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PHYSIOLOGICAL RESPONSES OF ROCKET (*Eruca Sativa* L.) PLANTS GROWN IN SEWAGE SLUDGE-AMENDED SOIL TO MAGNETIZED WATER APPLICATION

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ABSTRACT: This investigation was carried out in a greenhouse at the Experimental Farm of Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt during the two growing seasons of 2021 and 2022 to study the influence of dried sewage rates [0, 5, 10 and 20% (w/w, sewage: soil], irrigation with magnetized water and their interactions on some vegetative growth parameters, plant water relations and membrane stability (permeability), photosynthetic pigments, some biochemical compositions, some nutrient minerals of rocket (*Eruca sativa* L.) plants as well as behavior some heavy metals and their effect on human health. One sample was successively taken at random from every treatment at 60 days from sowing. The obtained results showed that sewage sludge increased most growth characters, RWC, LWD, OS, TR, total soluble sugars, total protein, polyphenol oxidase activity, proline and N, P, and K content, meanwhile DSc. MI, photosynthetic pigments and peroxidase activity were decreased. Application of sewage sludge caused a great increase in the concentration of Pb and Cd in the different organs of rocket plant over the safe limits. The irrigation with magnetized water and its interaction with sewage sludge caused an additive enhancement in the growth, some physiological, biochemical characters i.e. (photosynthetic pigments, sugars, total protein, total free amino acids, proline, activity of enzymes, N, P and K mineral status) as well as improved plant water relations and membrane permeability of rocket plants. Under the same condition, there were remarkable decreases in leaf water deficit, transpiration rate, Pb and Cd concentrations and uptake, BCF, TF and CR in rocket plants. Also, the magnetized water under the SS conditions has crucial role in improvement and enhancement the growth, biochemical constituents, a great reduction in Pb and Cd conc. in all organs especially shoot system of rocket plants and become safe for human consumption.

Key words: Sewage sludge, Rocket, Growth, Water relations, Photosynthetic pigments, Biochemical constituents, Heavy metals.

INTRODUCTION

Rocket plant is a bitter leafy green often used in Mediterranean cuisine. It's full of beneficial plant compounds and inflammation-fighting antioxidants, making it an incredibly healthy part of the diet. The nutrients in rocket leaves may reduce the risk of serious diseases, like heart disease, cancer and cognitive decline. Rocket plant is low in calories and other nutrients, but it does have substantial amounts of vitamin K, which is necessary for blood clotting, bone health and heart health. Rocket belongs to Brassicaceae family, which has many plant compounds and antioxidants. One compound, glucosinolates, exhibits anti-inflammatory and antioxidant effects that may prevent various diseases.

In Egypt, the raped increase of population, urban planning and the industrial developments resulted more accumulation of sewage sludge, leading to producing huge amount of it daily. Additionally, it causes a great environmental problem because the derived risk from the presence of pathogens, heavy metals and organic pollutants in sludge (Harrison *et al.*, 2006). Sewage sludge applications increased significantly length of both root and shoot, plant height, fresh and dry weight, grain yield, number of pods/plant and seed yield (Harangozo *et al.* (1984), Eid *et al.*, 2020, Al-zoabi *et al.*, 2023), as well as leaf area and leaf biomass (Boudjabi *et*

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al., 2015). Sewage sludge increased chlorophyll content and oxygen evolution (Charchar *et al.*, 2020), as well as total soluble sugars and sucrose content (EL Hocine *et al.*, 2020). Despite, sewage sludge (SS) provides agricultural soils with organic matter and several macro- and micro-nutrients (Roszyk *et al.,* 1989, Lewis *et al*., 1992, Fresquez *et. al*. 1990 and Shakarami and Maroufi, 2019) which are used as fertilization materials, heavy metal content in SS is a limiting factor for SS application due to the toxic effects of these metals on plants. Heavy metals phytotoxicity includes alteration of pigment biosynthesis, photosynthesis process, inactivation of enzymes, nutrients assimilation. Monitoring heavy metals in plants growing in soils amended with SS is an important issue as the accumulation of heavy metals may contaminate the food chain through entering animal and human bodies, causing severe health disorders (Bettiol and Ghini**,** 2011, Eid *et al.*, 2020, Abeed *et al.*, 2022, Lassoued and Essaid, 2022, Hassan *et al.,* 2023).

Magnetic field technique has shown various benefits which can improve the plant growth, the water relations and metabolic processes in plant, the solubility of nutrients in the soil, and crop yields. Several investigators indicated that the magnetic field helps for improvement the germination of seeds (Aladjadjiyan, 2002), the plant growth (Radhakrishnan and Kumari, 2012, Sarraf *et al.,* 2020), the plant water status and relations (Selim, 2016), the concentration and uptake of essential macro- and micro-elements and the chemical composition of plants (Radhakrishnan and Kumari, 2012, Jaime *et al.*, 2014, Rawabdeh *et al.,* 2014), saving the irrigation water (Selim and El-Nady, 2011 and Selim *et al*., 2019), and increasing the yield of many economic crops (Ali *et al.,* 2014, Doklega, 2017). Furthermore, different studies suggest that MFs prevent the large injuries produced/inflicted by diseases and pests on agricultural crops and other economically important plants and assist in reducing the oxidative damage in plants caused by abiotic stress situations such as drought, salt, heavy metal contamination in soil (Selim and El-Nady, 2011, Radhakrishnan, 2019, Sarraf *et al.*, 2020). Khoshravesh *et al.* (2021) stated that using magnetic technique reduced the solutes and heavy metals in the soil, providing the conditions for better cultivation in terms of reducing the toxicity of plants due to less absorption of heavy metals.

Very limited or rare studies have been attempted to determine the role of MF on plant tolerance against various stress conditions especially sewage sludge containing pathogens and heavy metals.

Therefore, this investigation aimed to study the effect of irrigation with magnetic water on growth, physiological behavior, biochemical constituents, heavy metals behavior in rocket plants grown in sewage sludge-amended soil under Egyptian conditions.

MATERIALS AND METHODS

This work was carried out in a greenhouse at the Experimental Farm of Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt during the two growing seasons of 2021 and 2022 to study the influence of dried sewage rates [0, 5, 10 and 20% (w/w, sewage: soil], irrigation with magnetized water and their interactions on some vegetative growth parameters, plant water relations and membrane injury (permeability), photosynthetic pigments, some biochemical compositions i.e. (total soluble sugars, total protein, total free amino acids, proline, activity of some enzymes, some nutrient minerals rocket (*Eruca sativa* L.) plant as well as behavior some heavy metals and their effect on human health. The seeds rocket plant used in this investigation were obtained from Crop Research Institute, Agricu1ture Research Center, Giza, Egypt. The polyethylene bags of 20 cm diameter and a depth of 30 cm were used and filled with 5 kg of clay loamy soil. The physical and chemical of the soil used are shown in Table 1. The seeds were sown on August 24^{th} 2021 and 2022. After 15 days from sowing, seedlings were thinned to 5 plants per bag. The treatments were arranged in complete randomized block design (two-ways) with 5 replicates. The normal practices for growing rocket plants recommended for the region were followed. The dried sewage sludge was obtained from the Sewage Water Station at Shebin El-Kom. The chemical characteristics were illustrated in Table 2. The chemical characteristics of sewage sludge were illustrated in Table 2. The sludge taken was air dried for 3 weeks in open air. Sludge was grinded manually to pass through 2 mm diameter sieve before using in the experiment. Different levels of (Sludge-Soil) mixture were used for this study. The sludge was mixed with soil at levels: 0, 5,10 and 20% (w/w, sewage sludge/soil). The irrigation water was applied under either normal irrigation water (M-) or magnetized water (M+). The magnetized water was passed through magnetron tube of 2 inches diameter and 4000 Gauss strength according to Selim (2008) and Amin and Qaseem (2009).

One sample from each treatment was taken after 60 DAS, to determine the following data:

-***Vegetative Growth characteristics*:** Root length (cm), plant height (cm), dry weights (g) for roots and shoot dry weight of whole plant (g). Plant materials were dried in an electric oven at 70^0C for 72 hours then used it for chemical analysis, and leaf area (cm^2/plant) and leaf area index were determined using the disk method of Bremner and Taha (1966), relative growth rate (RGR, mg/g/week) and net assimilation rate (NAR, g/cm^2/week) during the course of 40 to 60 days were determined according to Simane *et al*., (1993).

-***Chlorophyll (a), (b) and carotenoids*** (mg/L then quantified as mg/g dwt.) were determined from the fresh leaves using spectrophotometric method as described by Wettstein (1957).

-***Plant water relations:*** Total water content (TWC %) was estimated according to Gosev (1960), leaf water deficit (LWD %) and relative water content (RWC %) were measured using the methods of Kalapos (1994) and transpiration rate (TR) was measured according to Kreeb (1990). Membrane permeability was determined according to Yan *et al*. (1996).

Table 1 : The physical and chemical characteristics of the soil used.

Properties	Values
Physical analyses:	
Coarse sand%	2.31
Fine sand %	29.05
Silt %	40.60
Clay %	27.60
O.M %	0.44
Texture grade	Clay loamy
Chemical analysis:	
pH	7.90
Ec dS / m	2.50
Soluble ions (mg /100 g soil):	
Ca^{+2}	0.42
Mg^{+2}	0.68
Na^{+}	0.62
K^{+}	0.12
Cl^{-}	
SO_4^{-2}	0.40
Total N %	0.12
Total P %	0.26
Total HCO_3^{-}%	2.35
Pb µg/kg	1.10
Cd µg/kg	0.09

Table 2 : Chemical characteristics of the sewage sludge used in the experiment.

Variable	Sewage sludge
E.C (1-10) sludge/water dS/m	2.70
pH (1-10) sludge/water	7.30
Total HCO_3 %	4.20
Organic matter %	4.80
N %	2.80
P µg/g	7.06
K meq/L	2.40
Fe µg/g	5.20
Mn µg/g	4.20
Zn µg/g	9.50
Pb µg/kg	1694.26
Cd µg/kg	213.71

- ***Total soluble sugars (TSS,** mg/g dwt.)* were determined clorometrically using the method as described by Dubois *et al.* (1956).

-***Phenoloxidase activity and peroxidase activities*** and were measured in fresh leaves using the method described by Broesh (1954) and Fehrman and Dimond (1967), respectively.

-***Total proline*** in leaves (µmole / g Fwt.) was estimated according to Bates *et al.* (1973)

- ***Total crud protein*** (%) was calculated by, multiplying the nitrogen percentage by 6.25.

- ***Nitrogen, Phosphorus and Potassium*** concentrations (%) of plant leaves were determined in the fine powder of dry matter using the method described by Sadasivam and Monikom (1992).

- ***Pb and Cd Heavy metal***s were determined in plant organs by using Parken Elemer (2830) atomic absorption spectrophotometer according to Stewart (1973). *Pb and Cd Transfer Factor (TF), Bioconcentration Factor (BCF)*, and *Carcinogenic Risk (CR)*were determined using the formula of Padmavathiamma and Li, (2007), Wilson and Pyatt, (2007) and Shaheen *et al.* (2016), respectively.

Statistical analysis

Data were statistically analyzed according to Gomez and Gomez (1984) with the help of COSTAT (1985) Computer program for statistics least significant differences test (LSD 5%).

RESULTS AND DISCUSSION

1. Vegetative Growth Characters

Data recorded in Table 3 showed that all rates of dried sewage sludge rates significantly increased most growth parameters, plant height, dry weights of root, shoot and whole plant, LA and LAI, RGR and NAR of rocket plants. Root length was increased at the low level (5%), meanwhile it was significantly inhibited at the rates of 10 and 20% compared to the control plants. These results were true in both the two seasons. Similar results were obtained by Lonova *et al.* (2022) on lettuce, Hassan *et al.* (2023), on radish, carrot, turnip, spinach, and fenugreek AL-Huqail *et al.* (2023) on marigold, Sasi *et al.* (2019) on common bean *(Phaseolus vulgaris* L.*)* plants, Zafar *et al.* (2021) on kale and spinach, who found that plant height, dry weight of plant and leaf area of plants were increased by application of sewage sludge in different rates. Rucin´ska-Sobkowiak (2016) found that concentrations of heavy metals in soil to cause decreased elongation of the primary root, impaired secondary growth.

The increase in the most vegetative growth parameters of rocket plants especially at the lowest and moderate levels of sewage sludge may be attributed to the highest concentration of organic matter and macro- and micronutrients in sewage sludge and beneficial nutrients increased the green leaves and leaf area, or may be these elements enhanced the metabolic activities and hence vegetative growth (Sakr *et al.*, 2008, Singh and Agrawal, 2010 and Eid, 2012). Moreover, application of sewage sludge affected synthesis of photosynthetic pigments as shown in Table 5. The increased content of chlorophylls and carotenoids was in parallel with the enhancement of plant growth. On the hand, the reduction in some vegetative growth parameters such as in root length of rocket plants by using high concentration of sewage sludge may be attributed to increasing osmotic pressure of the soil solution in a point which retarded the intake of water (Abo-Bakr and Abou-Leila, 1990) resulting in water stress in the plant or accumulation of heavy metals leading to decrease of cell division, cell enlargement and the intensity of photosynthesis on plants (Welfare *et al.*, 2002, Gaballah and Gomaa, 2004 and Eid, 2012).

Data illustrated in the same Table as well as the analysis of variance showed that root length, plant height, dry weights of root, shoot and whole plant, LA and LAI, RGR and NAR of rocket plants irrigated with magnetic water showed a great increase in them comparing with control plants in the two seasons. The obtained results are in harmony with those demonstrated by Sestili *et al.* (2022) on durum wheat and lentil, Radhakrishnan and Kumari (2012) on soybean, Ismail *et al.* (2020) on rocket plant (*Eruca sativa* L.), Abd Ellateef and Mutwali (2022) on broad bean. Jasim *et al.* (2017) on wheat and rice plants and Selim *et al.* (2009) on pepper plants.

Table 3 : Effect of magnetized water, Sewage Sludge levels and their interactions on some vegetative growth characters of Rocket plants at age of 60 days during the 1st (a) and 2nd (b) growing seasons.

(a): 1st season

Treatments (Mag. T.)	Sewage sludge rate(%)	Root length (cm)	Plant height (cm)	Dry weight (g/plant) Root	Dry weight (g/plant) Shoot	Dry weight (g/plant) Whole	Leaf area (cm^2/plant)	RGR	NAR	LAI
Normal water		10.750	33.667	0.094	1.617	1.711	642.332	0.404	0.151	9.092
Magnetic water		10.667	35.083	0.131	2.451	2.582	954.848	0.686	0.227	13.515
LSD 5%		0.074	0.830	0.030	0.453	0.460	104.570	0.160	0.070	2.440
	00	11.333	32.667	0.084	1.461	1.545	553.058	0.312	0.098	7.828
	5	10.167	34.000	0.109	1.905	2.013	704.586	0.513	0.204	9.973
	10	10.167	37.833	0.137	2.692	2.829	1084.271	0.766	0.248	15.348
	20	11.167	33.000	0.121	2.080	2.201	852.448	0.589	0.206	12.066
LSD 5%		0.470	1.010	0.040	0.640	0.660	226.700	0.210	0.150	3.460
Normal water	00	12.333	32.667	0.077	1.270	1.347	538.777	0.280	0.141	7.626
	5	10.667	32.667	0.069	1.308	1.377	491.503	0.217	0.057	6.957
	10	10.000	37.333	0.124	2.270	2.395	834.914	0.697	0.263	11.818
	20	10.000	32.000	0.104	1.621	1.725	704.135	0.420	0.144	9.967
Magnetic water	00	10.333	32.667	0.090	1.652	1.742	567.338	0.343	0.055	8.030
	5	9.667	35.333	0.148	2.501	2.648	917.668	0.809	0.351	12.989
	10	10.333	38.333	0.149	3.113	3.262	1333.627	0.835	0.233	18.877
	20	12.333	34.000	0.137	2.539	2.677	1000.760	0.757	0.268	14.165
LSD 5%		2.143	1.794	0.090	1.470	1.532	344.357	1.260	1.310	4.241

(b): 2nd season

Treatments: Mag. T.	Sewage sludge rate(%)	Root length (cm)	Plant height (cm)	Dry weight (g/plant): Root	Shoot	Whole	Leaf area (cm^2/plant)	RGR	NAR	LAI
Normal water		13.708	33.042	0.289	2.633	2.922	803.985	0.896	0.469	5.690
Magnetic water		16.375	39.084	0.391	3.587	3.977	1231.949	1.063	0.448	8.719
LSD 5%		1.960	3.490	0.120	1.660	0.338	156.150	0.276	0.190	1.942
	00	15.584	32.500	0.378	3.285	3.663	1042.605	0.902	0.342	7.379
	5	18.833	34.250	0.514	3.439	3.952	1066.674	1.023	0.456	7.549
	10	13.500	36.667	0.232	2.905	3.136	972.849	1.007	0.531	6.885
	20	12.250	40.834	0.236	2.811	3.046	989.739	0.987	0.505	7.005
LSD 5%		2.78	6.35	0.18	2.35	4.78	193.620	0.391	0.270	1.014
Normal water	00	15.000	28.000	0.406	1.936	2.342	569.829	0.541	0.131	4.033
	5	16.833	30.833	0.279	2.661	2.940	819.547	0.915	0.499	5.800
	10	12.667	36.333	0.262	3.234	3.495	984.596	1.151	0.684	6.968
	20	10.333	37.000	0.209	2.702	2.910	841.966	0.977	0.560	5.959
Magnetic water	00	16.167	37.000	0.350	4.634	4.984	1515.381	1.263	0.552	10.725
	5	20.833	37.667	0.749	4.216	4.964	1313.800	1.130	0.412	9.298
	10	14.333	37.000	0.201	2.576	2.777	961.102	0.863	0.378	6.802
	20	14.167	44.667	0.262	2.920	3.182	1137.512	0.996	0.450	8.050
LSD 5%		2.780	2.996	0.43	4.083	5.245	295.069	0.958	0.670	3.030

As for the effect of the interaction between of magnetic water and sewage sludge on growth rocket plants presented in the same Table, it is clearly that the irrigation with magnetic water caused a significant increase in the above mentioned growth parameters of rocket plants compared with the SS controls. At the SS level of 20%, the increments were about 23% in root length, 6% in plant height, 32% in root dry weight, 57% in shoot dry weight, 55% in whole plant dry weight, 42% in leaf area, 80% in RGR and 86% in NAR, comparing with owing SS controls in the 2nd season. Similar trend was obtained in the 1st one. In this concern, these results go hand in hand with the results of Selim and El-Nady (2011), who found that magnetic treatments enhanced growth (Dry weight, leaf area, relative growth rate, net assimilation rate) of tomato plants grown under stress conditions, Mohamed and Ebead (2013) found that plant length, shoot and root fresh and dry weights of faba bean were significantly increased using magnetized irrigation water and the different soil organic and inorganic treatments, and Hafshajani *et al.* (2022) found that the interaction effects of Cd levels and irrigation with magnetized water treatment on shoot, and root was significant,

The positive effect of magnetic treatment on growth parameters under these conditions may be due to magnetic field reduced accumulation of heavy metals (Pb and Cd) in plants irrigated with magnetically treated water and amended with sewage sludge (Hafshajani *et al.*, 2022) and in the current study (Table, 8) may have helped the plants to continue their growth with less detrimental effects on plant yield.

2. Water Relations and Membrane Integrity (Membrane Permeability) (MI)

Data presented in Table 4 showed that, there was a decrease in the total water content (TWC, %), relative water content (RWC, %), succulence degree (DSc), membrane stability (MI) in leaves of rocket plants, whereas leaf water deficit

Table 4 : Effect of magnetic water, sewage sludge levels and their interactions on water relations in leaves of rocket plants at age 60 days after sowing during the 1st and 2nd growing seasons.

Treatments / Characters		1st season							2nd season						
Mag. T.	*Sewage sludge rate (%)*	Total Water content (%)	Rel. water content (%)	Leaf water def. (%)	Osmotic Pressure C.S. (bar)	Succulence mg H_2O. cm^{-2}	Transpiration rate mg H_2O. $cm^{-2}h^{-1}$	MI %	Total Water content (%)	Rel. water content (%)	Leaf Water def. (%)	Osmotic Pressure C.S. (bar)	Succulence mg H_2O. cm^{-2}	Transpiration rate mg H_2O. $cm^{-2}h^{-1}$	MI %
Normal water		89.283	75.957	24.293	3.281	22.475	1.437	22.743	85.631	63.61	36.39	3.012	10.168	1.923	27.013
Mag. water		89.343	81.213	20.537	3.556	20.811	3.804	25.698	89.428	84.167	15.834	2.864	10.228	4.23	34.021
LSD5%		0.121	3.166	2.166	0.10	1.033	1.190	2.557	2.971	3.759	3.753	0.120	0.651	1.708	4.108
	00	89.572	83.034	16.966	3.171	22.371	2.228	26.728	87.069	65.294	34.706	2.865	10.331	2.995	25.608
	5	89.368	78.864	23.137	3.417	22.618	2.041	26.393	87.097	83.437	16.563	2.904	10.503	2.694	34.999
	10	89.445	77.745	23.255	3.485	21.743	2.819	23.12	87.022	69.214	30.787	2.797	8.725	1.901	27.516
	20	88.866	74.698	26.303	3.602	19.84	3.393	20.643	88.932	77.609	22.392	3.186	11.234	4.716	33.944
LSD5%		0.668	4.728	4.728	0.23	2.294	0.270	3.688	0.770	5.206	5.207	0.170	0.921	2.417	4.568
Normal water	00	89.085	78.846	21.154	2.99	23.493	1.032	25.925	88.598	71.261	28.739	3.078	11.107	1.699	24.036
	5	88.828	78.667	22.333	3.218	21.654	1.008	23.954	85.338	76.197	23.803	2.677	9.719	2.167	27.395
	10	90.22	75.587	24.413	3.333	25.159	1.804	22.243	82.358	44.131	55.869	2.89	8.521	1.946	25.406
	20	88.997	70.728	29.272	3.583	19.592	1.902	18.851	86.231	62.851	37.149	3.402	11.324	1.881	31.213
Mag. water	00	90.058	87.222	12.778	3.351	21.248	3.424	27.531	85.539	89.327	10.673	2.651	9.554	4.291	27.179
	5	89.908	79.06	21.94	3.615	23.581	3.074	28.831	88.855	90.677	9.323	3.131	11.286	3.221	42.602
	10	88.669	79.903	22.097	3.637	18.327	3.833	23.997	91.685	94.296	5.704	2.704	8.929	1.856	29.626
	20	88.735	78.667	23.333	3.621	20.088	4.883	22.434	91.633	92.366	7.634	2.97	11.144	7.551	36.675
LSD5%		1.692	7.900	5.181	0.27	3.135	1.675	5.116	3.373	25.75	26.33	0.217	2.903	3.999	5.612

(LWD, %), osmotic pressure (OP) and transpiration rate were increased, compared with the untreated plants. These results were true in the 1st season but inconsistent in the 2nd one. These results are in agreement with those obtained by Singh and Agrawal (2009) who found that, the transpiration rate in lady's finger plants decreased at increasing sewage sludge when compared with those grown in un-amended soil, Eid (2012) who found that, the total water content and the transpirational water lose in wheat and faba bean plants were decreased with increasing sewage sludge rates, whereas the relative water content and leaf water deficit were increased, when compared with those grown in un-amended soil. Vijendra *et al.*, (2016) indicated that significant alternations in relative water content was observed in stressed seedlings of Moth bean (*Vigna aconitifolia* L.), Rajan *et al.* (2023) reported that the osmotic ratio was found to be higher when compared with the non-treated water, Abou Seeda *et al.* (2023) who pointed out that toxic symptoms of Cd appeared in plants such as, alterations in water relations.

This decrease might be explained due to accumulation the heavy metals especially Pb and Cd decreased the water uptake by root in different plant species (Haroun *et al.*, 2003). The decrease in the transpiration rate in rocket plants may be due to the harmful effect of the applied of sewage water on decreasing the stomatal conductance. Additionally, this effect may also be attributed to the increased accumulation the heavy metals in rocket plants grown ins amended soil as shown in Table 8.

It was apparent from the obtained results in the same Table (4) that LWD, DSc significantly decreased while TWC, RWC, OP, TR and MI recorded a marked increment as a result of treating rocket plants by irrigation with magnetic water comparing with the untreated plants. The improvement in the water relations of rocket plants as the result of the application of magnetic technique i.e. magnetized water, may be due to the magnetization of solutions through dipole or one pole magnetic systems has been reported to lower surface tension, to lower viscosity to lower osmotic pressure, increases permeability through the soil and creates greater water solubility (Takashinko, 1997 and Zhu *et al*., 1986).

Under all sewage sludge rates, application of magnetic irrigation had different effects on rocket plant water relations: RWC, OP, DSc, TR and MI increased, TWC not affected and LWD decreased. At the high SS level (20%), irrigation with magnetized water led to increase in RWC, DSc, OP and TR by about 13.7, 18.4, 1.1, 301.4 and 17.5% respectively, whereas LWD was decreased by about -35.6%, if compared with owing SS controls. These results go along with the results of Selim and El-Nady (2011), who found that magnetic treatments increased the relative water content (%) and osmotic pressure while leaf water deficit (%) of tomato plants was decreased under stress conditions.

The improvement in water relation and water uptake in rocket plants by magnetic treatment interacted with sewage sludge may be due to the reduction in the concentration and uptake of Pb and Cd (Table 8) which led to decreased the toxic reaction, may be due to the increasing in membranes permeability of cells [Table 4, Selim, 2008, Selim *et al.*, 2009 and Zlotopolski , 2017], may be the action of increasing the IAA, zeatin and GA syntheses and decreases the synthesis of ABA by magnetic treatments (Selim, 2008 and Zayed, 2010) bringing about promoting cell division and enlargement, may be increasing the concentration of proline and soluble sugar contents and the concentration and uptake of N, P and K which led to increase osmotic pressure in cells and thus increases water uptake, increasing the vessels number, reducing the vessels size in stems or increasing investment in the roots (Jackson *et al.*, 2000; Sobrado, 2007; Selim and El-Nady, 2011 and Selim, 2013). Magnetic field increased the phospholipids/sterol ratio in onion leaves, causing an increase in the fluidity of the membrane lipid bilayer (Novitskaya *et al*., 2006). Radhakrishnan (2019) indicated that during adverse conditions of abiotic stress such as heavy metal contamination in soil, MF mitigates the stress effects by increasing antioxidants and reducing oxidative stress in plants.

3. Photosynthetic pigments:

Concerning the effect of sewage sludge on the photosynthetic pigments i.e., chlorophyll a, chlorophyll b, total chlorophyll (a + b), carotenoids and total photosynthetic pigments in rocket leaves are illustrated in Table 5. The obtained results showed that chlorophyll a, chlorophyll b, total chlorophyll, carotenoids and total photosynthetic pigments of rocket leaves were affected by sewage sludge. Application sewage sludge led to markedly increases (1st season) or decreases (2nd season) in the above mentioned photosynthetic characteristics. At the high SS level (20%) caused increases in the chlorophyll a, b, carotenoids, chl. a+b and total photosynthetic pigments concentrations in leaves by about 74.2, 41.3, 29.8, 62.3 and 54.9% (1st season), whereas they decreased by -17.0, -16.5, -21.2, -16.6 and -17.4 % (2nd season), respectively if compared with the control plants. Similar results are in accordance with the obtained results of rocket plants by Singh and Agrawal (2007) on palak. Mazen *et al.* (2010) on soybean and Elloumi *et al.* (2016) on tomato plants. The decrease of photosynthetic pigments especially chlorophyll a at the high level of sewage sludge may be attributed to the high uptake and accumulation of heavy metals consequently their harmful effects on the photosynthesis (Krupa and Baszynski, 1995).

The concentrations of chlorophyll a, b, carotenoids, chl. a+b and total photosynthetic pigments in leaves of rocket plants irrigated with magnetized water showed a significant increases if compared with the untreated plants in the two seasons. The increases in the above mentioned traits were about 115.5, 92.8, 65.9, 107.4 and 97.9% (1st season), 47.7, 52.8, 41.7, 49.4 and 48.2% (2nd season),, respectively, id compared with the untreated plants. The obtained results are in harmony with those obtained by Abd Ellateef and Mutwali (2022) on broad bean and Alattar *et al.*, (2022) found that irrigating plants with magnetized water increase in chloroplast pigments (carotenoids, chlorophyll a, and b) and photosynthetic activity of crop yield, as well as Yi *et al.*, (2023) stated that irrigation with magnetized water can increase the chlorophyll content and net photosynthetic rate of cotton seedlings.

Application of magnetic treatment caused a remarkable increment in the concentration of chlorophyll a, b, carotenoids, chl. a+b and total photosynthetic pigments in leaves of rocket plants supplied by different sewage sludge (SS) rates. Application of magnetized water caused the highest increase in the concentrations of chlorophyll a, b, carotenoids, chl. a+b and total photosynthetic pigments in leaves at the high SS level (20%) by about 149.4, 176.7, 135.2, 157.6 and 153.1%, respectively if compared with their owing SS controls. Similar trend was observed in the 2nd one. These results are closed to the results of Selim and El-Nady (2011) who found that magnetic treatments enhanced photosynthetic pigments of tomato plants grown under stress.

The increasing in photosynthetic pigments due to the magnetic treatment under normal or SS supplying may be attributed to the enhancing effect of magnetic system on the absorption of the essential elements specially the iron (Fe^{++}), magnesium (Mg^{++}), potassium (K^{+}) and nitrogen (NH_4^{+}) cations, that necessary for enzymes activation and formation of chloroplasts and chlorophyll (Selim, 2008) or by alter the biological material so-called "ponderomotive effects" which may lead to change one or more biological parameters that affect on enzymatic activity, transport of assimilates, plant metabolism such as photosynthesis and growth regulators (De Souza *et al.,* 2006, Selim, 2008), may be attributed to the increase in GA_3 content in plants (Selim, 2008 and Selim *et al.,* 2009), which led to increase in the green pigments in the treated plats by stimulating the production of chlorophyll in leaves (Bethke and Drew, 1992 and Wasfy, 1995) or the increase in mesophyll tissue thickness (Selim, 2008).

4. Biochemical constituents:

The total soluble sugars (TSS) and total protein (TP), total free amino acids (TFAA) and proline (Pro) contents as well phenol-oxidase activity (PPO) in leaves of rocket plants were increased, meanwhile peroxidase activity (POX)

Table 5: Effect of Magnetic water, Sewage sludge levels and their interactions on the concentrations and the ratios of the photosynthetic pigments in leaves of rocket plants at 60 DAS during the 1st and 2nd growing seasons.

Season		1st season					2nd season				
Treatments / Characters		Chl.a	Chl.b	Caroten.	Total Chl.a+b	Total Photosynthetic pigments	Chl.a	Chl.b	Caroten.	Total Chl.a+b	Total Photosynthetic pigments
Mag. T.	*Sewage Sludge rates (%)*	mg/g DW.					mg/g DW.				
Tap water		3.094	1.732	1.436	4.826	6.261	6.261	3.199	1.797	9.460	11.257
Mag. water		6.668	3.339	2.382	10.01	12.389	9.247	4.884	2.546	14.131	16.678
LSD 5%		0.520	0.580	0.480	0.910	1.240	0.88	0.57	0.29	1.43	1.68
	00	3.358	1.893	1.536	5.251	6.787	8.412	4.373	2.464	12.785	15.249
	5	4.668	2.618	1.778	7.287	9.065	7.800	3.985	2.119	11.784	13.903
	10	5.650	2.957	2.327	8.607	10.934	7.797	4.158	2.162	11.955	14.116
	20	5.849	2.675	1.993	8.523	10.516	7.008	3.652	1.943	10.659	12.602
LSD 5%		0.740	0.820	0.680	1.290	1.750	1.24	0.80	0.41	2.020	2.380
Tap water	00	2.614	1.418	1.713	4.032	5.745	6.376	3.263	1.946	9.640	11.586
	5	2.969	2.018	1.365	4.987	6.352	6.243	3.174	1.632	9.416	11.049
	10	3.445	2.072	1.475	5.517	6.992	6.726	3.548	2.064	10.274	12.338
	20	3.348	1.420	1.189	4.767	5.956	5.699	2.810	1.546	8.509	10.055
Mag. water	00	4.101	2.368	1.359	6.469	7.828	10.447	5.482	2.982	15.929	18.911
	5	6.367	3.218	2.191	9.586	11.777	9.357	4.795	2.605	14.152	16.757
	10	7.855	3.841	3.179	11.696	14.875	8.868	4.767	2.259	13.635	15.894
	20	8.349	3.929	2.797	12.278	15.076	8.316	4.493	2.339	12.809	15.148
LSD 5%		1.284	2.027	1.666	1.585	3.570	1.366	1.399	1.02	1.875	2.060

was inhibited at all sewage sludge rates (Table, 6). At the high rate of SS (20%), the increase in TSS, TP, TFAA, Pro and PPO reached about 23.8, 24.4, 61.4, 88.8 and 29.9% (1st season), 16.5, 47.9, 87.6, 122.8 and 14.1% (2nd season), respectively, comparing with the plants un-amended SS. The decrease in POX activity reached about -26.3 and -20.4% in the 1st and 2nd seasons, respectively.

The obtained results are in harmony with those obtained by Mazen *et al.* (2010), Abd El-Samad *et al.* (2020), Zafar *et al.* (2021) and Ahmed *et al.* (2023) for TSS, Wyrwicka *et al.* (2019) for TP, Boudjabi *et al.* (2015) and Eid *et al.* (2020) for TFAA and Pro, Abdel Latef and Sallam (2015), Sasi *et al.* (2019) and Mansoora *et al.* (2021) for enzymes activity.

The increased of carbohydrates in sewage sludge treated plants may be due to the presence of photosynthetic pigments, i.e., chl. a, b, some essential mineral ions in SS (Table, 2) e.g. N, Fe, Cu, Mn that stimulate the two photosystems, Mn^{+2} is required for PSII (O_2 evolving system) and there is also a direct interaction between copper and ferredoxin on the reducing site of PSI. Cu^{++} stimulate the rate of overall electron transfer from water to NADP (Marschner, 2003).

The Increase in protein content of rocket leaves may be due to higher organic matter and N content of sewage sludge amended soil (Table 2), which led to slow release of N in the soil. In this connection, Wyrwicka *et al.* (2019) found that total soluble protein content tissues increased with greater SS doses in the soil.

The increase in proline content observed in leaves of the treated SS rocket plants in this study suggests that elevated levels of heavy metals in rocket plants supplemented with sewage sludge have affected the permeability of membranes (our results in Table, 4), causing water stress like condition leading to proline accumulation (Selim and El-Nady, 2011). The increase in proline may be due to detoxify the toxic heavy metals in the production of proline (Verma, 1999). The accumulation of proline in stressed plants is associated with the reduced damage to the membranes and proteins. Proline synthesis has been implicated in the alleviation of cytoplasmic acidosis and may maintain NADP / NADPH ratios at values compatible with metabolism (Hare and Cress, 1997).

The inhibition of peroxidase activity in leaves of rocket plants treated by sewage sludge may be ascribed to heavy metal polluted soil alter the metabolic processes inside cells through their effect on the enzymatic system (Mengel and Kirkby, 2001).

Irrigation with magnetic water led to a marked increase in TSS, TP, TFAA and Pro contents as well PPO and POX in leaves of rocket plants were increased. The %increase were about 4.6, 27.8, 8.1, 102.6, 6.0 and 5.5% (1st season) and 10.6, 13.1, 16.1, 34.4, 10.1 and 9.0% (2nd season), respectively, if compared with the plants irrigated with normal water. These results go along with the results of Selim *et al*., (2009), Zayed (2010) and Yusuf *et al*., (2020) for cabohydrates, Alzubaidy (2014) and Alkhatib *et al*., (2020) for total protein, Maria *et al*., (2008) and Selim *et al*., (2009) for amino acids and, Selim (2008), Radhakrishnan and Kumari (2012), Jasim *et al*., (2017), and Hafshajani *et al*., (2022) for the activity of enzymes.

Regarding the effect of combination of sewage sludge at different levels and magnetic treatment, it is clearly that irrigation the rocket plants grown in SS-amended soil by magnetic water led to a marked increase in TSS, TP, TFAA and Pro contents by about 2.6, 32.2, 7.0 and 104.9% (1st season), 8.4, 9.5, 7.4, and 43.7%, respectively, over their owing SS controls. These results are in conformity with the results acquired from Khattab *et al.,* (2000b) found that the interaction between GA and magnetized or non-magnetized diluted sea water influenced carbohydrate content and sugars in corms of gladiolus. Similar results were found by Hafshajania *et al.*, (2023) for total protein, Selim and El-Nady (2011) on tomato plants and Also, Xia and Guo (2001) on *Leymus chinensis* and Sutiyanti and Rachmawati (2021) for amino acids and proline, Chen *et al.*, (2009), Hafshajani *et al.*, (2022) on *Lantana* and Hafshajania *et al.*, (2023) on vitver plants for activity of antioxidant enzymes.

Table 6 : Effect of Magnetic water, Sewage sludge levels and their interactions on the some Biochemical constituents and enzymes activity in leaves of rocket plants at age of 60 days during the 1st and 2nd seasons.

Treatments: Mag Treatment	Sewage Sludge rates (%)	Total soluble sugars (mg/g DW.)	Total protein (%)	Total free Amino acids (mg/g DW.)	Proline µmole/g FW.	Enzymes activity: Phenol-oxidase (O.D./g FW.)	Enzymes activity: Peroxidase (O.D./g FW.)	Total soluble sugars (mg/g DW.)	Total protein (%)	Total free Amino acids (mg/g DW.)	Proline µmole/g FW.	Enzymes activity: Phenol-oxidase (O.D./g FW.)	Enzymes activity: Peroxidase (O.D./g FW.)
season		1st season						2nd season					
Normal water		43.485	13.283	26.901	3.298	0.369	0.362	40.547	14.925	21.587	6.735	0.379	0.401
Mag. water		45.500	16.970	29.066	6.682	0.391	0.382	44.829	16.880	25.068	9.051	0.417	0.437
	00	39.376	13.065	21.821	3.009	0.318	0.426	39.969	12.130	16.956	5.241	0.369	0.456
	5	42.657	16.250	25.704	3.803	0.391	0.396	40.157	17.190	19.796	6.971	0.396	0.452
	10	47.188	14.940	29.190	7.469	0.397	0.353	44.063	16.345	24.746	7.680	0.406	0.406
	20	48.750	16.250	35.220	5.680	0.413	0.314	46.563	17.945	31.811	11.679	0.421	0.363
Normal water	00	38.938	10.25	18.387	2.127	0.284	0.422	39.375	12.13	14.364	4.598	0.328	0.436
	5	41.250	15.75	26.099	3.257	0.387	0.346	37.188	16.38	16.983	6.764	0.363	0.436
	10	45.625	13.13	29.089	4.083	0.394	0.349	40.938	14.06	24.327	5.982	0.397	0.400
	20	48.125	14.00	34.030	3.725	0.411	0.332	44.688	17.13	30.672	9.594	0.427	0.333
Mag. water	00	39.813	15.88	25.255	3.891	0.352	0.429	40.563	12.13	19.548	5.884	0.409	0.476
	5	44.063	16.75	25.309	4.348	0.395	0.445	43.125	18.00	22.609	7.177	0.429	0.468
	10	48.750	16.75	29.290	10.855	0.400	0.356	47.188	18.63	25.164	9.377	0.415	0.411
	20	49.375	18.50	36.410	7.634	0.415	0.296	48.438	18.76	32.950	13.764	0.415	0.393

5. N, P and K concentrations and uptake

The results recorded in Table 7 pointed out that, the concentrations and uptake of N, P and K in rocket leaves increased under all SS-amended soil rates. At the high SS rate (20%), the %increases in the concentration of N, P and K in rocket leaves were about 39.7, 63.6 and 33.1%, for the uptake were about 47.8, 74.9 and 41.1, respectively over the untreated plants. Similar trend was found in the 2nd one. These results go hand in hand with the results of AbdEl-Kader (2011) found that seedlings planted in sewage sludge generally, had the highest uptake and total uptake of N, P and K in plant organs. Also, Sasi *et al.,* (2019) found that used of CWWS, especially at 1%, increase higher uptake of P, N and K. Bai *et al.,* (2022) found that SS addition significantly increased soil nutrient contents, and increased concentrations of total N, total P and mineral nitrogen.

Data listed in the same Table indicated that, using magnetic water resulted in a marked increment in the concentration and uptake of N, P and K in leaves of rocket plants in both two growing seasons. Generally, the highest increases in concentration and uptake were about were about 29.3 and 94.2% for N, 43.8 and 35.2% for P and 17.3 and 66.6%, respectively compared with control plants irrigated with non-magnetized water. These results are in line with the results obtained by Mohamed and Ebead (2013) found that shoot N, P and K contents and uptake of faba bean was significantly increased by using magnetized irrigation water compared with the non-magnetized water. The same results were observed by Rawabdeh *et al.* (2014), Selim and Selim (2019) and Putti *et al.* (2023).

Concerning the interaction between SS rates and magnetic treatment on the concentration and uptake of N of rocket plants, It was clear from the results that, the application of magnetized water caused the highest increment in the concentration of N in leaves of rocket plants by interaction of magnetized water with the level of 20%SS by about 33.4 and 107.0, respectively compared with owing controls plants. The P conc. seemed to be unaffected by the interaction between magnetized water and SS levels, but the P uptake was positively affected by the interactions, the best increase in it by about 85%, at the low SS level (5%) if compared with its owing control and other interactions. As for K, application of magnetized water caused generally increments in the concentration and uptake of K in rocket plants, they were recorded at the low level (5%) by about 18.7 and 127.0% respectively, when compared with their owing SS control. These results go along with the results of Khattab *et al.,* (2000a), who found that presoaking corms of young gladiolus in gibberellic acid and irrigated with different concentrations of magnetized seawater (0, 5, 10, 15 or 20%) after month of planting increased K contents in leaves compared with the control.

The high increase in N, P and K content and accumulation in different rocket plants supplemented with sewage sludge may be attributed to increase of N, P and K levels in the soil amended with sewage sludge as shown in Table (2) and as reported byEl-Kiey, (1983), Abd El-Hady, (1996) and Shalaby *et al.,* (1996). Moreover, Moreno *et al.* (1997) found that, the sewage sludge had higher organic carbon and nutrient contents, their amendment led to higher concentration of organic carbon total N, available K and exchangeable K.

6. Heavy metals behavior in plant and its effect on human health:

6.1. Pb and Cd conc. and uptake

Heavy metals such as Pb and Cd by sewage sludge application, considers one of the limited factors affecting the using of sewage sludge. So, the harmful effect of these heavy metals on plant growth, photosynthesis, enzyme activity and other physiological processes, which reflected on the final yield, is in compact with their concentration in the used rates. Therefore, Pb and Cd were determined in root and shoot of rocket plants supplemented with the sewage sludge (Table 8). The application of sewage sludge at rate 20% markedly increased the Pb and Cd concentration and uptake in roots and shoot of rocket plants. The %increase in Pb

Table 7 : Effect of magnetic water, Sewage sludge levels and their interactions on the concentration and uptake of some macro-elements in leaves of rocket plants at age of 60 days during the 1st and 2nd seasons.

Treatments / Characters		N		P		K		N		P		K	
Mag. Treatment	*Sewage Sludge rates (%)*	conc. %	Uptake mg/ plant	conc. %	Uptake mg/ plant	conc. %	Uptake mg/ plant	conc. %	Uptake mg/ plant	conc. %	Uptake mg/ plant	conc. %	Uptake mg/ plant
		1st season						2nd season					
Normal water		2.100	34.443	0.653	10.645	2.550	41.548	2.288	63.520	0.678	17.860	1.962	53.335
Mag. water		2.715	66.893	0.617	15.303	2.777	69.230	2.700	93.928	0.682	24.145	2.302	81.522
	00	2.720	34.115	0.439	5.435	2.840	35.660	1.740	63.730	0.652	21.455	1.761	64.166
	5	2.850	26.620	0.628	5.835	3.298	30.825	2.750	95.570	0.633	21.695	2.080	71.754
	10	3.330	42.675	0.661	8.450	3.237	41.400	2.615	74.765	0.662	19.180	2.333	67.501
	20	3.800	50.425	0.718	9.505	3.780	50.295	2.871	80.830	0.772	21.680	2.355	66.295
Normal water	00	1.540	20.828	0.549	6.972	2.291	29.096	1.540	37.558	0.649	12.565	1.291	24.994
	5	2.520	32.962	0.642	8.397	2.451	32.059	2.620	69.718	0.642	17.084	2.050	54.551
	10	2.100	47.670	0.646	14.664	2.556	58.021	2.250	72.765	0.646	20.892	2.254	72.894
	20	2.240	36.310	0.774	12.547	2.900	47.009	2.740	74.035	0.774	20.913	2.254	60.903
Mag. water	00	2.540	41.961	0.550	9.086	2.330	38.492	1.940	89.900	0.655	30.353	2.230	103.338
	5	2.680	67.027	0.621	15.531	2.910	72.779	2.880	121.42	0.624	26.308	2.110	88.958
	10	2.680	83.428	0.646	20.110	2.911	90.619	2.980	76.765	0.678	17.465	2.411	62.107
	20	2.960	75.154	0.649	16.478	2.955	75.027	3.001	87.629	0.769	22.455	2.455	71.686

concentration reached to 983% in root, 1020% in shoot and 994% in whole by application the sewage sludge at 20% compared to control. The Pb uptake in rocket plants seems to be the same manner of the Pb concentration. The % enhancement in the same rocket organs reached 467% in root, 1475% in shoot and 1260 in whole rocket plant when compared with the control plants. It is noteworthy that the shoot-Pb content was more affected by this treatment than that Pb-root. Regarding Cd concentration and uptake in roots, shoot and whole rocket plants, data in Table (8) showed that the treatment of sewage sludge caused a higher increase in Cd concentration and uptake in the above mentioned organs. They were 957 and 450% in root, 850 and 1215% in shoot and 918 and1164% in whole plant, respectively, compared to control.

The increasing in Pb and Cd heavy metals content may be attributed to increasing of these heavy metals content in sewage sludge. Also, it may attributed to the high uptake of heavy metals by plants and then accumulated in root and shoots then translocated to fruits and seeds (as shown in Table, 8 and Abd El-Hady, 1996). These results are in accordance with the results recorded by Keskin *et al.*, (2012) who found that sewage sludge increased Pb, Cd contents in Grass-legume mixtures.

Irrigation rocket plants grown in 20% SS-amended soil by magnetized water led to a great reduction in Pb concentration and uptake in all plant organs. The %reduction in Pb concentration and uptake reached about -55 and -44% in root, -68 and -65% in shoot and -58 and -55 in whole rocket plants, respectively. Also, it can be said that the magnetic treatment had a crucial effect on minimizing the concentration and uptake Pb in all plant organs to the safe limits for plant and human. Concerning the Cd content und uptake of rocket, irrigation rocket plants grown in sewage sludge amended soil led to a marked decrease in the concentration and uptake of Pb and Cd in all organs of plants (Table 8). The %reductions were -59 and -49% in root, -63 and -60% in shoot and -61 and -57% in rocket whole plant. Also, it can be stated that the magnetic treatment had a crucial effect on minimizing the concentration and uptake Cd in all plant organs to the safe limits for plant and human. The obtained results are in agreement with those obtained by Khoshravesh *et al.* (2021) found that the irrigation with magnetic water reduced the solutes and heavy metals Pb by 35.25%, and Cd by 56.11% in the soil. Hafshajani *et al.* (2022) indicated that the amount of soil Cd decreased by 39.49 % under the influence of magnetized water treatment. The reduction in Pb and Cd accumulation as a result of applying magnetic technique may be attributed to precipitation of metal ions, adsorption at bacterial sites and reduction by change of oxidation states (Hafshajania *et al.*, 2023).

Generally, Pb and Cd concentrations tended to increase in the sewage sludge treatment soils as shown in Table (2). It might be related to the higher levels of Pb and Cd in SS treated amended soils. The Pb concentrations in different organs of rocket plants ranged 2.8 - 6.5 mg kg^{-1} in the plants grown in SS-amended soil with 20%, 0.9 - 2.2 mg kg^{-1} in the same plant irrigated with magnetic water. These Pb concentrations in both plants were found so far below the critical level of phytotoxicity ranged from 30 – 300 mg kg^{-1} (Kabata-Pendias and Pendias, 1992) as well as the safe limit of heavy metal concentration in vegetable for human ranged from 0.3-9 mg/kg (FAO/WHO standard 1985, 2001 and SEPA, 2005).The Cd concentrations in rocket organs were found in the range of 1.9 – 3.7 mg kg^{-1} for rocket plants supplemented with 20% SS, 0.7 – 1.5 mg kg^{-1} for rocket plants under magnetic treatment. These concentrations of Cd were quite below the phytotoxicity levels 5 - 30 mg kg^{-1} according to Kabata-Pendias and Pendias (1992) and Alloway and Ayers (1997) as well as the safe limit of heavy metal concentration in vegetable for human levels 0.2-0.3 mg/kg (FAO/WHO standard 1985, 2001 and SEPA, 2005). Binder *et al.* (2002) and Hogan *et al.* (2001) reported that, higher concentration of Cd and Zn in rice plant by applied SS. The recommended levels are for Cd (0.05 - 0.20 ppm) and Pb (0.5 - 1.0 ppm), while the toxic levels of these elements are 5 - 30 ppm and 10 and 100 ppm, respectively (Davis *et al.*, 1978). Ahmed *et al* (2021) on Chilli plants found that fruits grown on high Pb contaminated soil exceeded the safe limit of 0.3 mg/kg. The concentrations of Pb and Cd in the edible parts of the test plants treated by sewage sludge (Table 8) were generally greater than the normal range but less than the phytotoxic levels as mentioned before.

6.2. Pb and Cd Bioaccumulation or Bio-concentration Factors (BAF or BCF), and Translocation Factors (TF):

The capability of plant to extract heavy metals from soils and accumulated in plant can be estimated using the BCF, which is defined as the ratio of metal concentration in whole plant to that in soil. According to Ghosh and Singh (2005), BCF values of 1 to 10 indicates hyper-accumulator plant, BCF values of 0.1 to 1 indicates moderate accumulator plant, BCF values of 0.01 to 0.1 indicates low accumulator plant, and BCF value of <0.01 indicates non-accumulator plant. The obtained results in Table (8) showed that BCF values of Pb was 2.75 in rocket plants treated with 20% SS, indicating that this plant is hyper-accumulator plant. Irrigation these plants with magnetized water caused a great reduction in BCF values and become 1.12. Also, the bioaccumulation factor (BCF) of Cd was 1.65 in rocket plants treated with 20% SS. When these plants were irrigated with magnetized water, the BCF value was decreased and become 0.65. Chang *et al.* (2014) found that the BCF values of Pb in a variety of vegetables were found within the range of 0.0001- 0.0648. These results are agreement with those obtained by Ghosh and Singh (2005), Wei *et al.* (2008), and Ahmed *et al.* (2021). AL-Huqail *et al.* (2023) showed that the bioaccumulation factor (BAF) values (>1) showed that the marigold plant was capable of uptake significant contents of six heavy metals in the order of Cd < Cr < Cu < Zn< Mn < Fe. Overall, this study presented a novel approach to floriculture by sustainable management of SS while reducing public health and environmental impacts.

Table 8: Effect of magnetic water, Sewage sludge levels and their interactions on (a): Pb and (b): Cd conc. and uptake as well as health effects of rocket plants.

(a) Pb

Characters / Treatments	Pb conc.			Pb uptake			*Transfer Factor (TF)*	*Bioconcen. Factor (BCF)*	*Carcinogenic Risk (CR)*
	root	shoot	whole	root	shoot	whole			
	µg/g dwt			µg/plant					
Control	0.60	0.25	0.43	0.24	0.48	1.00	0.42	0.251	0.00063
Sewage 20%	6.50	2.80	4.65	1.36	7.56	13.53	0.43	2.743	0.00700
Sewage 20% +magnetic w.	2.90	0.90	1.90	0.76	2.63	6.05	0.31	1.121	0.00225
%reduction due to Mag.	-55	-68	-59	-44	-65	-55	-	-	-

(b) Cd

Characters / Treatments	Cd conc. root	Cd conc. shoot	Cd conc. whole	Cd uptake root	Cd uptake shoot	Cd uptake whole	*Transfer Factor (TF)*	*Bioconcen. Factor (BCF)*	*Carcinogenic Risk (CR)*
	µg/g dwt			µg/plant					
Control	0.35	0.20	0.28	0.14	0.39	0.64	0.57	0.162	0.00070
Sewage 20%	3.70	1.90	2.80	0.77	5.13	8.15	0.51	1.652	0.00662
Sewage 20% +magnetic w.	1.50	0.70	1.10	0.39	2.04	3.50	0.47	0.649	0.00244
%reduction due to Mag.	-59	-63	-61	-49	-60	-57	-	-	-

The TF value of Pb metal from root to shoot was 0.43 in rocket plants treated with 20% SS. Treating these plants with magnetized water led to a sharp decrease in TF and become 0.31. Regarding TF of Cd, the results indicated that the TF value achieved 0.51 in rocket plants supplemented by 20% SS dose. This TF value was decreased by irrigation with magnetized water and reached 0.44. According to Napoli *et al.* (2020), a high value of TF (TF>1) signifies promising ability of a plant to translocate heavy metals from roots to aerial tissues. On the other hand, a low value (TF<1) indicates a limited capacity of a plant to translocate the metal to aerial tissues. In this study, rocket plants recorded TF values <1. This is indicative rocket's low capacity to uptake high quantity of Pb and Cd, potentially classifying the plants as an excluder of Pb and Cd. In this respect, the earlier studies revealed that the TF value of most plants was <1, which is analogous to our study. The Transfer Factor (TF) for Pb has been found in the order of leaves > shoots > roots > fruits at every level of contamination. Mohanty *et al.* (2010) found that *Brassica juncea* effectively transports lead from roots to leaves, which is essential for phytoextraction of lead. Also, low translocation of Pb indicates that plants were unwilling to transfer Pb from their roots to shoots possibly due to Pb toxicity. Lead can be toxic to photosynthetic activity, chlorophyll synthesis and antioxidant enzymes (Kim *et al*., 2003). High root to shoot translocation of heavy metals indicated that these plants have vital characteristics to be used in phytoextraction of these metals (Ghosh, and Singh, 2005). Eid *et al.*, (2020) found that in general, all heavy metals increased significantly in portions of *P. sativum* except Cd in the shoot. Bioaccumulation and translocation factors of Pb in *P. sativum* was >1. SS could be used for pea fertilization only at rates below 20 g/kg. For plant species with TF> 1, it is easy to translocate metals from roots to shoots than which restrict those metals in their roots.

From the above mentioned discussion, it can be concluded that both BCF and TF for Pb and Cd demonstrated that rocket plant is Pb and Cd accumulator plants.

6.3. Carcinogenic Risks (CR):

According to USEPA (2015), Carcinogenic Risks (CR) values exceeding 1×10^{-4} cause significant cancer risks. The CR values of Pb in our study was 7×10^{-6} for the treated rocket plants with 20% SS rate and irrigated with normal water, whereas it was 2.25×10^{-6} for the same plant irrigated with magnetized water. Regarding the CR values of Cd, they were 6.62×10^{-6} for the treated rocket plant with 20% SS and irrigated with normal tap water, whereas it was 2.25×10^{-6} for the same plant irrigated with magnetized water. This means that the obtained results of CR values of Pb and Cd for rocket plants grown in SS-amended soil at 20% level (Table, 8), showed that using shoot rocket plants treated with sewage sludge as foods can be said safe in terms of Carcinogenic Risks. Ruchuwararak *et al.* (2018) pointed out that the elevated level of carcinogenic risks posed by Pb was recorded in *Centella asiatica* and other several varieties of vegetable plants. Also, Ahmed *et al.* (2021) on chilli plants found that fruits grown on high Pb contaminated soil exceeded the safe limit of 0.3 mg/kg. Daily Intake of Metals (DIM) for Cr and Pb was deficient in all levels of contamination, and it was higher for Pb than Cr.

It can be concluded that using sewage sludge (SS) rates especially the low and moderate rates has a positive effect on growth, some water relations, some biochemical constituents, whereas, the high rate has harmful effect on some parameters of rocket plants. Moreover, SS caused a great increase in Pb and Cd concentrations, uptake, BCF, TF and CR over the safe limits in plants. Irrigation with magnetic water at all SS levels caused an improvement in growth, some physiological, biochemical compositions of rocket plants. Under the same conditions, great decreases were recorded in the concentrations and uptake of Pb and Cd heavy metals in different organs of rocket plants as well as BCF, TF and CR, leading to production save food plants for human consumption.

It can recommend that magnetized water can be used easily in irrigation of land amended sewage sludge in different rates to reduce the harmful effect of Pb and Cd heavy metals.

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استجابات نباتات الجرجير .*Eruca sativa* L الفسيولوجية النامية في تربة ممدة بحمأة الصرف الصحي لتطبيق الماء الممغنط

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أجريت هذه الدراسة في صوبة المزرعة التجريبية بكلية الزراعة، جامعة المنوفية، شبين الكوم، مصر خلال موسمي النمو ٢٠٢١ و٢٠٢٢ لدراسة تأثير معدلات اضافة حمأة الصرف الصحي المجفف الي التربة [٠، ٥، ١٠ و٢٠٪ (وزن/ وزن، حمأة الصرف الصحي : التربة]، والري بالماء الممغنط وتفاعلاتها على بعض قياسات النمو الخضري، وعلاقات النبات بالماء، وثبات الغشاء البلازمي (النفاذية)، وصبغات البناء الضوئي، وبعض المكونات البيوكيميائية، وبعض المغذيات المعدنية لنباتات الجرجير (*Eruca sativa* L.) كما تم دراسة سلوك بعض المعادن الثقيلة وتأثيرها على صحة الإنسان. تم أخذ عينة عشوائية من كل معاملة على التوالي عند ٦٠ يومًا من الزراعة. أظهرت النتائج المتحصل عليها أن حمأة الصرف الصحي زادت من معظم صفات النمو، محتوي الماء النسبيRWC و نقص الماء الورقي LWD والضغط الأسموزي OS و معدل النتح TR والسكريات الذائبة الكلية والبروتين الكلي ونشاط انزيم البوليفينول أوكسيديز والبرولين ومحتوى N و P و K ، في حين انخفضت درجة الغضاضة DSc وثبات الغشاء البلازمي MI وصبغات البناء الضوئي و نشاط انزيم البيروكسيديز. تسبب تطبيق حمأة الصرف الصحي في زيادة كبيرة في تركيز الرصاص والكادميوم في الأعضاء المختلفة لنبات الجرجير عن الحدود الآمنة. تسبب الري بالماء الممغنط وتفاعلها مع حمأة الصرف الصحي في تعزيز إضافي في النمو وبعض الصفات الفسيولوجية والبيوكيميائية أي (صبغات البناء الضوئي والسكريات والبروتين الكلي والأحماض الأمينية الحرة الكلية والبرولين ونشاط بعض الإنزيمات وحالة المعادن N و P و K) بالإضافة إلى تحسين العلاقات المائية في النبات ونفاذية غشاء نباتات الجرجير. تحت نفس الظروف، كان هناك انخفاضا ملحوظا في نقص الماء الورقي ومعدل النتح وتركيزات وامتصاص الرصاص والكادميوم ومعامل التراكم الحيوي BCF ومعامل التحويل TF ومخاطر الاصابة بالسرطان CR في نباتات الجرجير. أي أن: تطبيق الماء الممغنط تحت ظروف اضافة حمأة الصرف الصحي Sewage Sludge الي التربة له دور حاسم في تحسين وتعزيز النمو والمكونات البيوكيميائية وانخفاض كبير في تركيز الرصاص والكادميوم في جميع الأعضاء وخاصة المجموع الخضري في نباتات الجرجير وأصبحت آمنًة للاستهلاك الآدمي.