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Comparative Study of Zinc Fertilization in Two Wheat (*triticum aestivum* l.) Cultivars

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ABSTRACT

Zinc is an essential micronutrient whose deficiency is widespread in cultivated soils and affects the growth and productivity of many crops. The biofortification of highly consumed crops, including wheat, is a hopeful trend to enhance plants productivity and even human health, particularly in developing countries where diet is mainly dependent on grains. Different cultivars have different responses to metal treatment; therefore, it is crucial to select the suitable cultivar for each cultivation conditions. In the current study, two wheat cultivars, Sakha 94 and Gemmyza 10, were studied for their growth under different concentrations of Zn (2, 5, 10 and 25 mM) added to the soil. The experimented plants were assessed for a number of growth criteria (lengths, fresh weights, dry weights and water contents for both shoots and roots) and the contents of a number of minerals (Ca, Mg, K, Na and Zn). Zinc translocation factor, Zn accumulation in roots, shoots and total plants and Zn distribution in roots of the tested plants were estimated. The contents of soluble carbohydrates and proteins in roots and shoots were measured. The results revealed that cultivar Gemmyza 10 showed better growth under high Zn concentrations with general enhancement in plants physiological status and equal distribution of the absorbed Zn between roots and shoots. The other cultivar was superior in growing under control conditions while Zn treatment caused suppressed growth and disturbance in physiological parameters with localization of the absorbed Zn in roots rather than shoots. These results confirm the differential responses of different cultivars to Zn treatment and suggest Zn fertilization of cultivar Gemmyza 10, particularly by the 10 mM Zn concentration, for improvement of growth and physiology. Cultivar Sakha 94, on the other hand, is suitable for cultivation in low-Zn soils as its growth is suppressed by elevating Zn levels.

Key words: heavy metals, fertilization, micronutrients, wheat.

INTRODUCTION

Zinc is an essential plant micro-nutrient which enters in the structure of tens of proteins and also performs as a cofactor to various enzymes involved in several physiological processes including chlorophyll synthesis, carbohydrate metabolism, protein synthesis and maintenance of biological membranes (Alloway, 2008). Thus, its deficiency causes growth disorders and significant yield loss that can reach up to 40% reduction in crop yield in cases of acute deficiency in plants, including wheat (Ning et al., 2019). Both foliar and soil zinc application can enhance crop yields (Awad-Allah et al., 2008; Tariq et al., 2014). Zinc is also an essential nutrient for human health and is essential for several biological processes in the human body (Black 2008). One third of the world's population is estimated to be Zn- deficient, mainly due to chronic inadequate Zn intake particularly in developing countries where diets are dependent on cereal grains (Sarwar et al., 2020).

Wheat in comparison with other field crops has relatively better tolerance to Zn deficiency. However, its continuous cultivation in Zn deficient soils has resulted in wide spread Zn deficiency in grains; hampering crop production and causing low Zn supply to human. The reasons for increased Zn deficiency include Zn removal due to intensive cropping systems, less application of organic manures, phosphorus-induced Zn deficiency resulting from increased use of phosphatic fertilizers and using irrigation water of poor quality (Akram et al., 2017). About 50% of cereal crops are cultivated on low Zn availability soils worldwide (Alloway, 2009).

Wheat (*Triticum aestivum* L.) is an important staple food crop worldwide. Its grains have inherently low Zn contents (Ning et al., 2019). Therefore, increasing Zn contents of wheat grains and other cereal crops is being highly prioritized as a research topic (Chattha et al., 2017). Reduction of average wheat yields is severely affected by deficiency of nitrogen, phosphorus and zinc (Mathpal et al., 2015).

Even newly developed cultivars with a strong Zn absorption genetic capacity largely depend on the available Zn pool in soil. Zinc absorption also depends on the plant physiological efficiency to accumulate higher concentrations which is different among different cultivars of the same species (FAO, 2013; Liu et al., 2019). Nutrient deficiencies in crop plants may be

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corrected by soil and/or foliar spraying and priming treatments. In general, soil and foliar applications of micronutrients are the most prevalent methods (Liu et al,. 2017).

Increasing wheat Zn content through soil fertilization involves a number of physiological steps including the Zn uptake by roots, root-to-shoot translocation and remobilization of Zn. A better understanding of these steps will increase our ability to enhance the Zn content in grains via genetic and agronomic practices (Liu et al., 2019). Nutrient deficiencies related to early growth of crops can increase susceptibility to early-season stresses and thus result in yield loss. Despite acting as a plant nutrient and playing an important role in many metabolic reactions, zinc is toxic at higher concentrations (Jian et al., 2019).

Several studies were performed on the Egyptian wheat cultivars to assess the effect of Zn treatment, whether by foliar application or addition to the soil (Zeidan et al., 2010; El Metwally et al., 2012; El-Habbasha et al., 2015; El-Dahshouri et al., 2017). These studies were all performed in sandy soils aiming to compensate for the low soil fertility of the sandy soil by Zn application.

The aim of this study was to compare the response of two Egyptian wheat cultivars (Gemmyza 10 and Sakha 94) cultivated in clay soil with a normal average of Zn content to adding zinc to the soil in four concentrations (2, 5, 10 and 25 mM), in addition to the control, by assessment of growth parameters, mineral composition and the contents of soluble carbohydrates and proteins in both roots and shoots. This study aimed to evaluate the outcome of Zn fertilization on the growth of plants of the tested two cultivars in clay soil, to determine the Zn doses that are more likely to act as fertilizers rather than growth inhibitors, and to better understand the physiological effects of increasing soil Zn on these two cultivars.

MATERIALS AND METHODS

Cultivation conditions: The seeds of two wheat cultivars (Gemmyza 10 and Sakha 94) were obtained from the Egyptian breeding programs Gemmyza and Sakha. An open air pot experiment was conducted in the botanical garden of the Botany and Microbiology Department, Faculty of Sciences, Minia University in October 2019. Thirty plastic pots were prepared and each was filled with about 500 g of clay soil of the Botanical Garden. The pots were separated into two groups, one for each cultivar. Three pots were prepared for control as well as for each of the used zinc concentrations as replicates. Five seeds were sown per pot. Ten days after cultivation, germinated seedlings were thinned into three per pot and treated by the different assigned treatments. Zinc was added as $ZnSO_4.7H_2O$ in four concentrations, 2mM, 5mM, 10mM and 25mM, in addition to the control pots that were irrigated by distilled water. These concentrations were selected upon preliminary seed germination experiments. Each pot was irrigated by the corresponding solution up to the field capacity of the cultivated soil which was estimated as 330 ml/1000 g soil. The amounts of Zn in the added solutions were 43.6 µg g^{-1}soil in the 2 mM solution, 109 µg g^{-1} soil in the 5 mM solution, 218 µg g^{-1} soil in the 10 mM solution and 436 µg g^{-1} soil in the 25 mM solution. The pots were left under field conditions for 15 days. During the experimental period, they were observed and irrigated by distilled water whenever needed. At the end of the experimental period the growth differences among the tested plants were observed, so the field experiment was ended. The wheat plants were 25 days old at the end of the experimental period.

Growth criteria: The plants were carefully removed from the soil and thoroughly washed by tap water followed by distilled water. The shoots were separated from the roots and the lengths of both shoots and roots were measured and recorded. The fresh weights of shoots and roots were also determined and recorded. The shoots and roots were then put in a hot air oven at 70° C for 48 hours until a constant weight has been reached. The dry weights were then measured and recorded. The dried tissues were ground, passed through a 2 mm sieve and kept in paper bags for analysis. The water content of the different plant tissues was calculated as a percentage of the fresh weight by the equation:

Water content= [(fresh weight-dry weight)/fresh weight]*100

Soil sampling and extraction: A composite soil sample was taken from the cultivated soil, air-dried, ground and passed through a 2 mm sieve and kept for analysis. The pH was measured in 1:2.5 soil-water suspensions by pH-meter according to Black (1965). A soil sample was subjected to wet digestion by Diethylenetriamine pentaacetic acid (DTPA) and used for the determination of the contents of Zn, Cu, Fe and Ni (FAO, 2008). A soil-water extract was prepared by stirring 10 g of soil in 25 ml of distilled water for 30 minutes and then filtration through Wahatman no.2 filter paper. The resulted extract was used for the determination of water soluble calcium and magnesium according to FAO (2008) and water soluble potassium according to Weil and Brady (2017).

Estimation of Minerals

Extraction: A known weight of the dried tissue material was put in 10 ml of distilled water, which was

boiled in water bath for 2 hours. After cooling, the solution was filtered and then diluted to a definite volume. Samples of this solution were taken for Ca^{++}, Mg^{++}, Na^{+}, K^{+} and Zn^{++} determination and the data were expressed as m/g dry matter.

Estimation of Potassium and Sodium: Potassium and Sodium were estimated by the Flamephotometer method (Williams and Twine, 1960) using Carl Zeiss flamephotometer.

Estimation of Calcium and Magnesium: The versene (disodium dihydrogen ethylene-diamine-tetra acetic acid) titration method (Schwarzenbach and Biedermann, 1948) was employed for calcium and magnesium determination.

Determination of calcium concentration: Two ml of 10 % KOH solution was added to 5 ml of the plant or soil extract followed by 0.1 g of muroxide indicator powder. The amount of Ca^{++} in the solution was determined by titration against 0.005 N versene solution until purple end point is obtained (at this point one ml of used 0.005 N versene corresponds to 0.1 mg Ca^{++}).

Determination of calcium plus magnesium concentration: Five ml of ammonium buffer were added to 5 ml of the plant or soil extract. 2-4 drops of erichrome black T indicator were added. To eliminate the interference of copper and zinc, if present, one ml of Na_2S was added. The amount of calcium plus magnesium in the solution was then determined by titration against 0.005 N versene solution to a bright blue end point. The amount of Mg^{++} in the sample was calculated by subtracting the amount of calcium from that of calcium plus magnesium. In this estimation, 1 ml of the used 0.005 N versene solution corresponds to 0.06 mg magnesium.

Estimation of Zinc: The extracts of root and shoot tissues of the controls and the tissues treated by the medium zinc concentration (5mM) and the highest zinc concentration (25mM) were analyzed for the concentrations of zinc ions. The determination of zinc contents was performed at the Lab of Soils and Water Analysis in the Faculty of Agriculture, Minia University using the GPC 902 atomic absorption spectrophotometer and was represented as µg g^{-1} tissue dry weight. Soil contents of Zn, Cu, Fe and Ni were also estimated and expressed as µg g^{-1} soil.

Measurements of Zn accumulation: The accumulation of ZN in plant tissues, total Zn accumulation and distribution proportion of Zn in roots were calculated according to Fang et al. (2017) as follows:

Zn accumulation= biomass (DW) * Zn concentration in plant tissues,

Total Zn accumulation = Zn accumulation in root + Zn accumulation in shoot,

Zinc distribution proportion in root = Zn accumulation in root/total Zn accumulation

The translocation factor (TF) was calculated according to Amin et al. (2018) as follows:$TF = Zn_s/Zn_r$

Where Zn_s and Zn_r represent the Zn concentration in shoot and root, respectively.

Estimation of soluble carbohydrates: The soluble carbohydrates were determined by the classical anthrone sulfuric method (Fales, 1951; Schlegel, 1956) and were expressed as mg g^{-1} dry weight. The anthrone sulphoric acid reagent consists of 0.2 g anthrone in100 ml of concentrated H_2SO_4 (D = 1.84). This reagent must be always freshly prepared. One ml of the plant tissue extract was mixed with 4 ml anthrone reagent, heated at 100°C in water bath for 7 minutes and directly cooled under tap water. The developed blue green color was measured at wavelength of 620 nm against a blank. A calibration curve using pure glucose was constructed. The carbohydrates content was calculated as mg/g dry weight of the plant organ.

Estimation of soluble proteins: The total proteins were determined according to the method of Lowery et al. (1951).

Reagents: Reagent A (2% Na2CO3 in 0.1 N NaOH)**,** Reagent B (0.5% CuSo4 in 1% sodium-potassium tartarate)**,** the alkaline reagent solution (consists of 50 ml of reagent A and 1 ml of reagent B- should always be freshly prepared).

Procedures: Five ml of the alkaline reagent solution were added to 1 ml of the plant extract and were mixed thoroughly and allowed to stand at room temperature for 10 minutes. Then 0.5 ml of the diluted Folin-ciocalteau reagent (1:1 v/v) was added to the above mixture, and mixed immediately. After 30 minutes, the samples were measured against a blank at 700 nm. A calibration curve was constructed using albumin and the data were expressed as mg protein g^{-1} dry weight.

Statistical Analysis: The triplicate sets of the experimental data for the different tested parameters were subjected to the one-way analysis of variances (ANOVA) test in accordance with the experimental design using the SPSS program, version 20.0 and the means were compared using the least significant differences, L.S.D. at P level of 0.05.

RESULTS AND DISCUSSION

The cultivated soil was clay in texture and highly alkaline (pH=8.43). Some of the soil chemical properties are represented in table (1). This work studies the effect of increasing soil Zn concentrations on the two wheat cultivars Gemmyza 10 and Sakha 94. The data of different growth criteria for both roots and shoots are represented in tables 2 and 3, respectively

and reveal that growth of both roots and shoots of cultivar Gemmyza 10 is stimulated by high Zn concentrations while the cultivar Sakha 94 was, on the contrary, sensitive and showed reduced growth at the same high Zn levels. Exposure of plants to Zn has been reported to affect root and shoot growth parameters, including root and shoot lengths, fresh weights and dry weights which are all considered very sensitive parameters used as indicators to the response of plants towards Zn resistance and toxicity. The degree of these effects are dependent on soil Zn concentrations, plant species, genotype and also plant tissue (Kumar et al., 2012, Shakir et al., 2020). El-Dahshouri et al. (2017) worked on the effect of foliar application of Zn on the sandy soil-cultivated wheat cultivar Sakha 94, which is studied in this work, and the wheat cultivar Gemmyza 9 from the same line of the other cultivar in this work, Gemmyza 10. The results of the present work are in agreement with the results of El-Dahshouri et al. (2017) despite of the difference in the mode of Zn application and the type of cultivated soil. They also recorded highly significant differences between the two cultivars Sakha 94 and Gemmyza 9 in their response to Zn treatment with cultivar Gemmyza 9 recording better growth and yield components than Sakha 94 for almost all of the measured parameters under Zn treatment, which is also in accordance with the results obtained by the present work. The soil in their work was sandy soil with low Zn content (around 0.6 µg g^{-1} soil) while the soil in the present work is clay soil with a Zn content of 6.9 µg g^{-1} soil which is, according to Wani et al. (2013), within the Zn range suitable for cultivation as it is above the critical soil Zn level (0.6 µg g^{-1} soil) and below the maximum permissible soil Zn level (300 µg g^{-1} soil). However, the two wheat cultivars tested in this work recorded growth stimulation in most cases with increasing soil Zn concentration, which suggests the importance of Zn fertilization even in clay fertile soils.

Interestingly, on comparing the different growth criteria of the two cultivars at the control level and even at the lowest used Zn concentration, cultivar Sakha 94, which is sensitive to high Zn concentrations, recorded much higher values at all of the measured growth parameters. For example, the roots and shoots fresh weights at the level of control were 0.27 and 0.73 g for the roots and 1.4 and 2.5 g for the shoots in cultivars Gemmyza 10 and Sakha 94, respectively. This suggests that cultivar Sakha 94 is superior for growing in soils with relatively low Zn concentrations while the other cultivar, Gemmyza 10, gives better growth in soils with high Zn levels or under Zn fertilization. This also confirms the importance of appropriate selection of the cultivated cultivar in relation to the cultivated soil conditions.

Table 1. Some physicochemical characteristics of the cultivated soil

Soil texture	Soil pH	Macronutrients (mg g^{-1} soil)			Micronutrients (µg g^{-1} soil)			
		Ca	Mg	K	Zn	Fe	Cu	Ni
clayey	8.43	0.9	0.34	0.1	6.9	6.1	1.55	6.6

Table 2. Effect of different zinc concentrations on the root length (cm), root fresh and dry weights (g) and water contents (as % of fresh weight) of the wheat cultivars Gemmyza 10 and Sakha 94

cv.	Conc.	Root Length	% of control	Root f.w.	% of control	Root d.w.	% of control	Root water content	% of control
Gemmyza 10	Control	11.3±0.61	100	0.27±0.03	100	0.16±0.01	100	0.41±0.06	100
	2mM	11.5±0.58	101.77	0.27±0.06	100	0.15±0.02	93.75	0.44±0.05	107.32
	5mM	11.6±0.74	102.65	0.33±0.05*	122.22	0.16±0.02	100	0.52±0.08*	126.83
	10mM	12.2±0.63*	107.97	0.34±0.05*	125.93	0.15±0.01	93.75	0.56±0.08*	136.59
	25mM	14.3±0.48*	126.54	0.36±0.04*	133.33	0.16±0.02	100	0.44±0.06	107.32
Sakha 94	Control	11.7±0.57	100	0.73±0.09	100	0.16±0.03	100	0.78±0.09	100
	2mM	14±0.56*	119.66	0.91±0.08*	124.66	0.16±0.02	100	0.82±0.1	105.13
	5mM	13.8±0.88*	117.95	0.87±0.05*	119.18	0.17±0.02	106.25	0.81±0.09	103.85
	10mM	13.3±0.72	113.68	0.5±0.03*	68.49	0.19±0.01	118.75	0.62±0.07*	79.49
	25mM	12.8±0.68	109.40	0.4±0.05*	54.79	0.18±0.02	112.5	0.55±0.06*	70.51

* Significant differences as compared to the absolute control

Roots fresh weights showed varying responses to Zn treatment while root dry weights were almost identical in both cultivars under the varying tested Zn concentrations (around 0.16 g). Thus, the differences in root fresh weights were attributed to differences in roots water contents rather than dry matter yields. On the other hand, shoots of both cultivars under the different treatments recorded identical water contents and differences in fresh weights were corresponded by similar differences in dry weights.

Thus, the highly significant root fresh weight of control plants in cultivar Sakha 94 resulted mainly from highly significant water content. The success in the manipulation of water absorption in the control plants of this cultivar may be connected to the general higher growth of both shoots and roots of the Sakha 94 control plants in comparison with the other cultivar. Water absorption in the plants of this cultivar, Sakha 94, is troubled under Zn treatment which might be one of the reasons of the sharp reduction in the roots fresh weights.

The biphasic effect of Zn on wheat plants was reported by many authors. For example, El Rasafi et al. (2016) studying the effect of heavy metals on seed germination and early wheat seedling stage reported that low doses (10-100mg l^{-1}) of Zn better stimulated the growth of wheat, while the higher doses were highly toxic, particularly to roots. This was recorded in several growth parameters, including roots and shoots lengths. Also the results obtained by Liu et al. (2019) who studied Zn application on winter wheat found that application of Zn (11.4 kg ha^{-1}) significantly increased dry weights of roots among other root growth parameters while higher rates of applied Zn caused slight decreases in these root parameters. The biomass and Zn accumulation in shoots increased as Zn application rate increased due to improved root growth and enhanced availability of Zn in soil. Their study suggested Zn fertilization in order to obtain high yield and grain Zn concentration of wheat (Liu et al., 2019). Similar results were previously reported in other studies for *Zea mays* (Ernest et al., 2014), *Cicer arietinum* L. (Sharma et al., 2010) and *Medicago sativa* L. (Peralta et al., 2001).

The present work also recorded that wheat roots were more sensitive to Zn treatment than shoots. This finding is in accordance with the results obtained by many authors including El Rasafi et al. (2016) and Lingua et al. (2008) who found that roots were inhibited by 70%, while shoots were reduced only by 50% in the presence of Zn. Zinc treatment in this work reduced the roots fresh weights of cultivar Sakha 94 by 45% in comparison with only 23% reduction in the fresh weights of the shoots of the same cultivar. Roots are the first plant organs that are subjected to soil pollutants, so they are more sensitive to metal toxicity than shoots (DalCorso et al., 2019, Huang et al., 2020, Shakir et al., 2020). The inhibition of shoots and roots elongation resulted from heavy metals treatment may be due to their influence on cell division (Hargemeyer, Breckle, 1996) or cell wall elasticity and metabolic activities (Naseer et al., 2001).

Table 3. Effect of different zinc concentrations on the shoot length (cm), shoot fresh and dry weights (g) and water contents (as % of fresh weight) of wheat cultivars Gemmyza 10 and Sakha 94

cv.	Conc.	Shoot Length	% of control	Shoot f.w.	% of control	Shoot d.w.	% of control	Shoot water content	% of control
Gemmyza 10	Control	13.8±0.5	100	1.4±0.28	100	0.21±0.07	100	0.85±0.05	100
	2mM	14.7±0.38	106.52	1.8±0.13*	128.57	0.23±0.06	109.52	0.87±0.07	102.35
	5mM	15±0.42	108.7	1.8±0.18*	128.57	0.23±0.1	109.52	0.87±0.04	102.35
	10mM	16.8±0.36*	121.74	2.3±0.21*	164.29	0.29±0.08*	138.1	0.87±0.03	102.35
	25mM	15.3±0.29	110.87	2.2±0.17*	157.14	0.28±0.11*	133.33	0.87±0.04	102.35
Sakha 94	Control	16.3±0.40	100	2.5±0.09	100	0.30±0.03	100	0.88±0.06	100
	2mM	16.8±0.32	103.07	2.7±0.12	108	0.30±0.05	100	0.89±0.05	101.14
	5mM	16.5±0.36	101.23	2.4±0.11	96	0.28±0.04	93.33	0.88±0.07	100
	10mM	14±0.52*	85.89	1.83±0.2*	73.2	0.26±0.02*	86.67	0.86±0.05	97.73
	25mM	14.3±0.48*	87.73	1.93±0.18*	77.2	0.26±0.03*	86.67	0.87±0.04	98.86

* Significant differences as compared to the absolute control

Table 4. Effect of different zinc concentrations on the root and shoot contents of soluble carbohydrates and soluble proteins (mg /g dry weight) of the seedlings of the wheat cultivars Gemmyza 10 and Sakha 94

cv.	Conc.	Root Soluble carb.	% of control	Shoot soluble carb.	% of control	Root Soluble proteins	% of control	Shoot soluble proteins	% of control
Gemmyza 10	Control	68.6±4.27	100	31.5±1.92	100	3.11±0.18	100	7.27±0.48	100
	2mM	72.6±3.78	105.83	36.8±2.18*	116.83	3.54±0.15	113.83	7.8±0.39	107.29
	5mM	94.9±5.68*	138.34	40.3±2.34*	127.94	4.12±0.21*	132.48	8.35±0.56	114.86
	10mM	92.5±5.23*	134.84	48.1±2.5*	152.70	3.98±0.23*	127.97	9.46±0.72*	130.12
	25mM	64.7±4.51	94.31	26.9±1.86*	85.40	4±0.34*	128.62	9.26±0.68*	127.37
Sakha 94	Control	91.2±6.24	100	25.1±1.74	100	3.2±0.28	100	6.5±0.51	100
	2mM	67.1±4.92*	73.57	27.8±1.95*	110.76	3.4±0.19	106.25	6.7±0.38	103.08
	5mM	68.6±4.15*	75.22	26.0±1.06	103.59	3.57±0.2	111.56	8.3±0.52*	127.69
	10mM	43.2±3.29*	47.37	25.8±1.14	102.79	3.78±0.19*	118.13	9.3±0.74*	143.08
	25mM	32.8±2.18*	35.96	16.4±0.98*	65.34	4.11±0.25*	128.44	9.2±0.82*	141.54

* Significant differences as compared to the absolute control

The effect of different Zn treatments on the contents of soluble carbohydrates and soluble proteins in roots and shoots of the two studied cultivars are represented in table 4. Both cultivars accumulated more soluble proteins in their roots and shoots as a result of Zn treatment. Their shoot contents of soluble carbohydrates were also parallel to each other, with Sakha 94 having general lower values. The only difference between the two cultivars was recorded in the roots soluble carbohydrates which were accumulated significantly in the roots of Gemmyza 10 with increasing Zn treatments, while dropped sharply in Sakha 94.

The recorded stimulation in proteins synthesis could play a role in the adaptation of these wheat cultivars to increasing Zn levels in soil. This is in agreement with Jayasri and Suthindhiran (2017) who stated that plant exposure to heavy metals could induce synthesis of proteins related to stress to overcome the heavy metal stress effects which result in increasing protein content. Higher contents of soluble proteins have also been observed in salt tolerant cultivars of barley, sunflower, finger millet, and rice (Parvaiz and Satyawati, 2008). These results are also in agreement with Akram et al. (2017) who found a strong correlation between N and Zn in wheat plants. Levels of Zn played an important role in stimulating protein contents in grains as Zn is an indispensable nutrient for N metabolism due to its catalytic influence on numerous enzyme systems, biochemical activities responsible for nitrate reduction and protein synthesis (Akram et al., 2017, Hasan et al., 2017).

Table 5. Effect of different zinc concentrations on the root contents of calcium, magnesium, sodium and potassium (mg/g dry weight) of the wheat cultivars Gemmyza 10 and Sakha 94

cv.	Conc.	Ca	% of control	Mg	% of control	Na	% of control	K	% of control
Gemmyza 10	Control	11.25±0.82	100	4.5±0.14	100	14.25±0.95	100	31.13±1.54	100
	2mM	11.25±0.78	100	9±0.21*	200	15±1.01	105.26	32.63±1.81	104.82
	5mM	11.25±0.91	100	6.75±0.4*	150	14.63±0.89	102.67	33±1.68	106.01
	10mM	13.5±0.84*	120	5.62±0.27*	124.89	13.5±0.87	94.74	30.75±1.39	98.78
	25mM	9.75±0.76	86.67	5.4±0.21*	120	15.38±0.97	107.93	33±2.08	106.01
Sakha 94	Control	7.5±0.61	100	6.75±0.34	100	15.38±0.82	100	28.5±1.75	100
	2mM	8.25±0.52	110	4.95±0.29*	73.33	13.5±0.79	87.78	27.75±1.91	97.37
	5mM	9±0.58*	120	4.5±0.25*	66.67	13.5±0.62	87.78	29.25±1.65	102.63
	10mM	9.75±0.71*	130	4.3±0.27*	63.70	13.13±0.85*	85.37	30.75±2.04	107.89
	25mM	8.25±0.68	110	4.05±0.19*	60	12.75±0.69*	82.90	31.5±1.98*	110.53

* Significant differences as compared to the absolute control

Table 6. Effect of different zinc concentrations on the shoot contents of calcium, magnesium, sodium and potassium (mg/g dry weight) of the wheat cultivars Gemmyza 10 and Sakha 94

cv.	Conc.	Ca	% of control	Mg	% of control	Na	% of control	K	% of control
Gemmyza 10	Control	12.75±0.98	100	5.85±0.38	100	4.13±0.24	100	46.88±2.88	100
	2mM	13.5±1.1	105.88	6.3±0.42	107.69	4.5±0.29	108.96	50.25±1.93	107.19
	5mM	15±1.28*	117.65	5.2±0.29*	88.89	4.88±0.19*	118.16	48.75±2.48	103.99
	10mM	12.75±0.87	100	4.25±0.15*	72.65	4.5±0.11	108.96	52.88±3.1*	112.80
	25mM	11.25±0.79*	88.24	3.95±0.17*	67.52	4.5±0.26	108.96	47.25±2.07	100.79
Sakha 94	Control	9±0.56	100	2.25±0.20	100	4.88±0.19	100	48.38±1.98	100
	2mM	11.25±0.71*	125	3.15±0.21*	140	4.5±0.15*	92.21	46.5±2.15	96.11
	5mM	11.25±0.64*	125	5.85±0.35*	260	4.31±0.18*	88.32	45.38±1.56	93.80
	10mM	13.5±0.82*	150	4.95±0.28*	220	4.5±0.21*	92.21	45±1.42	93.01
	25mM	11.25±0.69*	125	4.5±0.37*	200	3.94±0.14*	80.74	45.75±1.85	94.56

* Significant differences as compared to the absolute control

Zn application is correlated to the plant tissue levels and utilization of other minerals since micronutrients can increase macronutrients use efficiency and results in sub-optimal nutrient-use efficiency (Brown et al., 1993). Loss of membrane integrity and increase in membrane permeability are very common in Zn-deficient plants (Cakmak, 2000). Therefore, the contents of Ca, Mg, Na and K of the two wheat cultivars under the different treatments in both roots and shoots are estimated and are represented in tables 5 and 6, respectively.

The general values of the four cations are, in most cases, generally higher in the Zn-resistant cultivar Gemmyza 10, even at the control level. For the Na and K contents, Zn treatment had no significant influence in most cases in either roots or shoots of the two cultivars with general tendency towards slight improvement in Gemmyza 10 and slight reduction in Sakha 94. Calcium contents increased in both roots and shoots of the two wheat cultivars under Zn treatment, except for the highest applied Zn concentration. On the other hand, an obvious disturbance was observed in the absorption and accumulation of Mg in response to adding Zn to the soil. With increasing Zn in the soil, Gemmyza 10 accumulated more Mg in its roots and less Mg in its shoots. The opposite was observed in the cultivar Sakha 94. The antagonism between Zn and divalent cations, particularly Mg is widely reported. As an example, Zinc toxicity is known to induce chlorosis in young leaves, and this has been suggested to result from a Zn-induced Fe or Mg deficiency, based on the fact that the three metals have similar ion radii (Marschner, 1995).

With increasing Zn concentration in the soil, the roots of cultivar Gemmyza 10 (the resistant cultivar) absorbed increasing amounts of both Mg and Zn. There was no competition between these two elements in the root tissues of this cultivar. In the shoots of this cultivar, the Zn contents also increased significantly with increasing Zn in the soil while the Mg contents decreased. Despite the reduction of Mg in the shoots of Gemmyza 10, the yield of these shoots was enhanced by increasing soil Zn level, which may suggest some compensation mechanism.

Table 7 shows the concentrations of Zn in the roots and shoots in µg g^{-1} tissue dry weight of the two tested cultivars as well as the Zn translocation factors from roots to shoots under the influence of Zn treatment. As expected, Zn contents in roots and shoots of the two cultivars increased with increasing Zn concentration in the soil. This increase in Zn contents was more pronounced in roots than in shoots for both cultivars. At all levels, including control level, tissues of Gemmyza 10 recorded higher Zn contents in comparison with Sakha 94. With increasing Zn level in the soil and increasing Zn contents in plant tissues, particularly in roots, the Zn translocation factor from roots to shoots dropped significantly in both cultivars, particularly in Sakha 94. According to Liu et al. (2019), very few studies investigated the correlation between fertilizer Zn doses and root-to-shoot Zn translocation efficiency under field conditions.

The total Zn accumulation in roots, shoots and whole plants as calculated in relation to dry weight as well as the Zn distribution proportion in roots are represented in table 8. In cultivar Gemmyza 10, total Zn accumulation in roots and shoots increased with Zn treatment in similar values, therefore, the root Zn distribution proportion was around 0.5 for all treatments in this cultivar, meaning that the accumulated Zn was distributed equally between roots and shoots. On the other hand, Zn treatment of cultivar Sakha 94 resulted in increasing Zn accumulation in roots while Zn accumulation in shoots was not changed. Therefore, the Zn distribution proportion in roots of cultivar Sakha 94 increased with Zn treatment, meaning that Zn tends to accumulate in roots more than in shoots of this cultivar.

It is noteworthy that all of the measured and calculated parameters concerning Zn contents within this study were much higher in the Zn resistant cultivar Gemmyza 10 than the Zn sensitive Sakha 94, even at the level of control in which Sakha 94 plants recorded better growth. This could indicate that Sakha 94 plants are genetically adapted to more efficient Zn utilization, therefore, they showed better growth at low Zn levels while suffered from Zn toxicity when soil Zn concentrations were raised. The low content of Zn in Sakha 94 plants in comparison with Gemmyza 9 plants is recorded in the work of El-Dahshouri et al. (2017). Cakmak et al. (1994) recorded that a Zn-inefficient durum wheat cultivar exhibited Zn-deficiency symptoms earlier and more intense than a Zn-efficient bread wheat cultivar even though the tissue Zn concentrations were similar in both lines, suggesting differential utilization of Zn in the two cultivars. Also Mathpal et al. (2015) stated that the two wheat cultivars UP262 and UP2628 showed similar accumulation of 65Zn in leaves; however, UP2628 exhibited better translocation efficiency and higher 65Zn accumulation in stem and grains than UP262. In the current study, cultivar Sakha 94 failed to export the increased amounts of absorbed Zn from roots to shoots which is recorded in the results of lower translocation factor, lower shoot Zn accumulation and higher root Zn distribution proportion in this cultivar. This failure may also have played a role in the reduced growth of Sakha 94 plants under Zn treatment.

Table 7. Effect of different zinc concentrations on the root and shoot contents of zinc (µg/g dry weight) and translocation factor (TF) of the wheat cultivars Gemmyza 10 and Sakha 94

cv.	Conc.	Root Zn (µg/g d.w.)	% of control	Shoot Zn (µg/g d.w.)	% of control	TF	% of control
Gemmyza 10	Control	21.75±1.21	100	17.5±0.95	100	0.81±0.03	100
	5mM	26.25±1.83*	120.69	19.88±0.87	113.6	0.76±0.05	93.83
	25mM	42.38±2.27*	194.85	22.5±1.03*	128.57	0.53±0.04*	65.43
Sakha 94	Control	13.13±0.86	100	10.88±0.07	100	0.83±0.06	100
	5mM	18.75±0.92*	142.80	11.42±0.06	104.96	0.61±0.04*	73.5
	25mM	31.13±1.15*	237.09	13.13±0.08*	120.68	0.42±0.02*	50.6

* Significant differences as compared to the absolute control

Table 8. Effect of different zinc concentrations on the root and shoot total Zn accumulation (µg/root or shoot), total plant Zn accumulation (µg/plant) and Zn distribution proportion in roots of the wheat cultivars Gemmyza 10 and Sakha 94

Cultivar	Conc.	Root total Zn accumulation	% of control	Shoot total Zn accumulation	% of control	Total Plant Zn accumulation	% of control	Zn distribution proportion in roots	% of control
Gemmyza 10	Control	3.48±0.12	100	3.68±0.17	100	7.16±0.48	100	0.49±0.03	100
	5mM	4.2±0.21	120.69	4.57±0.19	124.19	8.77±0.62*	122.49	0.48±0.03	97.96
	25mM	6.78±0.34*	194.83	6.3±0.25*	171.2	13.08±0.85*	182.68	0.52±0.04	106.12
Sakha 94	Control	2.1±0.09	100	3.26±0.21	100	5.36±0.38	100	0.39±0.02	100
	5mM	3.19±0.14*	151.91	3.2±0.25	98.16	6.39±0.47*	119.22	0.50±0.04*	128.21
	25mM	5.6±0.35*	266.67	3.41±0.19	104.6	9.01±0.71*	125.84	0.62±0.05*	158.97

* Significant differences as compared to the absolute control

CONCLUSION

The results of this work can be concluded in the following points:

- Adding zinc to soil can enhance the growth of wheat plants, even with clay soils in which zinc contents are within normal ranges.
- Cultivar Gemmyza 10 recorded highly significant growth stimulation under Zn treatment, particularly at the 10 mM Zn concentration.
- Cultivar Sakha 94 is sensitive to high zinc concentrations and recorded growth inhibition when treated by Zn levels beyond 2 mM Zn.
- Cultivar Sakha 94 recorded better growth under control conditions, so it could be more suitable for cultivation in soils whose Zn contents are not very high.

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الملخص العربي

دراسة مقارنة لتأثير التخصيب بالزنك على سلالتين من نبات القمح *Triticum aestivum*

خلود ناجي شاكر

يعتبر الزنك من المغذيات الصغرى الأساسية لنمو النباتات وتعاني مساحات كبيرة من الأراضي الزراعية من نقص في هذا العنصر الهام مما يؤثر على النمو والإنتاجية للعديد من المحاصيل. وتعد محاولات زيادة نسبة هذاالعنصر في المحاصيل الأكثر استهلاكا مثل القمح من التوجهات التي تطمح إلى زيادة إنتاجية هذه المحاصيل وكذلك تحسين الصحة العامة للمستهلكين وبخاصة في الدول النامية حيث يعتمد النظام الغذائي بصفة كبيرة على الحبوب. تختلف السلالات المختلفة في استجابتها للمعاملة بالعناصر المعدنية مما يفرض اختيار السلالة المناسبة للزراعة تحت الظروف الزراعية المختلفة. في هذا البحث تم دراسة نمو سلالتين من القمح (جميزة ١٠ و سخا ٩٤) تحت تركيزات مختلفة من الزنك المضاف إلى التربة (٢, ٥, ١٠, ٢٥ مللي مولار من الزنك). تم قياس عدد من دالات النمو لكل من الجذر والساق مثل الطول والوزن الرطب والوزن الجاف والمحتوى المائي. كذلك تم تقدير محتوى الجذر والساق للنباتات المختلفة من بعض العناصر المعدنية (الكالسيوم والماغنيسيوم والبوتاسيوم والزنك), كما تم حساب معامل انتقال الزنك من الجذر إلى الساق وتراكم الزنك في الجذر والساق والنبات الكامل وكذلك نسبة توزيع الزنك في جذور النباتات المختلفة. كما تم أيضا تقدير نسبة السكريات والبروتينات الذائبة في الجذور والسيقان للنباتات محل الدراسة. أظهرت النتائج أن السلالة جميزة ١٠ قد سجلت نموا أفضل عند المعاملة بالتركيزات المرتفعة من الزنك مع تحسن واضح في الحالة الفسيولوجية للنباتات, كما تميزت نباتات هذه السلالة بالتوزيع المتكافئ للزنك بين الجذور والسيقان. السلالة الأخرى (سخا ٩٤) سجلت نموا أفضل في ظروف الكنترول وتعرض هذا النمو للتثبيط التدريجي مع زيادة تركيز الزنك في التربة مع اضطراب في الحالة الفسيولوجية للنباتات وتركز الزنك في الجذور على حساب السيقان. تؤكد هذه النتائج على اختلاف استجابة السلالتين للمعاملة بالزنك وترجح إضافة الزنك إلى التربة عند زراعة السلالة جميزة ١٠ وبخاصة التركيز ١٠ مللي مولار لتحسين النمو والحالة الفسيولوجية للنباتات. السلالة سخا ٩٤ على الجانب الآخر مناسبة للزراعة في التربة ذات المحتوى المنخفض من الزنك ولا يجب استخدام التسميد بالزنك عند زراعة هذه السلالة نظرا لحساسيتها للتركيزات المرتفعة من هذا العنصر.