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Phytochemical Responses of Sesame Plants to Phosphorus and/or Iron Application under Drought Conditions

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Abstract

As a result of climate changes, plants are exposed to the problem of drought. Trial conducted on increasing plant tolerance to drought and improving the quality of its yield throughout the use of phosphate and iron fertilizer. A field experiment was conducted at the Research and Production Station of the National Research Centre, Nubaria region, Behira Governorate, Egypt to test the effects of phosphorus (0, 25, 50, 100 Kg fed^{-1}) and ferrous sulphate (0, 50, 100 and 150 ppm) on the phytochemical composition of sesame seeds resulted from plants grown under sufficient and deficit irrigation regimens. Increasing phosphorus rates was affiliated with increasing the macro and micronutrient, oil, protein, carbohydrates %. `Also, Antioxidant compounds (Phenol and flavonoids) and total DPPH radical scavenging of sesame seeds were increased($P<0.05$) significantly .Under both irrigation systems, the application of phosphorus (100 Kg fed^{-1}) with Fe sulphate (150 ppm) induced the most significant increase in all previous parameters . It can be concluded that, the use of triple phosphate fertilizer and spraying sesame plants with iron at 100 Kg/fed plus 150 ppm Iron improved the chemical components and consequently the nutritive value of sesame seeds due to increasing plant tolerant to water deficit.

Key words: Sesame plant, Water stress, NPK, Iron, Phosphorus, Oil , antioxidants.

1. Introduction

Globally, a drought is classified as a climatic occurrence that restricts agricultural production due to a prolonged period of no precipitation, long enough to reduce soil moisture levels and result in a loss in the water potential of plant tissues [1]. Plant growth is greatly affected by water shortage or drought stress, which is considered a severe environmental factor and an obstacle to crop productivity [2].

The plant can withstand drought through various mechanisms, such as closing the stomata, thickening of the cuticle, reducing transpiration, preventing protein depletion, and osmotic regulation [3]. The mechanisms of absorption and transfer of nutrients in plants, such as mass flow, emission or absorption and transfer by osmotic phenomena, are all a function of soil moisture substance, assimilation root development, and within the case of decreased moisture or root extension, the concentrated and amount of supplements assimilation is subject to change [4]. Drought avoidance is defined as the plant's ability to maintain a relatively high plant water status or cellular hydration despite water shortage, so that plant functions are relatively unexposed to tissue dehydration [5]. Moreover, most agronomic traits are expressed differently in normal and stress conditions and are known to be affected by environmental factors [6]. Drought stress leads to reduce the seed quality by producing small and medium-sized seeds; while deteriorating the seed vigour and rate of germination [7].

Sesame (*Sesamum indicum* L.) is a historically and culturally significant crop and one of the most significant and strategic oil crops in the world. The importance of producing oil economically [8]. Sesame and groundnut are two of the most significant oilseed crops grown in Egypt, used mostly for food processing as well as for supplying the country's food supply [9]. Sesame seeds are used in a wide range of edible products in raw or roasted form as well as for industrial uses such as soap, lubricants, lamp oil an ingredient in cosmetics; pharmaceutical uses, and animal feed [10]. Sesame plants are adversely affected by continuous flooding conditions or environments with severe drought [11].

Egypt's soils had an alkaline pH, which caused the phosphorus concentration to change into an undesirable form, namely tri-calcium phosphate. It is

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commonly known that using mineral fertilizer promotes healthy growth, which leads to increased yields of many plant types [12]. The addition of phosphorus encourages root growth, which improves the availability of other nutrients and water to the growing sections of the plants, increasing their photosynthetic area and, as a result, the accumulation of dry matter [13]. In plants, phosphorus plays a role in a number of functions, including the preservation of energy metabolic systems, improved root development, and root hydraulic conductivity [14]. When P is sufficient, plants respond better to soil water shortages, which would be assumed to be caused by greater water usage efficiency [15].

The importance of micronutrients on crop growth and productivity has been noted by numerous researchers. Rehm and Albert [16] reported that micronutrient fertilizers increase the crop production and yield component. In this respect, Dar [17] reported that dry matter production, loss of crop's economic yield occurs due to the death of plants with the absence of an essential nutrient or nutrients. Ferrous is an immobile element; therefore, it obvious lacks young leaves. It is essential in chlorophyll synthesis, hydrocarbon production, respiration, as well as redox processes in plants. The ferrous rate ranges from 400 to 200 ppm in plant tissues. However, its rate must be more than 100 ppm in healthy plants. Its main sign is chlorosis usually seen in young leaves [18]. Ferrous deficiency has developed in almost 30 percent of the soils under cultivation around the world [19]. In addition, ferrous absorption decreases in the soils with law organic matters [20]. The objectives of the current research work were to study the effects of adding triple phosphate fertilizers to the soil and foliar application of iron on the nutritional content and chemical composition of sesame plants under water stress conditions

MATERIALS AND METHODS

Experimental procedures

Field experiment was carried out at the Research and Production Station of the National Research Centre, Nubaria region, Behira Governorate, Egypt during 2020/2021. Seeds of Sesame *(Sesam umindicum L.)* cv. Shandwiel, were sown on May season. The experimental design was a split plot with three replications.

Phosphorus treatments occupied the main plots at the rates (0, 25, 50 and 100 kg P fed^{-1}) and the foliar application of Iron at a rate of 0, 50, 100 and 150 ppm under sufficient and deficit irrigation. The plot area was 9 m^2. Some physical and chemical properties of a representative soil sample of the experimental site were analyzed before sowing according to Rebecca [21] and presented in (Table 1).

Table (1): Some physical and chemical properties of the soil and compost

Soil pH (1:2.5)	EC (dSm^{-1})	OM (%)	$CaCO_3$ (%)	Particle size distribution			Texture Class
				Sand (%)	Silt (%)	Clay (%)	
7.42	1.18	0.72	2.16	74.5	5.81	17.95	Sandy loam
Soil cations (mg/100 g soil)				Soil anions (mg/100 g soil)			
Na^+	K^+	Ca^{++}	Mg^{++}	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}
3.54	1.52	3.44	1.62	0.36	3.26	1.71	3.44

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Nitrogen in the form of ammonium nitrate (33.0%N) at the rate of 20 Kg N fed^{-1} as starter dose was added before first irrigation. Potassium sulphate (48% K_2O) was added at the rate of 50 Kg fed^{-1} to the soil in two equal doses at 20 and 40 days after sowing. Sesame plants were irrigated and maintained during the whole growth season using drip irrigation system. Foliar spray of ferrous sulphate was applied three doses to sesame plants during the growth stage. The interaction of different concentrations of both compounds was also assessed in addition to untreated plants (control).

.At harvest, the seeds nutritive content values such as of Macronutrients (nitrogen, phosphorus, potassium and calcium) and micronutrients (Iron, Zinc, Manganese and Copper) were estimated. Also, phytochemical composition and nutritive value (Total phenolics, flavonoids, total soluble sugars (TSS), essential oil, carbohydrate, protein content and antioxidant activity) were measured.

Chemical analysis

Some biochemical aspects were determined. Mineral ions content (some macro and micronutrients) was determined according to Rebecca [21]. Phenolic content was measured as described by Danil and George [22]. Total flavonoids were determined using the method reported by Chang et al.[23].Total soluble sugars (TSS) extracted according to Homme et al.[24] and assayed according to Yemm and Willis [25]. Extraction of essential oil was determined by Hydro distillation for 3h according to Guenther [26]. Total carbohydrate using the colorimetric method described Dubois et al. [27]. Crude protein percentage was extracted and determined by Micro-Kjeldahl method as described by A.O.A.C [28].The value of total crude protein was calculated by multiplying total values of total-N by factor 6.25. The antioxidant activity was determined using the method of Liyana-Pathiranan and Shahidi [29].

Statistical analysis

The analysis of data was statistically analyzed according to the technique of analysis of variance (ANOVA) for the split–plot design using MSTAT-C [30] computer software package. Least Significant

Difference (LSD) method was used to test the differences among treatment means at 5% level of probability as described by Snedecor and Cochran [31].

RESULTS

Changes in nutrients content:

Macronutrients content:

Data in Table (2) showed that the application of triple phosphate at the rates (0, 25, 50, 100 Kg fed^{-1}) and ferrous sulphate at the rates 0, 50, 100 and 150 ppm Iron, had a significant effect on the nutrient content of sesame. The values of the nitrogen, phosphorus, potassium and calcium content of sesame seeds were higher under sufficient irrigation than under water stress.

Table (2): Macronutrients content of sesame plant as affected by Trible phosphate (Trible P) and Iron foliar application under sufficient and deficit irrigation.

Trible P (Kg/fed.)	Iron (Fe)	Nitrogen %		Phosphorus %		Potassium %		Calcium %	
		Sufficient	*Deficit*	*Sufficient*	*Deficit*	*Sufficient*	*Deficit*	*Sufficient*	*Deficit*
(Zero)	Zero	2.97	1.68	1.11	0.74	0.23	0.20	0.79	0.62
	50 ppm	3.45	1.97	1.29	0.91	0.27	0.22	0.94	0.64
	100 ppm	4.14	2.47	1.66	0.96	0.32	0.25	1.04	0.72
	150 ppm	4.43	2.65	1.77	1.11	0.34	0.26	1.11	0.78
(25)	Zero	3.31	1.97	1.25	0.91	0.25	0.22	0.86	0.66
	50 ppm	3.68	2.05	1.39	0.96	0.27	0.23	1.01	0.66
	100 ppm	4.16	2.54	1.73	1.15	0.33	0.26	1.15	0.74
	150 ppm	4.65	2.75	1.88	1.17	0.35	0.28	1.20	0.81
(50)	Zero	3.79	2.16	1.45	0.97	0.29	0.23	1.04	0.71
	50 ppm	4.39	2.28	1.56	1.01	0.30	0.25	1.09	0.75
	100 ppm	4.71	2.74	1.82	1.12	0.34	0.27	1.20	0.84
	150 ppm	5.35	2.86	1.99	1.36	0.36	0.29	1.27	0.94
(100)	Zero	3.98	2.19	1.51	0.97	0.29	0.24	1.03	0.72
	50 ppm	4.57	2.41	1.62	1.07	0.31	0.25	1.11	0.81
	100 ppm	4.65	2.59	1.76	1.23	0.33	0.26	1.17	0.83
	150 ppm	5.06	2.79	1.93	1.17	0.36	0.29	1.23	0.91
Main effect of Trible P	Zero	4.21	2.38	1.46	1.05	0.31	0.25	0.97	0.76
	25 kg/fed	3.95	2.33	1.56	1.05	0.30	0.24	1.06	0.72
	50 kg/fed	4.56	2.51	1.70	1.11	0.32	0.26	1.15	0.81
	100 kg/fed	4.56	2.49	1.70	1.11	0.32	0.26	1.13	0.82
Main effect of Iron	Zero	3.51	2.00	1.33	0.90	0.26	0.22	0.93	0.68
	50 ppm	4.02	2.18	1.47	0.99	0.29	0.24	1.04	0.72
	100 ppm	4.41	2.58	1.74	1.11	0.33	0.26	1.14	0.79
	150 ppm	4.87	2.76	1.89	1.20	0.35	0.28	1.20	0.86
LSD (0.05)	Trible P	0.307	0.059	0.133	0.065	0.006	0.012	0.031	0.052
	Iron (Fe)	0.144	0.041	0.118	0.084	0.007	0.008	0.038	0.019
	Interaction	0.412	0.091	0.229	0.136	0.011	0.018	0.063	0.064

LSD= Least Significant Difference.

In the same table, under sufficient irrigation and water stress treatments, the increase of triple phosphate rate concomitant with macronutrient increment content of sesame seeds. The minimum and maximum values of macronutrient content were observed at control of triple phosphate (0 Kg) and 100 Kg fed^{-1}, respectively. It is obvious to state that the greatest loss of macronutrient content under water stress condition was found at zero and 25 Kg fed^{-1} applied triple phosphate relative to 50 and 100 Kg fed^{-1} applied triple phosphate, respectively. It became clear from the results that application of 50 Kg fed^{-1} triple phosphate increased the values of nitrogen, phosphorus, potassium and calcium content by about 8.41, 16.77, 4.14 and 18.18% under sufficient irrigation treatments relative to a control treatment, respectively. And increased values of the aforementioned elements by about 5.36, 6.09, 4.69 and 6.70% under water stress irrigation treatments relative to control treatment, respectively. Also, application of 100 Kg fed^{-1} triple phosphate increased the values of nitrogen, phosphorus, potassium and calcium content by about 8.53, 16.78, 4.35 and 16.61% under sufficient irrigation treatments relative to a control treatment, respectively. And increased values of the aforementioned elements by about 4.72, 5.77, 3.76 and 7.55% under water stress irrigation treatments relative to control treatment, respectively.

According to the iron treatment at a rate of (0 ppm) with all triple phosphate treatment observed the lowest level of macronutrient content as compared to control treatment. Whereas, increased values of the nitrogen, phosphorus, potassium and calcium contents in sesame seeds by about (25.62, 31.29, 24.98 and 22.48%) and (29.21, 24.09, 17.80 and 15.96%) were observed after application of 100 ppm iron foliar spray combined with 100 kg fed^{-1} triple phosphate as soil application under sufficient irrigation and water stress treatments, respectively. While the increase was by about (38.71, 42.83, 32.98 and 29.34%) and (38.18, 34.10, 26.99 and 27.02%) were observed after application of 150 ppm iron foliar sprays combined with 100 Kg fed^{-1} triple phosphate as soil application under sufficient irrigation and water stress treatments, respectively.

In the same table, data at hand showed that all triple phosphate treatments with untreated iron gained the lowest results, whereas treatments with 150 ppm iron and 100 Kg fed^{-1} triple phosphate got the highest.

According to phosphate treatment on the amount of macronutrients in plants, 100 Kg fed^{-1} of triple phosphate scored the highest results, with increases in percentage of 7.15, 12.17, 4.07 and 12.63%, respectively compared to control. The similar pattern was seen when iron was applied at 150 ppm, which increased the micronutrient content of sesame seeds by roughly 38.51, 39.31, 30.25 and 28.36% in the same order as before.

II- Micronutrients content:

Regardless of treatment, it was observed from data provided in Table (3) that there was gradually increase the micronutrients content of sesame seeds, this increases is due to the increase of triple phosphate rates with the foliar application of ferrous sulfate, data presented that the application of phosphorus at the rates (0, 25, 50, 100 Kg fed^{-1}) and ferrous sulphate at the rates 0, 50 and 100 and 150 ppm, It had a clear effect on the micronutrient content in sesame. Data illustrated in Table (3) showed some nutrient content of sesame (Iron, Zinc, Manganese and Copper) affected by the rates of triple phosphate and iron application and their interaction under different water irrigation (sufficient and deficit irrigation).

The data showed that the values of the sesame seeds examined micronutrient content were higher under normal irrigation than under water stress. While all phosphorus application rates for the control treatment of iron (0 ppm) produced the lowest values relative to the lowest values recorded at the control. Whereas, the highest values of the studied factors observed after foliar application of Fe at the rate of 150 ppm and triple phosphate at the rate of 100 Kg fed^{-1}. Regarding the highest ones were observed at 100 Kg fed^{-1} triple P and 150 ppm Fe, similar trend was shown where increasing rates were correlated with increased sesame micronutrient content under normal irrigation.

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Table (3): Micronutrients content of sesame plant as affected by Trible phosphate (Trible P) and Iron foliar application under sufficient and deficit irrigation.

Trible P (Kg/fed.)	Iron (Fe)ppm	Iron (ppm)		Zinc (ppm)		Manganese (ppm)		Copper (ppm)	
		Sufficient	*Deficit*	*Sufficient*	*Deficit*	*Sufficient*	*Deficit*	*Sufficient*	*Deficit*
(Zero)	Zero	245.7	213.6	27.8	21.3	11.9	5.7	4.8	4.5
	50	288.0	222.9	29.8	23.0	13.4	7.5	5.8	4.9
	100	367.3	259.7	31.8	25.2	15.9	11.0	7.5	5.4
	150	400.4	280.1	35.1	26.9	17.6	12.1	8.2	5.9
(25)	Zero	269.7	218.3	28.8	22.0	12.7	7.5	5.7	4.7
	50	305.4	229.2	30.0	23.6	14.1	8.5	6.4	5.1
	100	379.1	265.2	34.3	25.5	16.6	11.1	7.8	5.4
	150	433.5	320.0	39.4	29.1	19.5	13.9	9.2	6.0
(50)	Zero	325.4	235.7	30.1	23.9	14.7	8.5	6.3	5.1
	50	337.7	241.4	31.2	24.4	15.3	9.4	7.1	5.3
	100	408.7	282.9	38.2	28.0	17.9	13.1	9.0	5.9
	150	483.1	348.3	42.3	31.7	21.1	15.0	10.1	6.4
(100)	Zero	331.6	238.2	30.6	24.2	15.3	9.3	6.8	5.2
	50	354.1	249.9	31.5	24.6	15.9	10.2	7.6	5.3
	100	395.4	270.8	34.7	25.9	16.7	12.2	8.7	5.6
	150	438.3	320.9	40.7	30.1	20.2	14.1	9.8	6.2
Main effect of Trible P	Zero	325.3	244.1	31.2	24.1	14.7	9.1	6.6	5.2
	25 Kg/fed	347.0	258.2	33.1	25.1	15.7	10.3	7.3	5.3
	50 Kg/fed	388.7	277.1	35.4	27.0	17.2	11.5	8.2	5.7
	100 Kg/fed	379.8	270.0	34.4	26.2	17.0	11.5	8.2	5.6
Main effect of Iron	Zero	293.1	226.4	29.3	22.8	13.7	7.8	5.9	4.9
	50 ppm	321.3	235.9	30.6	23.9	14.7	8.9	6.7	5.1
	100 ppm	387.6	269.7	34.8	26.1	16.8	11.9	8.2	5.6
	150 ppm	438.9	317.3	39.4	29.5	19.6	13.8	9.4	6.1
LSD (0.05)	Trible P	4.92	5.14	1.08	1.51	0.34	0.31	0.36	0.23
	Iron (Fe)	11.97	9.35	1.35	1.43	0.40	0.54	0.60	0.19
	Interaction	15.42	13.23	2.22	2.69	0.68	0.78	0.88	0.38

LSD= Least Significant Difference.

The results showed that application of 50 Kg fed^{-1} triple phosphate increased the values of (Iron, Zinc, Manganese and Copper) content by about 19.49, 17.20, 13.73 and 23.80% under sufficient irrigation treatments relative to a control treatment, respectively. And increased values of the aforementioned elements by (13.52, 26.63, 12.06 and 9.43%) under water stress irrigation treatments relative to control treatment, respectively. Also, application of 100 Kg fed^{-1} triple phosphate increased the values of Iron, Zinc, Manganese and Copper content by about 16.76, 15.47, 10.37and 25.04% under sufficient irrigation treatments relative to a control treatment, respectively. And increased values of the aforementioned elements by about 10.61, 26.19, 8.73and 7.96% under water stress irrigation treatments relative to control treatment, respectively

Concerning ferrous sulphate application rates effect on micronutrient content (Iron, Zinc, Manganese and Copper) under both irrigation treatments (Table 3), data indicated that the maximum and minimum values were recorded at 0 and 150 ppm. The highest increase in Iron, Zinc, Manganese and Copper were 32.24, 22.95, 18.60, 39.07% and 19.09, 52.83, 14.44, 14.44% comparing 100 ppm Iron with control, respectively. As well, increase by about 49.73, 43.65, 34.32, 57.85% and 40.14, 47.44, 28.95, 25.75% comparing 150 ppm Iron with control, respectively.

Regardless irrigation treatments, data in Table (3) demonstrated the impact of both triple phosphate and iron application rates as well as their interactions on the micronutrient content of sesame plants. Data available showed that all triple phosphate treatments with (0 ppm) iron gained the lowest results, whereas treatments with 100 Kg fed^{-1} triple phosphate and 150 ppm iron resulted in the greatest values. According to data on the impact of phosphate on plant micronutrient content, 100 Kg fed^{-1} of triple phosphate scored the greatest results, with increases in percentage of 14.12, 19.56, 9.65 and 17.53%, respectively, in comparison to controls. Similar trend was seen when iron was applied at 150 ppm, which increased the macronutrient content of sesame seeds by roughly 45.55, 55.95, 31.97and 43.39% in the same previous sequence.

Changes total phenolics, flavonoids and total soluble sugars on seeds:

Data in Table (4) and Figures (1a &b) represents the changes in some phytochemical composition (Total phenolics, flavonoids, total soluble sugars and TSS) in sesame seeds grown under sufficient and deficit irrigation after treatment with phosphorus fertilizer (0, 25, 50 and 100 Kg/fed), iron foliar spraying (0, 50, 100 and 150 ppm). Data shows that under drought stress (deficit irrigation) resulted in a significant ($P<0.05$) a reduction in total phenolics and flavonoids, but total soluble sugars increased of sesame seeds as compared with the plant irrigated with sufficient water. Moreover, the treatment of sesame plants with the tested concentrations of phosphorous fertilizer and iron significantly ($P<0.05$) ascending incremented contents of compatible solutes in the unstressed plants (sufficient irrigation) as well as those of the drought-stressed plants (Deficit irrigation) relative to the corresponding controls.

Table (4): Phytochemical composition of sesame plants as affected by Trible phosphate (Trible P) and Iron foliar application under sufficient and deficit irrigation

Trible P (Kg/fed.)	Iron (Fe; ppm)	Phytochemical composition (mg/g dry wt.)					
		Phenolic		Flavonoids		Total soluble sugars	
		Sufficient	*Deficit*	*Sufficient*	*Deficit*	*Sufficient*	*Deficit*
Zero	Zero	8.56	6.94	0.421	0.282	8.23	13.86
	50	8.72	7.17	0.430	0.294	8.55	14.23
	100	8.92	7.38	0.448	0.314	8.93	14.92
	150	9.33	7.81	0.458	0.330	9.07	15.18
25	Zero	8.73	7.13	0.438	0.314	8.39	14.00
	50	8.90	7.49	0.445	0.323	8.84	14.79
	100	9.39	7.86	0.456	0.331	9.14	15.18
	150	9.70	8.09	0.468	0.339	9.28	15.54
50	Zero	8.97	7.47	0.450	0.331	8.73	14.70
	50	9.31	7.72	0.461	0.342	9.36	15.31
	100	9.68	8.11	0.470	0.354	9.53	15.77
	150	10.30	8.62	0.484	0.369	9.62	15.98
100	Zero	9.05	7.50	0.450	0.328	9.20	14.93
	50	9.38	7.70	0.457	0.335	9.39	15.13
	100	9.87	8.39	0.469	0.343	9.55	15.79
	150	10.20	8.47	0.478	0.374	9.61	15.91
LSD (0.05)	Trible P	0.124	0.183	0.0090	0.0137	0.142	0.297
	Fe	0.049	0.153	0.0044	0.0076	0.088	0.153
	Interaction	0.158	0.307	0.0123	0.0194	0.210	0.411

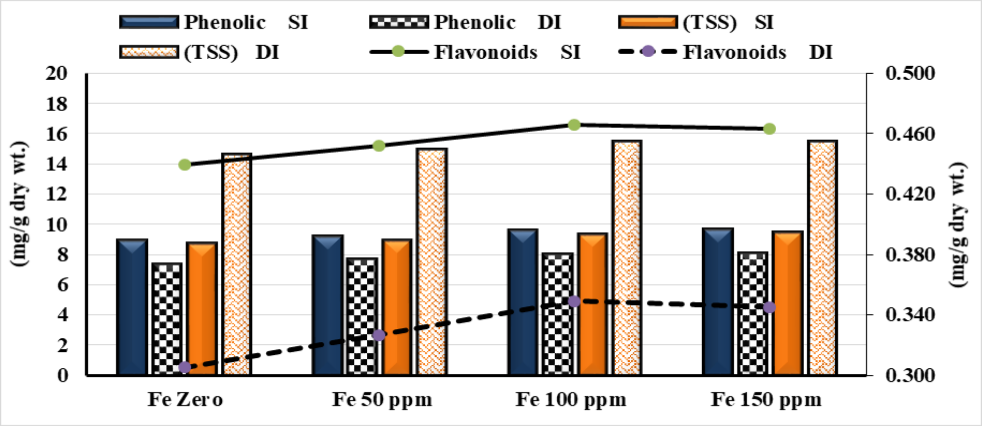

Figure (1a): Main effect of Phosphorus on Phytochemical composition of Sesame plant

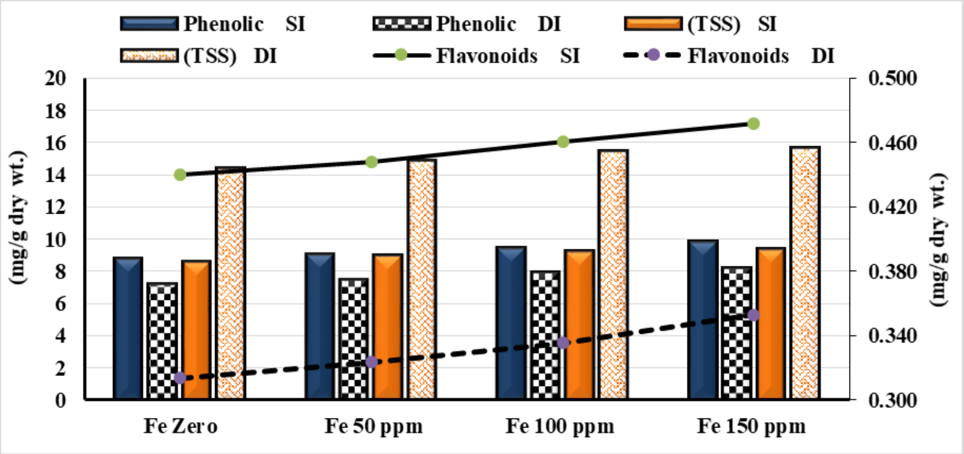

Figure (1b): Main effect of Ferrous sulfate on Phytochemical composition of Sesame plant

Seed Quality:

Seeds quality (oil, carbohydrates, proteins and total antioxidant activity; DPPH) of sesame plant after treated with phosphorus fertilizer **(**0, 25, 50 and 100 Kg P fed^{-1}), iron foliar spraying (0, 50, 100 and 150 ppm) grown under sufficient and deficit irrigation are presented in Table (5) and Figures (2a &b). All measured chemical components of seeds were significantly (P<0.05) decreased by water stress. As compared to the plants grown in sufficient irrigation, the seeds quality under water stress decreased from 35.0 to 26.9, 15.9 to 11.3, 14.3 to 10.9 and 17.0 to 12.3 in oil, carbohydrate, protein and DPPH% , where the rate of reductions were 23.14, 28.93, 23.78 and 27.65% respectively. Application of triple phosphorous fertilizer and iron spraying on water-stressed and well-watered plants induced a significant (P≤0.05) increase in the chemical constituents of sesame seeds. It is obvious from our data that the highest increase in these constituents in the yielded seeds was most pronounced with the greatest concentration used in comparison with the corresponding water controls. The best treatment improving these parameter tested is the highest concentration of both phosphorous and iron in general.

Table (5): Phytochemical composition (%) of sesame seeds as affected by Trible phosphate (Trible P) and Iron foliar application under sufficient and deficit irrigation

Trible P (Kg/fed.)	Iron (Fe; ppm)	Phytochemical composition (%)							
		Oil content		Carbohydrates		Protein content		Antioxidant Activity (DPPH)	
		Sufficient	*Deficit*	*Sufficient*	*Deficit*	*Sufficient*	*Deficit*	*Sufficient*	*Deficit*
Zero	Zero	35.0	26.9	15.9	11.3	14.3	10.9	17.0	12.3
	50	36.1	27.3	16.3	11.5	14.7	11.3	18.1	12.8
	100	38.1	28.4	17.0	12.3	15.1	11.6	18.4	13.9
	150	39.6	28.8	17.4	12.7	15.4	11.8	18.7	14.2
25	Zero	35.7	27.2	16.1	11.6	14.5	11.2	17.3	12.6
	50	36.7	28.3	16.5	11.9	14.9	11.4	17.8	12.9

	100	39.1	29.1	17.4	12.5	15.4	11.9	18.4	13.9
	150	40.7	31.6	17.8	13.0	15.7	12.2	19.6	14.8
50	**Zero**	37.5	28.2	16.8	12.0	14.8	11.5	17.5	12.9
	50	39.2	29.7	17.3	13.2	15.1	11.8	18.3	13.2
	100	40.8	30.9	17.9	13.5	15.7	12.1	19.1	13.8
	150	43.0	33.1	18.4	13.8	15.9	12.7	20.9	14.9
100	**Zero**	37.8	29.1	16.8	12.1	14.9	11.5	17.8	13.2
	50	39.7	30.1	17.4	13.2	15.1	11.9	18.5	14.0
	100	40.7	31.0	17.9	13.5	15.7	12.1	19.0	14.4
	150	42.7	33.1	18.3	13.7	15.8	12.8	20.9	15.0
LSD (0.05)	**Trible P**	0.714	1.495	0.337	0.087	0.063	0.114	0.235	0.506
	Iron (Fe)	1.103	1.286	0.131	0.102	0.060	0.092	0.292	0.294
	Interaction	1.659	2.540	0.428	0.172	0.112	0.188	0.481	0.730

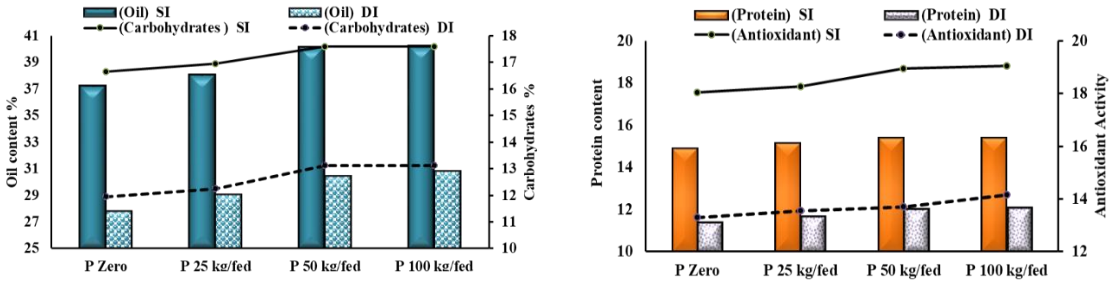

Figure (2a): Main effect of Phosphorus on Phytochemical composition of Sesame plant

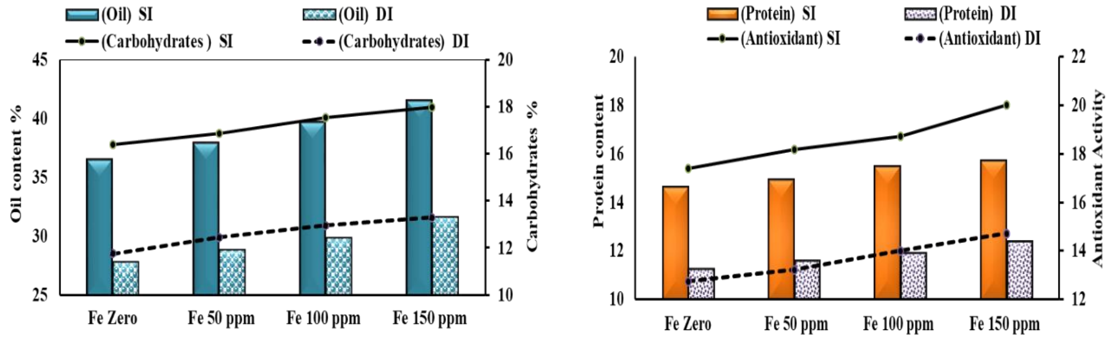

Figure (2b): Main effect of Ferrous sulfate on Phytochemical composition of Sesame plant

DISCUSSION

Nutrient content:

1-Macronutrient content

Sandy soils' weak chemical composition, which hampered plant growth and productivity, make it clear that plants could not meet their needs for water or nutrients in these soils. Application of triple phosphate alone and/or ferrous sulphate nutrients as fertilizers can be used to stop the loss of water and nutrients that growing plants require, which may be helpful in solving these issues.

Perusal of data in Table (2) showed that the application of triple phosphate alone and/or ferrous sulphate addition significantly increased the macronutrient content (nitrogen, phosphorus, potassium and calcium) of sesame seeds compared to untreated and drought stress plants .Meanwhile, the drought stressed plant showed a significant reduction in these tested macro elements compared to the sufficient irrigated plants In this respect, Farooq et al. [32] showed that drought stress inhibits cell amplification more than cell division. It inhibits a variety of physiological and biochemical processes, especially nutrient metabolism and ions uptake, which reduce plant development.

The increase in macronutrients due to phosphate fertilizer application maybe attributed to the increase of absorption elements and thus increases the macronutrient content and uptake in sesame. Good supply of phosphorus is usually associated with increased root density and proliferation, which aid in extensive exploration and supply of nutrients and water to the growing plant parts [33&34]. Phosphorus is an important element of nucleic acids (RNA and DNA), nucleoproteins, amino acids, protein, phosphatides, phytin, and numerous co-enzymes and plays a vital part in the synthesis of energy-rich phosphate bonds like ADP and ATP, nuclear protein, and phospholipids [35]. Additionally, phosphorus plays a role in the basic reaction of photosynthesis, the transformation of sugar and starch, and the flow of nutrients in plants [36]. In addition, Hafiz and El-Bramawy [37] discovered that raising the phosphorus fertilizer rate up to 95 Kg P_2O_5 ha^{-1} considerably improved sesame seed yield.

Concerning iron treatments, numerous researchers have noted how micronutrient components affect crop performance and production. Ghasemi et al [38], Rehm and Albert [16] and Ramadan et al [39] showed that micronutrient supplementation increased yields.

II-Micronutrient content:

The interaction effect of mineral fertilizers ,application of triple phosphate and iron foliar treatment combined together was better than the use each one alone especially the highest concentration in sufficient and deficit irrigation as compared with corresponding control which gave the highest significant effect on Iron, Zinc, Manganese and Copper content on seeds of sesame plants (Table 3). These results are in agreement with Froese et al.[40] who pointed out an important role of phosphorus in the fertilization in crops. Phosphorus is a crucial nutrient that plays multiple roles in plant growth and development, including flower and seed production, more uniform and early crop maturity, improved crop quality, and higher resistance to plant diseases [41]. For the production of winter oil seed crops, macro- and microelement fertilization is essential. The plant can receive some nutrients during the growing season [42].

Concerning of ferrous sulphate application rates, the data are in a good harmony with those obtained by Yadav et al. [43], Heidari et al. [44], Hamideldin & Hussein [45] and Mahdi [46]. Experimental results of Odeley and Animashaun [47] also showed that foliar application of micronutrients improved soybean production, they added that micronutrients such as copper, boron, iron, zinc and manganese play major roles in the development of plant cell walls and their ability to withstand environmental stress.

Changes in total phenolics, flavonoids and total soluble sugars on seeds:

Data in Table (4) and Figures (1a &b) shows that under drought stress (Deficit irrigation) resulted in a significant ($P<0.05$) reduction in total phenolics and flavonoids and increment in TSS of sesame seeds compared with the plant irrigated with sufficient water. Meanwhile, the treated sesame plants with phosphorus fertilizer and iron foliar spraying in the same table induced a gradual increase in the tested parameters in unstressed plants (Sufficient irrigation) as well as those of the drought-stressed plants (Deficit irrigation) relative to the corresponding controls. The decrease in the antioxidant compounds (Total phenolics and flavonoids) and increase in osmoprotectant (Total soluble sugars and TSS) in sesame leaves as a result of water stress were confirmed by several authors. El-Bassiouny et al. [48] on sunflower plants, and El-Sayed et al.[49] on peanut plants, found that drought stress caused significant ($P<0.05$) decreases in the antioxidant substances (Total phenolics and flavonoids), and increased the content of TSS compared to the relative control (Unstressed).

In response to water stress, plants can adapt and respond by changing their cellular metabolism to stimulate a variety of defence mechanisms, which is known as secondary metabolite accumulation [50]). It involves the synthesis and accumulation of soluble sugar, proline, glycine betaine and some inorganic ions (osmolytes) [51]. These substances aid in the maintenance of the dehydrated state of the cells as well as the structural integrity of the membranes, providing resistance to drought and cellular dehydration [52]. In this domain, Bakry et al. [53] found that total soluble sugars in two linseed cultivars were important for carbon storage, osmotic adjustment, and radical scavenging under water stress conditions.

An increase in antioxidant compounds (Phenolics and flavonoids) may improve stress tolerance. To combat ROS-induced tissue harm, plants have evolved an effective enzymatic and non-enzymatic antioxidant mechanism. Non-enzymatic antioxidants, such as phenolic compounds, are a large group of plant secondary metabolites that can act as ROS scavengers, enhancing oxidative damage tolerance [54&55]. Also, the increased contents of flavonoid which scavengers to reduce oxidative stress under drought conditions may reflect some kind of defense against stress conditions [56].

The ameliorative effects of iron foliar spraying and phosphorus fertilizer on the contents of total phenolics, flavonoids, total soluble sugars in sesame plants are in line with Ramadan et al.[39] who found that foliar spraying of FeO on soybean plants increased significantly TSS, free amino acids and total soluble protein as well as the content of phenolic compounds. According to Liu et al.[57], nano-ferric oxide increased the amount of soluble sugars and protein in peanut plants. Malusà et al.[58] discovered that phosphate deficit causes secondary metabolism chemicals to be linked to the synthesis of bean root exudates (*Phaseolus vulgaris* L.). They added that phosphate shortage reduced the total soluble phenolic content of roots, but increased the total soluble phenolic content of exudates. Increases in growth indices and photosynthetic pigments may explain the stimulating effect of iron foliar spraying and phosphorus fertilizer on carbohydrate content, flavonoids, and total phenols of produced seeds. These increases in carbohydrate content could also be attributed to enhanced photosynthetic production, which boosted carbohydrate formation in leaves and hence increased glucose translocation from leaves to growing seeds. Iron stimulates a number of enzymes, aids in the creation of RNA, and enhances the efficiency of photosynthetic activities, according to Sheykhbaglou et al. [59] and Liu et al.[57]. Phosphorus is a key component of energy-rich molecules, and as a result, it provides energy for a variety of cellular biological processes. It's required for reproduction, glucose metabolism, and protein synthesis [60].

Changes in seed quality:

The reduction in seeds quality (oil, carbohydrate, protein and DPPH%) in the yielded seeds as the results of water stress condition (Table (5) and Figures (2a &b). are confirmed with El-Sayed et al. [49] who showed that soil water deficient (from 60 to 40% WHC) persuaded decreases in the % of oil, carbohydrate and antioxidant compounds (DPPH activity, flavonoids and total phenol) in the yielded seeds of peanut in comparison control. Also, Rezaei et al. [61] reported that water deficit**s** (WIR at 75 and 50%) decreased starch and protein content of wheat cultivars. Drought stress reduced photosynthetic rate which would disrupt carbohydrate metabolism in leaves and possibly result in a reduction in assimilate delivered to the sink organs [62].

These obvious increase in the estimated chemical components in sesame seeds (Table 5) as the result of phosphorus fertilizer confirmed by Badawi et al. [63] who showed that phosphorus fertilizer levels increased seeds quality characters of some rice cultivars, excluding total carbohydrates and crude protein %. Also, Taliman et al. [64] found that leaf photosynthesis increases with phosphorous application, consequently the whole plant dry weight and the plant growth. Moreover, Wang et al.[65] found that the activity of Rubisco, a crucial photosynthesis enzyme, and protein concentrations in cotton cultivar leaves were increased due to high phosphorous application.

Concerning the effect of iron on sesame seed quality, the significant increase due to iron treatment were confirmed by Ghafari and Razmjoo[66] who found that foliar application of different source of iron (nano-iron oxide, iron chelate "EDTA", iron sulfate) increased the content of seed carbohydrates, protein and iron contents of durum wheat. They explain that these increases due to the increase in activities of all leaf enzymes and chlorophyll of leaf. Also, Monsef et al. [67] reported that application of 1 per 1,000 nano-iron chelate raised the protein and Fe content of cowpea seed. Karimi et al. [68] showed that Urea and iron chelate application and their interaction, significantly ($P \leq 0.001$) increased glucose and sucrose concentration at harvest. In the same field, Ramadan et al. [39] found that the application of foliar FeO NPs increased ($P<0.05$) significantly the percentages of protein, carbohydrate, and oil in produced seeds.

CONCLUSION

It can be said that fertilization with enough amounts of phosphate accompanied by spraying the leaves with Iron leads to the transformation of dissolved Iron into an insoluble form due to the union of Iron with phosphate, forming Iron phosphate. This strategy improved plant tolerance to water stress throughout motivating the antioxidant compounds (Total flavonoids, total phenol and DPPH %) activities. The use of 100 Kg/fed triple superphosphate plus foliar spraying with 150 ppm Iron produce tangible results in terms of macro, micro-nutrient, phytochemical constituents, antioxidants and consequently enriched of yielded seeds' quality (Oil, protein and carbohydrate) of sesame plants under water stress condition.

2. Conflicts of interest

The authors whose names are listed in this submission certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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