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The Impact of Minerals on Wheat Plants Grown under Salinity Stress

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Abstract

The present work has been conducted to study the impact of Zn (20 and 200 μM) or Ni (1 and 100 μM) on growth, metabolic activities, osmotic pressure and heavy metal of wheat cultivar (cv. Gimiza 11) under salt stress conditions. Harvest index was significantly decreased by 75% at −0.3 MPa and −1.2 MPa decreased by 53%. Length of root, stem and spike, and leaf area were slightly reduced up to −0.9 MPa NaCl level, after that a significant reduction was recorded. Total sugar was increased in the shoot and spike, while decreased in the root with increasing salinity levels. On the other side, total protein was increased in the shoot while decreased in both the root and spike. Osmotic pressure was increased as increasing salinity levels. Treatment of wheat plants with Zn or Ni alleviated generally salt injury in the harvest index, length of root, shoot and spike and leaf area. This effect was more obvious with Zn treatments. Mineralization treatments increased total sugar in the three tested organs while did not change the total protein. Zn content was increased at −1.2 MPa level while Ni was decreased. Treatments with Zn or Ni mostly increased Zn while causing a reduction in the Ni content. These treatments also increased the values of osmotic pressure compared with the equivalent levels of control plants.

Keywords

Osmotic Stress, Wheat, Zn, Ni, Tolerant, Sensitive

1. Introduction

Wheat plant is a cereal grain, which is the best of the cereal foods because it provides more nourishment for humans than any other food source [1]. Salt stress is abiotic stress that can affect plant growth, physiological and biochemical activi-

ties such as photosynthesis process and chlorophyll content [2] [3]. Many studies were reviewed the physiological and molecular mechanisms of tolerance to osmotic and ionic components of salinity stress; these studies were reviewed at the cellular, organ, and whole-plant level. Plant growth responds to salinity in two phases: a rapid and osmotic phase that inhibits the growth of young leaves, and a slower, ionic phase that accelerates senescence of mature leaves [4] [5].

The application of zinc improved growth and biomass yield of rice under saline conditions. Zinc plays an important role to regulate the nutrient balance in rice by regulating the uptake of Na^+ and K^+ and affecting photosynthetic rate [6]. Several studies that related to determining the genotypic potential to survive against salinity were conducted by various authors and documented varietal differences in Zn nutritional uptake during salinity stress but are rather poorly understood [6]. However, studies on soil salinity-Zn interaction in paddy fields are rather scarce for the calcareous soils [7] [8]. Jagetiya *et al.* (2013) [9] studied the effect of Ni on water potential, one μM of Ni treatment increased chlorophyll, turgor potential and decreased osmotic potential of plant cells, so plant growth increased, while at higher concentrations of Ni (10, 100 and 1000 μM) osmotic potential increased inside plant cells, and turgor potential and growth were significantly decreased. Kumar *et al.* (2018) [10] [11] illustrated that foliar application of Ni has higher efficiencies and is preferred over soil application in view of its very low requirement [12].

2. Materials and Methods

2.1. Experimental Sites for Osmotic Stress with Zn or Ni Treatments

This work was conducted to study the effect of different osmotic stress levels as well as the interactive effect of different osmotic stress levels and some micronutrients such as (Zinc and Nickel) on growth and some metabolic activities of wheat cultivar (vegetative growth and crop yield stages). A pot experiment was carried out in open air at the garden of the Faculty of Science-Minia University during winter season. Wheat seeds cultivar Gimiza 11 which were brought from International Research Centre of Agriculture. Wheat plant in Egypt was one of the main crop plants for feeding. Wheat seeds were surface sterilized by immersion in a mixture of ethanol 96% and H_2O_2 (1:1) for 3 minutes, followed by several washings with sterile distilled water. The concentrations of NaCl were chosen after preliminary experiments in which the seeds were subjected to different concentrations of NaCl. Five seeds were sown per pot, each pot contained 100 g of garden clay soil in three replicates. All pots were irrigated with tap water for two weeks until full germination. The seedlings were then irrigated by different concentrations of NaCl solutions (0, −0.6 MPa, −0.9 MPa and −1.2 MPa) in the first group. The previous treatments were repeated with Zn 20 μM in the form $ZnSO_4$ in the second group, another group for Zn 200 μM, another group for 10 μM Ni and later one for 100 μM Ni.

2.2. Laboratory Analysis for Growth Parameters

Wheat plants were grown under these conditions for 120 days. Harvest index was determined by the following equation: Harvest index = (wt. of spike/total wt. of shoot) [13]. Leaf area (cm^2 $plant^{-1}$) was determined by measuring the leaf length and the maximum width and applying the formula:

$$\text{Leaf area} = k\,(\text{leaf length} \times \text{leaf maximum width}), \text{ where } (K = 0.75).$$

The coefficient k was calculated and assigned different values for different grasses [14] [15] and recently reviewed and given a value of 0.75 for monocot.

2.3. Laboratory Analysis for Metabolities

Total sugar was determined by using anthrone-sulfuric acids method in water extracted sample [16]. Total protein contents were measured according to Lowry *et al.* (1951) [17] in also water extracted samples. Osmotic pressure was measured by Osmometer in plant water extract.

3. Statistical Analysis

The experimental data were subjected to the one way analysis of variances (ANOVA test) using the SPSS version 11.0 to quantify and evaluate the source of variation and the means were separated by the least significant differences, L.S.D. a.t P level of 0.05% [18]. Experimental data were subjected to one way analysis of variance and the means were separated by the least significant differences, L.S.D. Correlation coefficients were calculated using statgraphics 5.0 software.

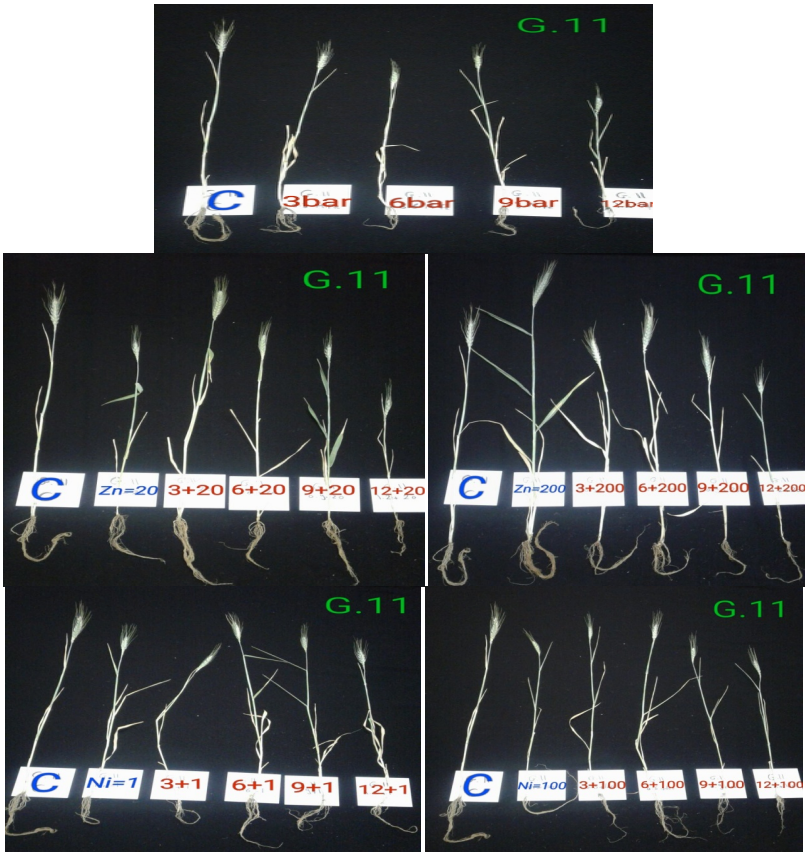
4. Results

4.1. Growth Parameters as Affected by Osmotic Stress and Zn or Ni Treatments

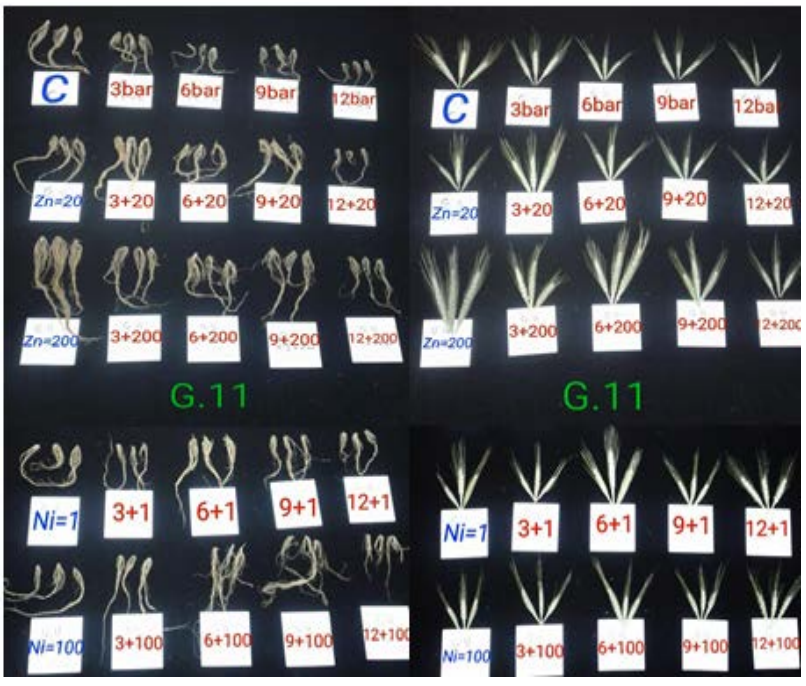
Increasing salinization levels decreased the harvest index of wheat plant until reach a maximum low value at −1.2 MPa (55.4%) compared with control (Table 1 and Figure 1). The length in roots, shoots and spikes was lowered with elevating salinity levels, by 73.8%, 61.5% and 78.4%, respectively at −1.2 MPa level compared to control plants. Leaf area was markedly decreased with increasing salinity stress by 59.5% at −1.2 MPa level (Table 1). Applications of Zn or Ni with low or high concentrations mostly increased the length of root, shoot and spike. Treatments the soil with Zn (20 and 200 μM) or Ni (1 and 100 μM) induced an enhancement effect in the leaf area and harvest index especially at higher salinization levels of wheat plant compared with corresponding level of control plants (Table 1).

4.2. Metabolites as Affected by Osmotic Stress and Zn or Ni Treatments

Total saccharides showed a variable response in the different organs, while tended to decrease in the roots, it have a tendency to accumulate in both shoot and



(a)



(b)

Figure 1. The whole plant (a), the roots, and spikes (b) of wheat grown under different osmotic stress levels alone or with treatment with either Zn (20 and 200 μM) or Ni (1 and 100 μM).

Table 1. Length (cm) in roots, shoots and spikes, leaf area and harvest index of wheat grown under different osmotic stress levels alone or with treatment with either Zn (20 and 200 μM) or Ni (1 and 100 μM).

Treat. (−Mpa)	Length						Leaf area		Harvest Index	
	Root	%	Shoot	%	Spike	%		%	Aver.	%
0.0	20.3	100	13.6	100	51.3	100	15.3	100	1.07	100
0.3	18.0*	88.7	10.1*	74.2	48.6*	94.7	13.6*	88.8	0.808	75.5
0.6	17.3*	85.2	10.1*	74.2	46.0*	89.7	13.3*	86.9	0.635	59.3
0.9	17.3*	85.2	11.6*	85.2	46.3*	90.2	13.5*	88.2	0.592	55.3
1.2	15.0*	73.8	8.0*	58.8	45.0*	87.7	12.0*	78.4	0.571	53.4
Zn (μM) 0.0 + 20	19.0	93.5	21.9*	78.6	45.6*	88.8	15.3	100	0.777	72.6
0.3 + 20	21.3	104.9	21.9*	161.0	56.3*	109.7	15.6	101.9	0.874	81.7
0.6 + 20	18.0*	88.6	24.1*	177.2	50.0	97.7	14.3*	93.4*	0.800	74.8
0.9 + 20	19.6*	96.5	14.0	103.1	50.0	97.4	14.0*	91.5	0.721	67.3
1.2 + 20	10.0*	49.2	10.7*	78.6	30.0*	58.4	12.3*	80.8	0.636	59.4
0.0 + 200	27.6*	135.9	24.1*	177.2	66.6*	129.8	18.3*	119.6	0.804	75.1
0.3 + 200	16.3*	80.2	26.4*	194.1	53.0*	103.3	17.7*	115.7	1.03	96.3
0.6 + 200	16.3*	80.2	19.6*	144.1	54.6*	106.4	17.0*	111.1	0.862	80.6
0.9 + 200	16.6*	81.7	19.6*	144.1	54.6*	106.4	14.0*	91.5	0.756	70.7
1.2 + 200	15.0*	73.8	8.6	63.2	39.0*	76.0	12.3*	80.3	0.660	62.2
Ni (μM) 0.0 + 1	17.0*	83.7	12.0	88.2	50.0	97.4	17.0*	111.1*	0.629	58.9
0.3 + 1	23.0*	113.7	16.6*	122.1	52.8*	102.9	17.7	115.7*	0.750	70.1
0.6 + 1	17.6*	86.6	12.0	88.2	55.6*	108.3	14.3	93.4	0.901	84.2
0.9 + 1	13.3*	65.5	12.0	88.2	54.0*	105.2	14.2	93.4	0.962	89.9
1.2 + 1	11.3*	55.6	10.8*	79.4	47.0*	91.6	14.3	93.4	0.872	81.5
C + 100	21.6*	106.4	13.2	99.2	48.3*	94.1	15.3*	100	0.559	52.2
0.3 + 100	20.0	98.5	13.5	99.2	51.0	99.4	14.3*	93.4	0.545	50.9
0.6 + 100	20.0	98.5	14.0	103.1	54.0*	105.2	14.0*	91.5	0.679	63.5
0.9 + 100	19.6*	96.5	9.3*	68.3	47.0*	91.6	13.3*	86.9	0.600	56.1
1.2 + 100	8.3*	42.5	8.1*	59.5	40.6*	79.1	12.6*	82.3	0.696	65.5
L. S. D. 0.05%	1.2		1.5		1.3		1.7		0.02	

* The mean difference is significant at the 0.05% level.

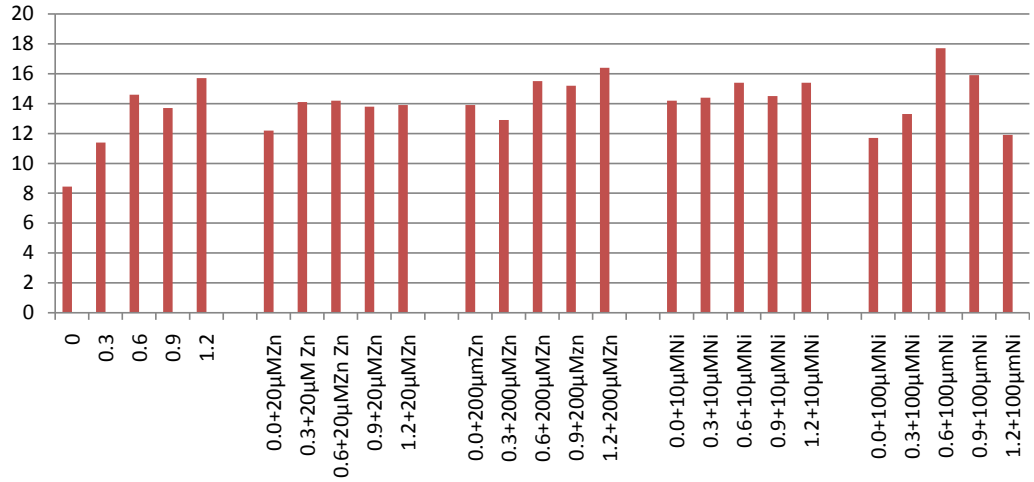
spike of wheat plants (Table 2). Total protein was greatly decreased as salinity stress levels increased in roots and spikes (Table 2). This effect was greatly observed at high osmotic stress levels (−1.2 MPa) by 82.7% and 95.6%, respectively, however there was an increasing effect in shoots by 124.6% compared with control plants. Application of Zn or Ni were significantly enhanced the accumulation of total sugars in the root and shoot while these contents did not change in the

Table 2. Total saccharides (mg·g^{-1} d. m.) and total protein (mg·g^{-1} d. m.) in roots, shoots and spikes of wheat grown under different osmotic stress levels alone or with treatment with either Zn (20 and 200 µM) or Ni (1 and 100 µM).

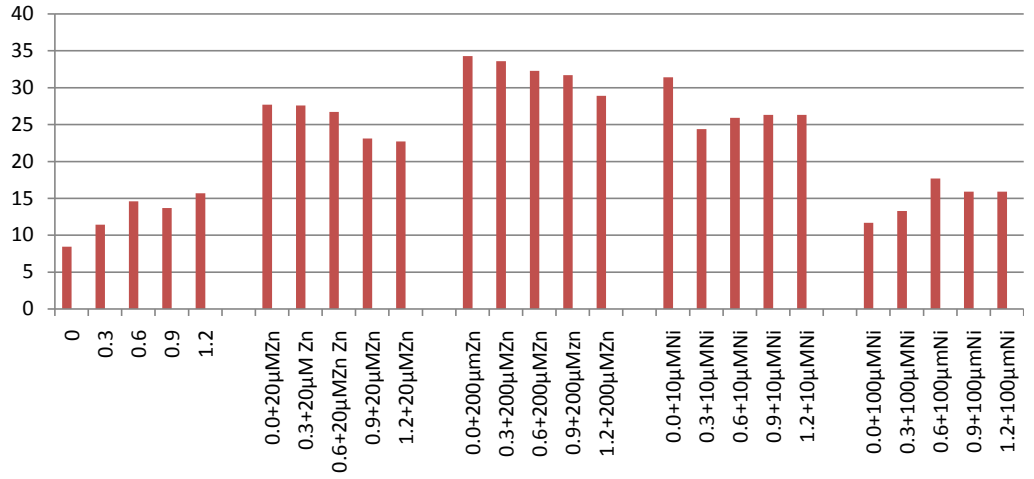
Organ	Total Saccharides						Total Proteins					
	Root		Shoot		Spike		Root		Shoot		Spike	
Treat. (−Mpa)	Aver.	%	Aver.	%	Aver.	%	Aver.	%	Aver.	%	Aver.	%
0.0	99.3	100	80.2	100	106.0	100	99.4	100	90.2	100	141.0	100
0.3	91.1*	91.7	101.3*	126.3	118.6*	111.9	95.4*	95.9	113.2*	125.5	120.8*	85.7
0.6	98.5*	99.2	101.3*	126.3	169.8*	158.9	90.4*	90.9	115.6*	128.2	120.8	85.7
0.9	95.0*	95.7	117.4*	146.4	171.4*	161.7	92.4*	92.9	112.8*	125.1	117.8*	83.5
1.2	91.4*	92.0	70.1*	87.4	181.1*	170.8	82.2*	82.7	112.4*	124.6	117.8	81.5
Zn (µM) 0.0 + 20	119.1*	119.9	91.6*	114.2	65.4*	61.7	73*	73.4	94.2*	104.4	140.0	99.3
0.3 + 20	143.4*	144.4	73.2*	91.3	64.1*	60.5	75.4*	75.9	123.2*	135.3	141.6*	100.4
0.6 + 20	145.3*	146.3	106.5*	132.8	70.0*	66.0	77.8*	78.3	104.0*	115.9	138.6*	91.2
0.9 + 20	152.6*	153.7	116.2*	144.9	92.9*	87.6	79.2*	79.7	103.8*	115.1	138.6*	91.2
1.2 + 20	124.2*	125.1	90.8*	113.2	92.9*	87.6	82.4*	82.9	100.2*	111.1	119.2*	84.5
C + 200	103.6*	102.3	106.5*	132.8	74.8*	70.6	92.4*	92.9	113.0*	125.8	161.0*	114.2
0.3 + 200	133.1*	134.0	111.1*	138.5	92.5*	87.3	85.4*	85.9	104.2*	115..5	136.2*	96.6
0.6 + 200	119.8*	120.6	113.1*	141.1	73.2*	69.1	89.4*	85.9	108.6*	120.4	140.0*	99.3
0.9 + 200	126.9*	127.8	102.5*	127.8	77.7*	73.3	92.6*	93.2	109.0*	120.8	143.2*	101.6
1.2 + 200	103.4*	104.4	95.1*	118.6	77.7*	73.3	94.8*	95.4	110.2*	122.2	151.4*	107.4
Ni (µM) 0.0 + 1	133.1*	134.0	143.6*	179.1	98.4*	92.8	60.6*	60.9	100.0*	110.9	88.0*	62.1
0.3 + 1	158.5*	159.9	183.2*	228.4	89.6*	84.5	84.8*	85.3	109.0*	120.8	91.8*	65.1
0.6 + 1	147.4*	148.4	194.8*	242.9	86.9*	81.9	85.4*	93.9	115.0*	127.5	92.2*	65.3
0.9 + 1	193.4*	194.8	105.2*	131.2	63.4*	59.9	93.4*	93.9	112.2*	124.4	104.6*	74.2
1.2 + 1	157.2*	158.3	100.1*	124.8	63.2*	59.6	90.6*	91.1	104.6*	115.9	114.2*	80.9
0.0 + 100	166.2*	167.4	86.5*	107.9	74.4*	70.2	81.0*	81.5	107.4*	119.1	102.0*	72.3
0.3 + 100	183.7*	184.5	86.2*	107.5	90.6*	85.5	84.8*	85.4	109.4*	121.3	110.8*	78.0
0.6 + 100	170.9*	172.1	107.7*	134.3	74.9*	70.7	94.0*	94.7	112.4*	124.6	126.4*	89.6
0.9 + 100	136.2*	137.2	103.4*	128.9	87.7*	82.7	89.6*	90.1	103.0*	114.2	107.0*	75.9
1.2 + 100	127.8*	128.7	103.4*	128.9	87.7*	82.7	80.4*	80.9	87.4*	96.9	105.4*	74.8
L.S.D 0.05%	0.13		0.12		0.2		0.25		0.11		0.07	

* The mean difference is significant at the 0.05 level.

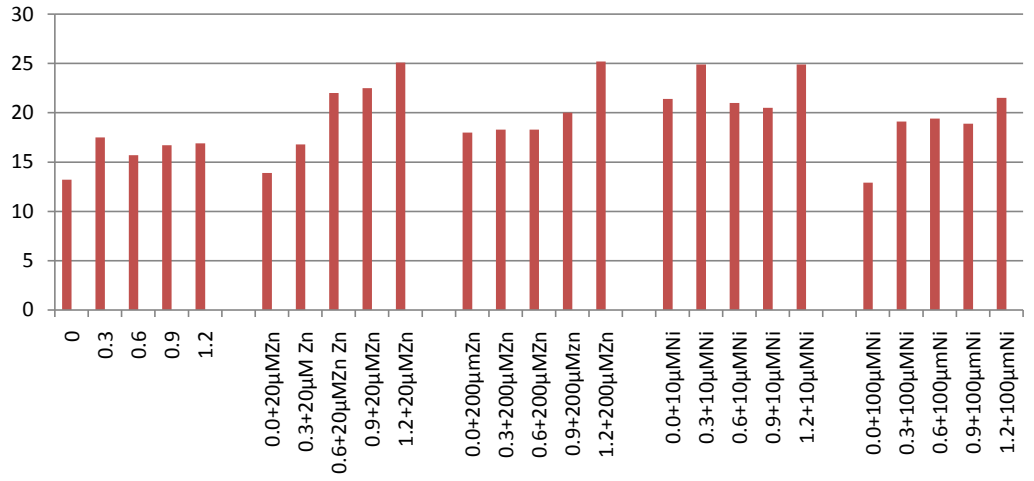
spike compared with the corresponding osmotic stressed plants (Table 2). Generally, the total proteins did not alter in plants exposed to low or high concentrations of Zn or Ni (Table 2). Exclude for this trend total proteins were slightly elevated in plants exposed to salinity stress levels plus 200 µM of Zn (Table 2). Our results indicated that osmotic pressure was increased as increasing salinity levels in root, shoot and spike (Figures 2(a)-(c)). Treatments with Zn or Ni



(a) L.S.D. 0.05%: 0.26



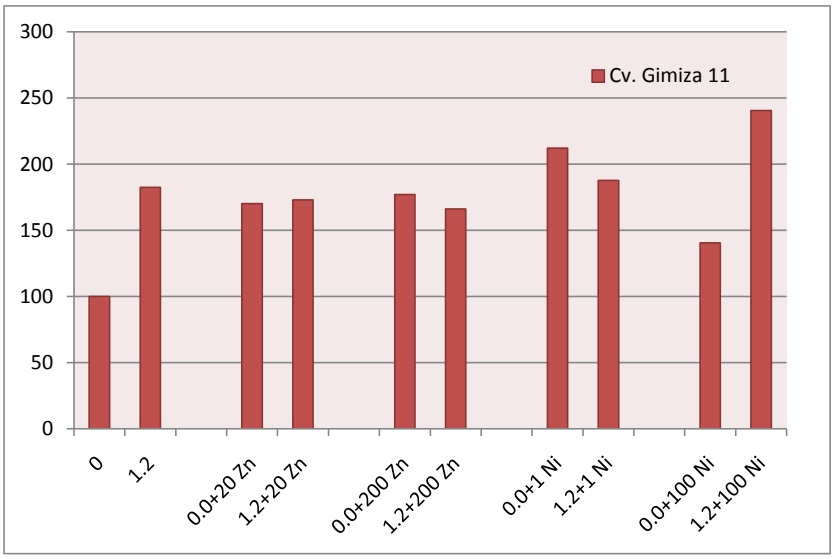
(b) L.S.D. 0.05%: 0.33



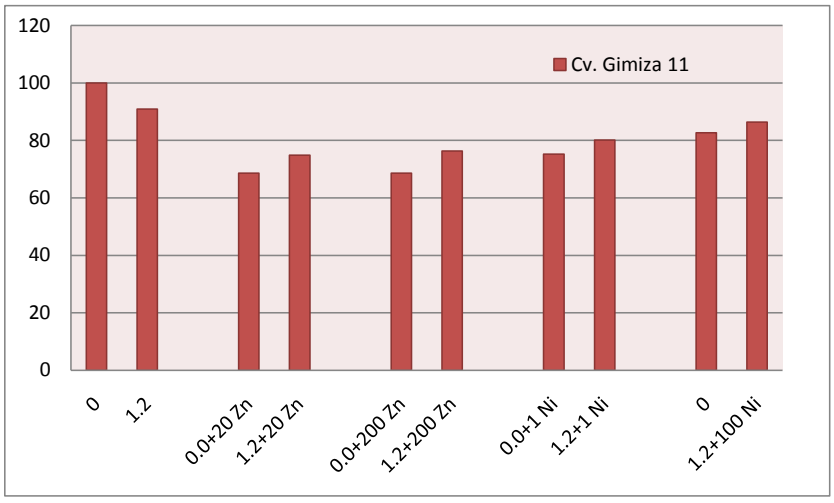
(c) L. S. D. 0.05%: 0.37

Figure 2. Osmotic pressure (mOsmo/H_2O) in roots (a), shoots (b) and spikes (c) of wheat grown under different osmotic stress levels alone or with treatment with either Zn (20 and 200 µM) or Ni (1 and 100 µM).

mostly increased the values of osmotic pressure in the three tested organs compared with the equivalent levels of control plants (Figures 2(a)-(c)). The data showed that Zn content was increased in the spikes which reach 2-fold at -1.2 MPa osmotic stress level (0.74 to 1.35 mg/100g d. m.) (Table 3 & Figure 3(a)). Mineral treatments mostly stimulated the accumulation of Zn element in the spikes with or without osmotic stress treatments. A slight reduction in the accumulation of Ni was recorded in spikes of that treated at −1.2 MPa osmotic stress level in relations to control (2.87 to 2.61 mg/100g d. m.) (Table 3 & Figure 3(b)). Minerals treatment with both low and high concentrations of Zn or Ni induced a significant reduction in the accumulation of Ni with control or osmotic stress level −1.2 MPa (Table 3 and Figure 3(b)).



(a)



(b)

Figure 3. The percentage of Zn a and Ni b content in wheat grown under osmotic stress level (−1.2 MPa) alone or with treatment with either Zn (20 and 200 μM) or Ni (1 and 100 μM).

Table 3. Zinc (A) and nickel (B) contents (mg/100g d. m.) in wheat grown under osmotic stress level (−1.2 MPa) alone or with treatment with either Zn (20 and 200 μM) or Ni (1 and 100 μM).

Treat. (−Mpa)	Zinc	Ni
0.0	0.74	2.87
1.2	1.35	2.61
Zn (μM) 0.0 + 20	1.26	1.97
1.2 + 20	1.28	2.15
0.0 + 200	1.31	1.97
1.2 + 200	1.23	2.19
Ni (μM) 0.0 + 1	1.57	2.16
1.2 + 1	1.39	2.30
0.0 + 100	1.04	2.37
1.2 + 100	1.78	2.48

5. Discussion

The present investigation exposed that the harvest index of wheat plants was decreased by 75% at −0.3 MPa NaCl level, whereas at −1.2 MPa NaCl level it was decreased by 55.4%. In addition, the decrease in length of root, shoot and spike at −0.3 MPa NaCl level was 88.7%, 74.2%, 94.7%, respectively. Currently, this reduction was more obvious at −1.2 MPa level by 73.8%, 61.5% and 78.4%, respectively at −1.2 MPa level. Confirmed this, the decline in leaf area at −0.3 MPa NaCl level was 74.2% and at −1.2 MPa it was 59.5% as compared with 100%. Salinity lowered the plant productivity and growth due to osmotic stress, nutritional imbalance, and oxidative stress [19] [20]. The salt stress results in the accumulation of sodium and chloride ions in the cytosol, eventually causing considerable damage to the cell [21]. Accordingly, one can say that the criteria of the green area could be linked in some way with the efficiency of photosynthetic apparatus and consequently food manufacturing. This conclusion was greatly confirmed by the differences in the carbohydrate and nitrogen metabolism among the wheat organs. This run parallel with general tolerance of wheat plants and the production of spike yield. This was observed also by Karimi and Kuhbanani (2014) [22] and Rahneshan *et al.* (2018) [23], the later showed that salinity caused damaging effects on growth and leaf area of two pistachios (*Pistachio vera* L.). Actually, the reduction in growth parameters was associated with the reduction in the total sugar in root, and total protein in both root and spike. This agreement with Rajput *et al* (2017) [24] and Kamran *et al.* (2019) [19] stated that salinity stress lowered the economic yield of several crops via inducing biochemical and physiological perturbations. A reduction in plant biomass in this cultivar under higher levels of salt stress, salt stress, is possibly because of the decrease in carbohydrate accumulation that was caused by reduction in carbon

assimilation [25]. Under salt stress, consumption of metabolic energy increased while the amount of carbohydrate accumulation decreased [25]. Also, Arbona *et al.* (2005) [26] reported that salinity induced progressive reduction of carbohydrates in leaves and roots of citrus plants and they concluded that sugar accumulation is not a chief component of the osmotic adjustment mechanism in citrus. The decrease in starch concentration in plant tissue is the direct effect of decreased CO_2 fixation due to reduction in stomata conductance and content of chlorophyll in plant tissues under salt stress [27] [28].

Plants under salinity condition change their metabolism to overcome the changes in environmental condition [5] [29] [30]. While total sugars were smoothly decreased in root organ, it tended to significantly increase in both shoots and spikes of wheat plants. This accumulation provided wheat plants to tolerate the increase in osmotic stress levels. Relative constant level of glucose in salinity conditions may recount to the role of glucose in respiration. It means that, released glucose from starch was consumed in respiratory reactions [31] [32]. Treatment the soil with Zn or Ni accumulated total sugars in roots and mostly in shoots. This correlated with increase in the growth of wheat plants under mineralization treatments. Total protein was greatly decreased as osmotic stress levels increased in both shoots and spikes. This reduction was correlated with reduction in growth parameters (length and leaf area). Salinity causes significant modifications in gene expression of plants. Such modifications may affect the accumulation or reduction of certain metabolites, consequential in the inequality in the levels of a relatively little set of cellular proteins, which could increase, decrease, appear, or disappear after salt exposure [33]. Several salt-induced proteins have been recognized in plant species [34] [35].

Treatments wheat plants with Zn or Ni did not affect on the accumulation of total protein in roots, shoots and spikes. These were confirmed with Manivagaperumal *et al.* (2011) [36] which recording that amino acid and protein contents were high at lower Zn concentrations (10 and 25 $mg{\cdot}L^{-1}$), after that the values were decreased. This inhibition might be due to binding of metals with sulfhydryl group of protein and producing deleterious effect in the normal protection form. Excluding this trend, a significant increase in the total proteins was detected in spikes that grow with 20 or 200 μM of Zn concentrations as compared with corresponding levels. The present results indicated that osmotic pressure was increased as increasing salinity stress in the root, shoot and spike of wheat plants. This increase was correlated with increasing metabolites in the cytoplasm which result in an increase in the water uptake that finally activated plant growth parameters (harvest index, length and leaf area) of wheat plants. During water deficit stress, osmotic stress sensing and signaling are pivotal to plant water status and lead to rapid changes in gene expression [37]. Osmotic adjustment helps to maintain cell turgor, which can allow cell enlargement and plant growth during water stress; and it can allow stomata to remain at least partially open and CO_2 assimilation to continue at water potentials that would be otherwise inhibitory [38] [39]. Enhancement of organic and inorganic solutes can be used as a

suitable trait to discriminate genotypes for salt tolerance and osmotic stresses. Mohammed (2007) [40] reported that it is important to know how the sink source relationships are affected in plant growth under salt stress conditions, because the efficient use of assimilating may be a limiting factor to plant growth under salinity. The relative ability of the plant or plant organ to stimulate the accumulation of cytosol substances in its tissues (osmotic adjustment) will partially determine its tolerance to stress conditions [4] [33]. Treatments wheat plants with Zn or Ni generally increased the values of OP under salinity stress. This increase explains the important role of minerals in increasing cytosolutes which increase crop yields. This was confirmed by Khan *et al.* (2004) [41]. Bhatia *et al.* (2005) [42] showed that hyperacumulation of certain metals in plants may play a role in osmotic adjustment under water stress. When wheat plants were exposed to higher osmotic stress level, Zn accumulation was increased which reach 2-fold in relation to its control. The amount of Zn accumulation was (0.74 to 1.35 $mg \cdot g^{-1}$ d. m.) This accumulation might be related with the reduction in growth of spikes. In contrast to our results in saline soils, the solubility of micronutrients as (Zn) is mainly low, and plants that grow in these soils often suffer from deficiencies in these nutrients. Differences can be attributed to plant type, plant tissue, salinity level and environmental conditions [43].

Additionally, exogenous mineral treatment with Zn or Ni exhibited mostly an accumulation in Zn content in the tested plants. This was supported by results obtained by Tavallali (2016) [44] who demonstrated that the addition of Zn up to 10 $mg \cdot kg^{-1}$ in soil developed plant growth under salt stress and can inhibit the uptake and accumulation of Na^+ in pistachio leaf and stem and increase mineral nutrients absorption [45] [46] [47]. On the other side, Ni content was markedly reduced in spikes of wheat plants at −1.2 MPa NaCl level or under mineral treatment, this reduction play an important role in salinity tolerance of this plant and coincided with the alleviating effect of exogenous Zn or Ni treatment in lowering the negative effects of Ni toxicity. This result concluded that Zn or Ni applications have an antagonistic effect in salinity injury. Ain *et al.* (2016) [8] indicated that Ni declined by increasing levels of Ni in both control and salinity conditions. Stetsenko *et al.* (2017) [46] illustrated that the compact Ni content decreased the toxic effect of Ni present in the medium. Sharma and Dhiman (2013) [47], Nie *et al.* (2015) [48] and Mohamed *et al.* (2020) [49] demonstrated that after exposure to high levels of Ni in soil, tissue Ni concentrations of plants are usually uppermost Ni in the roots and less Ni being detected in stems and leaves. The activities of several enzymatic antioxidants increased under Zn or Ni treatments, these enzymes enable the plants to withstand osmotic stress. Therefore, application of Zn or Ni alleviated to some extent the salinity stress injury in the wheat plant.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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