractable potassium, changed when it soil irrigated with magnetized water (Abedinpour & Rohani, 2017; Mohamed & Ebead, 2013).

In a prior study, soil was irrigated with magnetized water to lower the pH, but an increase in soil electric conduction and available phosphorus was also noted (Ibrahim, 2013). This result is consistent with Al-Ghamdi, 2020 report, which discovered that plants supplied with magnetized water had higher levels of metals like Ca, Mg, and K. On the other hand, plants irrigated with magnetic water absorbed less Fe (Al-Ghamdi, 2020).

In this study, soil irrigated with magnetized water contained significantly more K than soil irrigated with regular water. In one experiment, (Al-Faidi, 2014) discovered that Guinea grass that had been irrigated with magnetic water had higher levels of N, K, and P. However, the researcher discovered diminished Cd, Pb, and Na levels under-irrigation with grey water treatments that included fertiliser amendments showed increased trends in the composition of macroelements (N, P, and K). (Kiziloglu et al., 2008)**.** This may be explained by the high availability of N, P, and K in wastewater, which increased their concentration in soil.

Effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (*Brassica oleracea* L. var. Botrytris) and red Micronutrient (Fe, Mn, Cu, and Zn) content also demonstrates that irrigation with various wastewater concentrations alone and in conjunction with fertilization significantly increased the concentration of these nutrients within plant tissues compared to irrigation with tap water alone. In the soils irrigated with distillery effluents, (Silva et al., 2016) also noted similar outcomes.

The favourable effects of water magnetization could be primarily attributed to the MW's lower surface tension, which enhances roots' capacity to absorb water and nutrients and, as a result, enhances various biosynthesis processes (Elhindi et al., 2017).

The physical-chemical parameters and microbiological analysis of water sample data are shown in Tables 4 and 5. (TP, GW and MGW). In general, the amount of total suspended solids rose following the ablution and body wash procedure, while the percentage of dissolved oxygen (DO) fell as a result of the rise in organic matter. After the ablution and body wash process, the nitrogen values in the form of ammonium decreased while the nitrogen values in the form of nitrate increased. The nitrifying bacteria that turn ammonia into nitrate are to blame for this (nitrification process). The ablution and wash procedure caused a significant increase in turbidity.

Concerning EC and TDS, values of magnetized water decreased in MGW when compared to TP and GW. On the other hand, the obtained pH in TP and GW seemed to be not affected by magnetization range (0.151 to 1.903 KG). The reduction of all soluble cations in magnetized water (MGW) as compared to TP and GW was also noticed when examining the effects of magnetic treatment on soluble cations (Ca^{++}, Mg^{++}, Na^{+}, and K^{+}). Additionally, soluble anions (HCO_3^{-}, Cl^{-}, and SO_4^{--}) decreased in MGW as compared to TP and GW. These findings are consistent with those of (Hachicha et al., 2018; Shahin et al., 2016)**,** who discovered that the presence of magnetic water at a 40 mT (0.4 KG) field significantly reduced the concentrations of measured cations and anions as well as TDS and EC values.

Numerous studies have shown that magnetic water treatment (MWT) affects the physicochemical and molecular characteristics of water, which changes the water's quality. The alteration of the water nucleus is the cause of the physical and chemical modulations of water molecules under magnetic treatment, according to (Cai et al., 2009; Coey & Cass, 2000)

. Different water treatments (TP, GW, and MGW) were found to contain trace elements and heavy metals within acceptable limits. Trace elements and heavy metals were unaffected by the use of ablution and body wash procedure. Additionally, according to the microbiological analysis, all treatments were negative with the exception of the Coli form counts, which rose by 7% after the use compared to before the use. The results obtained are typically anticipated to happen with water after the use. According to some studies, using magnetized water for irrigation improves soil qualities while lessens the stress that salinity and drought have on plants (Kney & Parsons, 2006; Mostafazadeh-Fard et al., 2012)

Pharmaceuticals, health and personal care items, biological microbes, dyes, and microorganisms have all been found in greywater (Oteng-Peprah et al., 2018). According to (Maheshwari & Grewal, 2009)**,** one of the adaptive responses that protects chlorophyll and enables plants to finish their life cycles is an increase in carotenoids. Also, according to (Hopkins & N.P.A. Hüner, 2008)**,** a high shoot root ratio, a high stomata conductance, and a high rate of photosynthesis can stimulate plant growth rates under such conditions. By interfering with electron transport, stomata control, and CO_2 assimilation, environmental stresses can have an immediate impact on the photosynthetic apparatus and ultimately slow growth rates (Anjum et al., 2011). The findings demonstrated that when watering C. pepo with GW and MGW, their contents of Chl-a, Chl-b, and Car increased, as shown in Figure 3.

In accordance with earlier studies that support this result, watering C. pepo with MGW resulted in the highest Chl-a, Ch-b, and Car contents at the 10th and 20th days from the cultivation compared to control (Baghel et al., 2016; Hasan et al., 2019; Kataria et al., 2015; Radhakrishnan & Kumari, 2013; Rochalska, 2005; Türker et al., 2007).

As a result, under MW and abiotic stress conditions, maize and soybean leaves may contain more chlorophyll, and corn plants may contain more chlorophyll (Anand et al., 2012). As a result, it directly affects the photosynthesis system (Aladjadjiyan, 2002).

Increased ion fluidity and uptake in the magnetic field promote chlorophyll pigments, chlorophyll activity, translocation efficiency, and light assimilation in the plant, which in turn promotes increased chlorophyll activity, translocation efficiency, and photo assimilation (Mihaela et al., 2009).

By using magnetic water irrigation to increase leaf area and photosynthetic rate, more nutrients are taken up via vegetative growth and the amount of chlorophyll may also increase (Sadeghipour & Aghaei, 2013).

Additionally, because magnetized saline water lessens the negative effects of saline water on the effectiveness of pigments, it has an impact on the photosynthetic pigments of plants. More recently, it was discovered that barley plants' photosynthetic pigment values significantly increased when they were irrigated with magnetized saline water rather than non-magnetized saline water (Liu et al., 2019).

It was reported that the magnetized water increased photosynthetic characteristics and total chlorophyll (Liu et al., 2020b). This is explained by the higher nutrient uptake through the roots of magnetized water compared to untreated water. Irrigation with magnetized water (Eşitken & Turan, 2004). can also promote plant metabolism, which includes the harmony of enzyme activity and photosynthesis as well as secondary metabolites (Rani et al., 2022). Similar increases in pigment fractions were seen in water in the cultivation of lupine, as well as Celosia argentea plants that were irrigated with magnetized water (Niu et al., 2021).

Other researchers also noted that irrigation with magnetized water increased chlorophyll content, which is consistent with our findings (Moussa, 2011). Reactive oxygen species (ROS) are harmful in excess because they harm membranes, proteins, chlorophyll, and nucleic acids when drought stress occurs (Smirnoff, 1993). According to (Ojeda-Barrios et al., 2018), Plants employ sophisticated defence mechanisms to lessen this oxidative damage, including the enzymatic antioxidants superoxide dismutase (SOD, EC 1.15.1.1), peroxidase (POD, EC 1.11.1.7), and catalase (CAT, EC 1.11.1.6).

SOD converts oxygen into O_2 and H_2O_2, making it a significant oxygen scavenger. These results are in direct opposition to the claims made by (Badea et al., 2002) that MW increased POD and SOD activity. Furthermore, claims that MW reportedly activates the common bean plants' defence system (Moussa, 2011). It has been shown in numerous studies that magnetic water stimulates plant defence mechanisms, which may also explain why MW irrigation increases crop-resistant-related enzyme activity (SOD and POD). The latter is subsequently transformed by CAT into H_2O and O_2, whereas POD oxidizes cosubstrates to break down H_2O_2. Plants that produce fewer ROS and have more active antioxidant enzymes may be better able to withstand drought stress. Other researchers also noted that irrigation with magnetized water increased chlorophyll content, which is consistent with our findings (Moussa, 2011).

A marker for lipid peroxidation, malondialdehyde (MDA), accumulates more frequently in response to environmental stresses (Cakmak & Horst, 1991). POD is essential for reducing H_2O_2 buildup, removing MDA-induced cell peroxidation of membrane lipids, and preserving the integrity of cell membranes (Shao et al., 2008). Additionally, increased POD activity was also noticed higher in drought-stressed soybean (Zhang et al., 2008). and chives plants (Egert & Tevini, 2002). When wheat and *Phaseolus acutifolius* were subjected to drought stress, similar results were reported (Shao et al., 2008; Türkan et al., 2005). Tetrameric heme-containing enzyme CAT is prevalent in the glyoxysomes of tissues that store lipids (Helm et al., 2004).

Under drought stress, similar findings were presented in plants like rice (Farooq et al., 2009). It is well known that higher plant lipid membrane peroxidation reflects oxidative damage caused by free radicals at the cellular level under abiotic stress (Hernández et al., 1995; Nouairi et al., 2009). Accordingly, water stress caused cellular damage in tomato plants under water stress treatments, especially under moderate water stress (MoWS) and severe water stress (SeWS) treatments, as determined by the higher MDA content. It was found that irrigation with water that had undergone magnetic treatment increased the content of all elements except sodium. This is due to sodium's paramagnetic nature, which has a negligible positive susceptibility to magnetic fields (Nave et al., 2008), as opposed to other elements, which are diamagnetic and are only weakly attracted to magnetic fields.

The addition of more necessary elements helped the chlorophyll content of treated water plants increase. Magnesium ions are located at the center of chlorophyll molecules, and since chlorophyll is a necessary element in the process of photosynthesis, which generates energy for growth, magnesium ions are crucial (Bohn & Federle, 2004).

These findings could be supported by those of (Shahin et al., 2016), who discovered that the use of magnetised irrigation water significantly enhances cucumber plant's shoot as well as its levels of macro- and micronutrients (N, P, K, Fe, Mn, Zn, and Cu) (40 mT).

Additionally, nutrients that are adsorbed on colloidal soil aggregates may be affected by magnetised irrigation water, increasing the availability of those nutrients to plant roots and promoting better plant growth and productivity. According to (Nie et al., 2021) the magnetised water results in the highest values for vegetative development traits like bud length and thickness, the number of leaves, the surface area of leaves, as well as the chemical components of shoots (N, P, K, Ca, Mg). Cotton absorbs N, P, and K nutrients more readily when fertilizers are magnetised with water in a drip irrigation system, to varying degrees (Nie et al., 2021).

In addition, (Noran & Tang, 1996) noted variations in the concentrations of K, N, P, Na, Ca, and Mg in soils irrigated with magnetic water in comparison to regular water (under drip irrigation system). They claimed that magnetic water made it easier for plants to absorb nutrients from soil solutions because it accelerated the processes by which the solute minerals crystallised and precipitated. Results show that when magnetic water was used for irrigation, nitrogen, phosphorus, and potassium percentages as well as Fe, Mn, Zn, and Cu (ppm) increased significantly.

The magnetic treatment of irrigation water, according to (Grewal & Maheshwari, 2011), led to a significantly higher level of N, K, Ca, Mg, S, Zn, Fe, and Mn in snow pea and chickpea seedlings. Magnesium serves as the chlorophyll's central ion, and a porphyrin makes up the bulk of the organic compound.

The porphyrin has four nitrogen atoms that bond to magnesium in a square planar arrangement, causing magnetic water to absorb more N and Mg, increasing the chlorophyll content (Shen and Ryde, 2005). In contrast, potassium and phosphorus are required for the chemical processes that take place within plant cells, the formation and movement of carbohydrates, the growth of roots that are essential for absorbing minerals and water, ATP, which is essentially a molecule of energy, and nucleic acids (Daniel et al., 1998).

5. Conclusion

Good quality GW was not used to irrigate the zucchini plant only, but also its properties were improved by magnetizing it, which led to a significant increase in the germination percentage compared with the non- magnetization of zucchini seeds. Using MGW significantly reduced the values of Na^+ and Cl^- from 11.75 and 10.80 mmol/l before soil irrigation to 8.20 and 7.90 mmol/l, respectively. Soil irrigated with magnetized water contained significantly more K than soil irrigated with regular water. The results demonstrated that when watering C. pepo with GW and MGW, the contents of Chl-a, Chl-b, and Car increased. Trace elements and heavy metals were unaffected by the use of ablution water and body wash. Additionally, according to the microbiological analysis, all treatments are negative with the exception of the Coli form counts, which rose by 7% after the use compared to before the use. Therefore, this study recommends the reuse of GW coming out of public institutions and mosques in irrigating edible plants without treatment or can be magnetized before use.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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Competing interests

The authors declare no competing interests.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest:

The authors declare no conflict of interest.

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