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Research of the Effect of Ni (Nickel) Treatment at Different Concentrations on Morphological Features of Some Grain Sorghum Varieties

Hava Şeyma İNCİ[1*] **Kağan KÖKTEN[2]**

[1]Department of Crop and Animal Production, Vocational School of Food, Agriculture and Livestock, University of Bingol, Bingol, Türkiye

[2]Sivas University of Science and Technology, Faculty of Agriculture and Technology, Department of Herbal Production and Technologies, Sivas, Türkiye

A R T I C L E I N F O

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A B S T R A C T

There is no doubt that agricultural production is one of the most affected parts of environmental pollution, which is increasing day by day. Among these pollution factors, heavy metals are the most common. Ni element is used in many fields, especially in industry, and it contaminates the soil and water where agricultural production is made. In this study, it was aimed to determine the changes in the morphological features of the plants by treatmenting different concentrations of Ni to some sorghum varieties (Akdarı, Beydarı and Öğretmenoğlu) registered in our country and obtained from the Batı Akdeniz Agricultural Research Institute (BATEM). The research was carried out in the greenhouses of Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, during the summer crop growing season in 2017. 0, 100, 200, 300, 400 and 500 mg kg^{-1} nickel (Ni) was treatmented to grain sorghum varieties. The features examined at the end of the 130-day growing period; grain weight, cluster length, plant height, plant stem diameter, stem ratio, leaf ratio and cluster ratio. Although the morphological features of the plants generally show a neutral or positive effect up to 200-300 mg kg^{-1} levels at different Ni concentrations applied, it has been observed that the morphological features of the plants were adversely affected at Ni levels above these doses. In this study, it is thought that depending on the concentration of the Ni element, in some cases it has a nutrient effect, and in some cases it causes heavy metal stress.

1. Introduction

Sorghum bicolor, which is included in the Poaceae family, is an annual and warm season plant. It is cultivated for different purposes such as grain, feed, sugar and bioenergy (Smith and Frederiksen 2000). While 50% of the universally grown sorghum plant is used in human nutrition, 90% of it is used in animal nutrition in the USA (Hamman et al. 2001). Sorghum has a yield potential comparable to rice, wheat and maize under favorable conditions (House 1985). In regions with a semi-tropical climate, sorghum double crops can be grown (Banks and Duncan 1983).

*Correspondence author: hsyilmaz@bingol.edu.tr

The term we call heavy metal is actually used for metals with a density higher than 5 g cm^3 in terms of physical properties. There are more than 60 metals including lead, cadmium, chromium, iron, cobalt, copper, nickel, mercury and zinc (Kahvecioğlu et al. 2007).

Nickel (Ni), one of the 23 polluting metals, seriously threatens the ecosystem and human health (Duda-Chodak and Baszczyk 2008). It is predicted that the global nickel production will be 1,614 Mt in 2008 (USDI 2009). Reck et al. (2008) reported that the element nickel is used in the stainless steel industry (68%). Ni-alloys are widely used in the production of magnetic-electrical devices, and they are also used in medicine and food technology. Ni compounds are used in paints, ceramics and glass production, and batteries in the form of Ni-Cd compounds. Nickel is considered an extremely serious pollutant from metal processing plants and originating from coal-oil burning. In addition, some sewers and phosphate fertilizers can be important contamination points of nickel in agricultural production soils (Kabata-Pendias 2011).

Previously, there was no evidence that nickel plays an important role in plant metabolism, but some researchers (Mishra and Kar 1974; Mengel and Kirkby 1978) stated that the element nickel may be necessary for plants and proved that nickel is necessary in a number of bacterial biosynthesis. The role of nickel in the nodulation of legumes and its effects on the mineralization and nitrification of some organic matter are described. Therefore, the element nickel is considered essential for urease metabolism for some legumes (Eskew et al. 1983).

The mechanism of Ni toxicity and the biological effects of nickel are related to the forms of the element nickel. Ni^{2+} in the cation form is more easily absorbed and more toxic than its complex forms. The Ni content of the plants is a parameter controlled by the soil in which the plants are grown, and the most prominent factor is the soil pH. The mechanism of plants against Ni toxicity is not fully understood, but it has been observed for a long time that the growth of plants is limited due to the excess of the element nickel (Kabata-Pendias 2011).

This study was carried out to investigate the effect of nickel element, which spreads easily to the environment and can easily contaminate soil and water, which is the most important point of agricultural production, on the morphological characteristics of sorghum, which has an important feed value and is tolerant to many stress factors.

2. Materials and Methods

2.1. Plant cultivation, nickel treatment and harvesting

This research was carried out in the greenhouses of Kahramanmaraş Sütçü İmam University Faculty of Agriculture between April 28 and September 10, 2017. The soil used for the experiment was obtained from Kahramanmaraş Sütçü İmam University Campus and the soil analysis results are as in Table 1.

Table 1. Some properties of the soil used in this study

Saturation (%)	pH	Salinity (%)	$CaCO_3$ (%)
58.3	7.33	0.1	0.71
Organic matter (%)		**K (mg kg^{-1})**	**P (mg kg^{-1})**
0.6		275.2	8.12

The grain sorghum varieties used in the study are Akdarı, Beydarı and Öğretmenoğlu and were obtained from the Batı Akdeniz Agricultural Research Institute. The element nickel is commercially supplied in the form of NiSO4 6H2O. The study was designed according to a split-plot experimental design (3 varieties x 6 doses x 1 element x 3 replications). The soil was sieved with a 4 mm sieve. Then it was waited in the greenhouse to reach its dry weight. Then they were weighed 10 kg and placed in pots. 5 seeds (per pot) were planted in pots. After germination, the weak seedlings were diluted and the only strong sorghum seedling was left. Fertilization; (20 kg N $da^{-1}$and 10 kg P2O5 da^{-1}) were calculated according to the amount of soil used, weighed and applied. Until the plants were 20-25 cm tall, only irrigation (tap water) was made according to the field capacity. Ni element was given to pots at concentrations of 0, 100, 200, 300, 400 and 500 mg kg^{-1}. After the application, all irrigations until the harvest time were made with tap water according to the field capacity and nickel washing/leakage was tried to be prevented.

At the end of the 130-day growth period, the plants were harvested manually. Morphological characteristics such as plant height, plant stem diameter, cluster length, thousand-grain weight, leaf ratio, stem ratio and cluster ratio were measured.

Statistical analysis of the data belonging to the parameters examined was carried out according to the split plot design (analysis of variance). The results were compared with the LSD test (SAS, 1999).

3. Results and Discussion

3.1. Plant height (cm)

Means of doses, varieties, dose x variety interactions and LSD test groups were given in Table 2 and the graph of change is given in Figure 1. According to the results of the variance analysis of the Ni doses of plant heights, variety, dose and the interaksiyon of variety x dose was found to be very significant ($p<0.01$). When the effect on plant heights of grain sorghum varieties under Ni stress was examined, it was seen that the plant heights varied between 73.35-92.99 cm in the average of the varieties, the highest plant height was found in Akdarı and Beydarı varieties and the lowest plant height was on Öğretmenoğlu variety. In the averages of the doses, it was observed that increasing Ni doses caused an increase in plant height up to 400 mg kg^{-1} treatment, and it started to decrease plant height in 400 mg kg^{-1} and above treatments. The smallest plant height (73.12 cm) was obtained from 500 mg kg^{-1} Ni treatment, while the highest plant height (95.02 cm) was obtained from the control group plants. In the variety x dose interaction, it was observed that the highest plant height was obtained from 0 mg kg^{-1} Ni (control) dose of Beydarı variety in Ni treatment, while the smallest plant height was obtained from 500 mg kg^{-1} treatment, which is the highest Ni dose of Öğretmenoğlu variety.

The treatment of plants with different concentrations of nickel caused an increase in plant height at some doses and a decrease at some doses in all varieties. While this situation was generally positive up to 300 mg kg^{-1} Ni treatment, it had a negative effect at higher doses. Al Chami et al. (2015) cultivated sorghum plant under Ni stress at 6 different doses in hydroponic culture and stated that the plant failed to grow after the 3rd level dose. Ahmad et al. (2007) reported that the growth of mung bean regressed after a certain dose (40 mg L^{-1}) of increasing Ni level in the nutrient solution in their study with mung beans. In cases where the plant perceives the Ni element as stress, the fact that the plant height does not increase is similar to the studies carried out.

Table 2. Averages of the Effect of Different Ni Doses on Plant Height (cm) of Grain Sorghum Varieties

	Varieties			
Ni dose (mg kg^{-1})	**Akdarı**	**Beydarı**	**Öğretmenoğlu**	**Mean**
0	94.86±4.02 C**	106.11±2.52 A	84.07±3.74 EF	**95.02 a****
100	93.50±3.91 CD	86.33±4.04 DE	76.33±8.33 FG	**85.39 bc**
200	95.00±5.96 C	97.00±2.65 BC	76.67±5.51 FG	**89.56 ab**
300	95.67±0.58 C	104.33±4.04 AB	78±8.72 FG	**92.67 a**
400	92.20±3.70 CD	81.5±2.50 EF	65.00±70 HI	**79.57 c**
500	86.70±3.20 DE	72.67±2.52 GH	60.00±50 I	**73.12 d**
Mean	**92.99 a****	**91.33 a**	**73.35 b**	

**: 1%, level of significance; capital letters show significant differences between the interactions of varieties and doses; small letters show significant differences between the averages of varieties and doses.

3.2. Plant stem diameter (mm)

Means of doses, varieties, dose-variety interactions and LSD test groups were given in Table 3 and the graph of change was given in Figure 1. According to the variance analysis results of the plant stem diameters of the Ni doses, the variety and dose were very important ($p<0.01$), while the variety x dose interaction was found to be insignificant.

It was observed that the plant stem diameters of the grain sorghum varieties varied between 9.46 mm and 11.30 mm on average against Ni treatment, and the thickest stem diameter was observed in Beydarı variety and the thinnest stem diameter in Akdarı variety.

Although the increase in Ni doses caused an increase in stem diameter at doses other than control treatments (up to 400 mg kg^{-1} treatment), 400 mg kg^{-1} and subsequent treatments decreased the plant stem diameter. On the average of the doses, the thinnest stem diameter (9.14 mm) was obtained from 500 mg kg^{-1} Ni treatment, while the thickest stem diameter (11.58 mm) was obtained from the control group plants. The cultivar x dose interaction, on the other hand, plant stem diameter varied between 8.44-13.00 mm.

Like other plant growth factors, plant stem diameter also varied depending on whether plants perceive Ni as stress or perceive it as a nutrient element. While it showed improvement in plant morphological properties at certain doses, it was observed that it was adversely affected at certain doses. Tsui (1955) in his study to investigate the effects of nickel (Ni) on wheat seeds reported that when 100 mg kg^{-1} Ni treatment is applied, the root and stem of the plant show the best growth compared to other concentrations, but when 250 mg kg^{-1} and above Ni treatment the growth is inhibited. Similar situations are present in our study as in this study.

Table 3. Averages of the Effect of Different Ni Doses on Plant Stem Diameters (mm) of Grain Sorghum Varieties

	Varieties			
Ni dose (mg kg^{-1})	**Akdarı**	**Beydarı**	**Öğretmenoğlu**	**Mean**
0	9.84±0.58	11.91±0.8	13.00±4.33	**11.58 a****
100	9.10±0.96	11.67±0.49	10.57±0.73	**10.45 ab**
200	9.91±0.03	11.88±0.92	10.61±1.32	**10.80 a**
300	10.09±1.01	12.6±0.26	10.85±0.56	**11.18 a**
400	8.96±0.62	11.3±0.67	10.29±0.79	**10.19 ab**
500	8.85±0.18	8.44±1.06	10.14±1.22	**9.14 b**
Mean	**9.46 b****	**11.30 a**	**10.91 ab**	

**: 1%, level of significance; small letters show significant differences between the averages of varieties and doses.

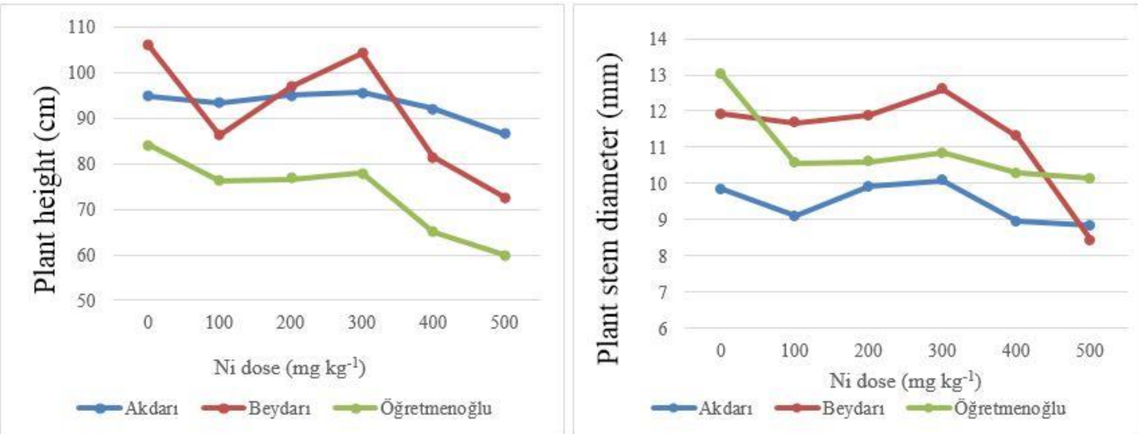

Figure 1. Change Graph of the Effect of Different Ni Doses on Plant Height and Plant Stem Diameter in Grain Sorghum Varieties

The graph on the left shows the change in plant height at different concentrations of Ni doses. The graph on the right shows the change in plant stem diameter with different concentrations of Ni doses.

3.3. Cluster length (cm)

Means of doses, varieties, dose-variety interactions and LSD test groups were given in Table 4 and the graph of change was given in Figure 2. According to the results of cluster length variance analysis of Ni doses, the interaction of variety, dose and variety x dose was found to be very significant (p<0.01). The cluster length of the varieties varied between 15.25 cm and 17.36 cm, and the longest cluster length was found in the Beydarı variety, while the shortest cluster length was found in the Akdarı and Öğretmenoğlu varieties. Increasing Ni doses caused an increase in cluster length up to 400 mg kg^{-1} Ni treatment at doses other than control plants, but decreased cluster length in 400 mg kg^{-1} and subsequent treatments. On average, the lowest cluster length (13.82 cm) was obtained from 500 mg kg^{-1} Ni treatment, while the longest cluster (18.25 cm) was obtained from the control group plants. In the variety x dose interaction, while the longest cluster was obtained from 0 mg kg^{-1} Ni/control plants of Beydarı variety, the shortest cluster was obtained from 500 mg kg^{-1} Ni treatment of Öğretmenoğlu variety.

The effects of nickel on the cluster lengths of the grain sorghum varieties used varied depending on the doses. In nickel treatment, while some doses had a positive effect on the cluster length, at some doses the cluster length was negatively affected. Wyszkowska et al. (2007), in their study, treated two different soils of loamy sandy and slightly silty loam with Ni at a concentration of 200 mg kg^{-1} and examined the yield of the oat plant. They reported that the yield decreased by 65% and 40%, respectively. In this study, similar to the situation in which the yield of the oat plant was affected, the development status of the generative organs/cluster length in sorghum was also negatively affected after certain doses.

Table 4. Averages of the Effect of Different Ni Doses on cluster length (cm) of Grain Sorghum Varieties

	Varieties			
Ni dose (mg kg^{-1})	**Akdarı**	**Beydarı**	**Öğretmenoğlu**	**Mean**
0	15.57±1.09 E-G**	21.16±0.49 A	18.03±0.73 BC	**18.25 a****
100	14.8±0.80 F-I	16.63±1.18 C-E	15.23±0.4 E-H	**15.56 b**
200	15.83±1.61 E-G	16.8±1.32 C-E	15.27±1.25	**15.97 b**
300	17.8±1.06 B-D	18.65±0.95 B	15.87±1.03 E-G	**17.44 a**
400	13.83±0.47 HI	16.27±0.59 D-F	15.2±1.31 E-H	**15.10 b**
500	13.67±0.35 HI	14.63±0.35 G-I	13.15±0.85 I	**13.82 c**
Mean	**15.25 b****	**17.36 a**	**15.45 b**	

**: 1%, level of significance; capital letters show significant differences between the interactions of varieties and doses; small letters show significant differences between the averages of varieties and doses.

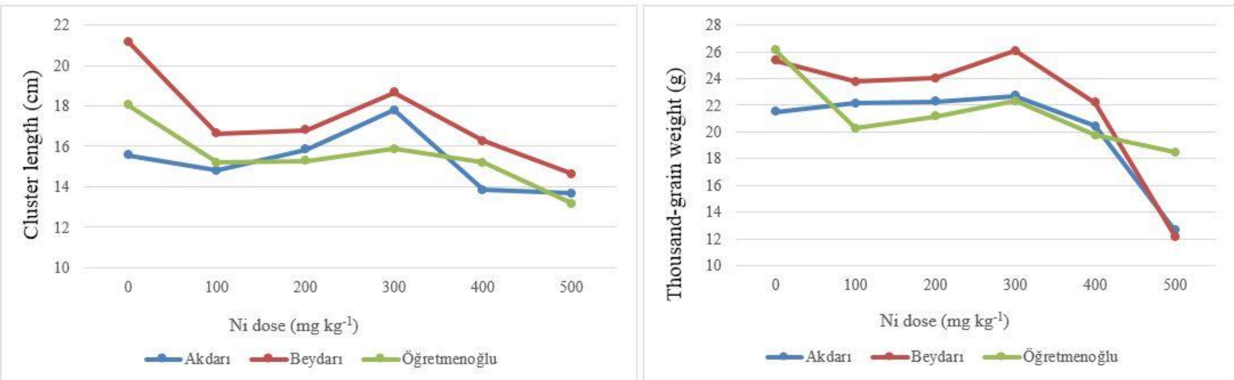

Figure 2. Change Graph of the Effect of Different Ni Doses on Cluster Length (cm) and Thousand-Grain Weight (g) in Grain Sorghum Varieties

The graph on the left shows the change in Cluster Length (cm) of Ni doses at different concentrations. The graph on the right shows the change in the thousand-grain weight of Ni doses at different concentrations.

3.4. Thousand-grain weight (g)

Means of doses, varieties, dose x variety interactions and LSD test groups were given in Table 5 and the graph of change was given in Figure 2. According to the thousand grain weight variance analysis results of Ni doses, the interaction of variety, dose and variety x dose was found to be very significant (p<0.01).

The thousand-grain weights of the varieties varied between 20.28 g and 22.26 g. While the highest thousand grain weight was in Beydarı and Öğretmenoğlu varieties, the lowest thousand grain weight was in Akdarı variety. The increase in Ni doses caused an increase up to 400 mg kg^{-1} treatment in the doses other than the control plants, but decreased the thousand grain weight in 400 mg kg^{-1} and subsequent treatments. On average, the lowest thousand grain weight (14.42 g) was obtained from 500 mg kg^{-1} Ni treatment, while the highest thousand grain weight (24.32 g) was obtained from the control group plants. In the variety x dose interaction, the highest thousand grain weight was obtained from 0 mg kg^{-1} Ni/control treatment of Öğretmenoğlu variety, while the lowest thousand grain weight was obtained from 500 mg kg^{-1} Ni treatment of Akdarı and Beydarı variety.

Although there were some changes in the form of increase and decrease in the thousand-grain weight of all sorghum varieties used in the study, decreases were observed in all three varieties at doses above 400 mg kg^{-1}. Zengin and Munzuroğlu (2005) stated that chlorophyll production affects negatively in cases where nickel is at the toxicity level, and thus the roots cannot get the macro and micro elements they need as much as they need, and as a result, the plant suffers from a lack of nutrients. The grains of the plant, which suffers from nutrient deficiency, may have remained weak and this may have adversely affected the weight of a thousand grains.

Table 5. Averages of the Effect of Different Ni Doses on thousand-grain weights (g) of Grain Sorghum Varieties

	Varieties			
Ni dose (mg kg^{-1})	**Akdarı**	**Beydarı**	**Öğretmenoğlu**	**Mean**
0	21.49±1.8 D-F**	25.36±0.95 AB	26.11±0.11 A	**24.32 a****
100	22.15±1.35 C-E	23.78±2.28 BC	20.27±1.68 E-G	**22.07 bc**
200	22.25±2.22 C-E	24.03±1.34 A-C	21.14±0.9 D-F	**22.47 bc**
300	22.71±0.69 CD	26.06±1.20 AB	22.3±0.75 C-E	**23.69 ab**
400	20.44±0.71 D-G	22.2±1.40 C-E	19.76±0.49 FG	**20.80 c**
500	12.63±0.97 H	12.13±1.91 H	18.48±2.18 G	**14.42 d**
Mean	**20.28 b****	**22.26 a**	**21.34 a**	

**: 1%, level of significance; capital letters show significant differences between the interactions of varieties and doses; small letters show significant differences between the averages of varieties and doses.

3.5. Stem ratio (%)

Means of doses, varieties, dose-variety interactions and LSD test groups were given in Table 6 and the graph of change was given in Figure 3. According to the variance analysis results of the stem ratios of Ni doses, the variety, dose and the interaction of variety x dose was found to be very significant (p<0.01). The stem ratios of the varieties varied between 50.36% and 53.26%. While the highest stem rate was in Beydarı variety, the lowest stem rate was determined in Akdarı and Öğretmenoğlu varieties. As a result of the increase in Ni doses, 100, 400 and 500 mg kg^{-1} Ni treatments were included in the same mean group, while the control group plants and 200, 300 mg kg^{-1} Ni treatments formed a different mean group. The highest stem rate (54.66%) was obtained from 500 mg kg^{-1} Ni treatment, while the lowest stem rate (47.94%) was obtained from 0 mg kg^{-1}. In the varietiy x dose interaction, the highest stem rate (56.33%) was obtained from the 500 mg kg^{-1} Ni treatment of Beydarı, while the lowest stem rate (42.36%) was obtained from the Öğretmenoğlu variety at 0 mg kg^{-1} Ni/control

In this study, the stem ratio; It was determined by the ratio that the leaves and clusters of the plant were also taken into account. In this case, when the varieties were examined, it was observed that the leaf ratio did not change much, and the change was in parallel with the increase or decrease in the cluster ratio and the increase and decrease in the stem ratio. In other morphological parameters, nickel element caused us to observe an increase in some doses, while it caused us to observe a decrease in some doses. In cases where the plants were adversely affected by nickel, the generative parts were adversely affected, which caused a decrease in the cluster ratio and an increase in the stem ratio. Phytotoxic Ni concentrations vary widely with plant species and varieties and have been reported to range from 40 to 246 mg kg^{-1} for various plants (Gough et al. 1979). The mechanism of Ni toxicity to plants is not fully understood, but limited growth of plants due to excess of this metal has been observed for quite some time (Kabata-Pendias 2011). The situations that the researchers stated may have caused this situation in a similar way.

Table 6. Averages of the Effect of Different Ni Doses on Stem Ratio (%) of Grain Sorghum Varieties

	Varieties			
Ni dose (mg kg^{-1})	**Akdarı**	**Beydarı**	**Öğretmenoğlu**	**Mean**
0	49.29±0.45 FG**	52.19±0.83 A-F	42.36±0.92 H	**47.94 c****
100	52.12±1.49 B-F	53.61±3.49 A-E	55.59±4.12 A-C	**53.77 a**
200	50.51±3.84 D-G	51.71±1.10 C-F	54.17±1.86 A-D	**52.12 ab**
300	47.44±0.51 G	49.68±3.18 E-G	53.34±0.97 A-F	**50.15 bc**
400	50.81±0.92 D-G	56.07±3.98 AB	54.14±0.92 A-D	**53.67 a**
500	52.00±4.07 B-F	56.33±2.11 A	55.67±2.58 A-C	**54.66 a**
Mean	**50.36 b****	**53.26 a**	**50.54 b**	

**: 1%, level of significance; capital letters show significant differences between the interactions of varieties and doses; small letters show significant differences between the averages of varieties and doses.

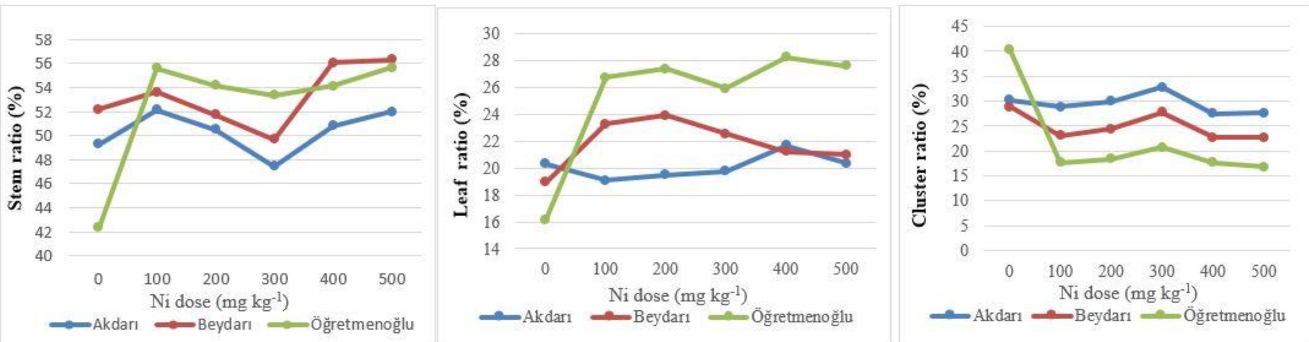

Figure 3. Change Graph of the Effect of Different Ni Doses on in Grain Sorghum Varieties

The graph on the left shows the change in the stem ratio of Ni doses at different concentrations. The graph in the middle section shows the change in leaf ratio of Ni doses at different concentrations. The graph on the far right shows the change in the cluster ratio of Ni doses at different concentrations.

3.6. Leaf ratio (%)

Means of doses, varieties, dose-variety interactions and LSD test groups were given in Table 7 and the graph of change was given in Figure 3. According to the variance analysis results of Ni doses and leaf ratios, the interaction of variety, dose and dose x variety was very significant ($p<0.01$). The average leaf ratios of the varieties varied between 20.12% and 25.35%. While the highest leaf rate was observed in Öğretmenoğlu variety, the lowest leaf rate was observed in Akdarı and Beydarı varieties. As a result of the increase in Ni doses, leaf ratios increased in all doses except 0 mg kg^{-1} Ni /control treatment and included in the same mean group. In the variety x dose interaction, the highest leaf rate (28.25%) was obtained from the 400 mg kg^{-1} dose of Öğretmenoğlu variety. In this group, 200 and 500 mg kg^{-1} treatments of Öğretmenoğlu variety were also included, and the lowest leaf rate (16.14%) was obtained from 0 mg kg^{-1} Ni/control treatment of Öğretmenoğlu variety.

With the increase in doses, all doses were in the same mean group, except for the control plants; that is, the plants did not show a significant change in leaf ratio with the increase of Ni level. The changes in the ratios were generally determined by the cluster and stem parts. Tiffin (1972) reported that Ni is bound to anionic and organic complexes in the xylem and that Ni is mobile in plants, although Ni transport and storage seem to be metabolically controlled. The fact that the leaf ratio did not experience great changes in our study is perhaps due to this mobility of the Ni element in the plant. Also, there was previously no evidence that nickel plays an important role in plant metabolism, but some researchers (Mishra and Kar 1974; Mengel and Kirkby 1982) have suggested that nickel may be important to plants. In plants under Ni stress, the absorption of nutrients, root development and metabolism are adversely affected. It is known that high concentrations of this metal in plant tissues inhibit photosynthesis and transpiration, usually before symptoms of Ni toxicity become evident (Bazzaz et al. 1974). These studies show that nickel can cause both positive and negative physiological changes in plant metabolism.

Table 7. Averages of the Effect of Different Ni Doses on Leaf Ratio (%) of Grain Sorghum Varieties

	Varieties			
Ni dose (mg kg^{-1})	**Akdarı**	**Beydarı**	**Öğretmenoğlu**	**Mean**
0	20.33±0.15 E-G**	18.93±0.33 GH	16.14±0.07 H**	**18.47 b****
100	19.09±2.19 GH	23.3±4.40 C-E	26.76±2.55 AB	**23.05 a**
200	19.48±2.29 F-H	23.9±0.97 B-D	27.39±2.61 A	**23.59 a**
300	19.78±0.84 FG	22.55±3.37 C-F	25.94±0.34 A-C	**22.76 a**
400	21.69±1.65 D-G	21.22±2.84 D-G	28.25±1.13 A	**23.72 a**
500	20.34±0.51 E-G	21.01±1.91 D-G	27.6±1.74 A	**22.98 a**
Mean	**20.12 b****	**21.82 b**	**25.35 a**	

**: 1%, level of significance; capital letters show significant differences between the interactions of varieties and doses; small letters show significant differences between the averages of varieties and doses.

3.7. Cluster ratio (%)

Means of doses, varieties, dose-variety interactions and LSD test groups were given in Table 8 and the graph of change was given in Figure 3. According to the variance analysis results of the effect of Ni doses on the cluster ratio of the varieties, the interaction of dose, variety and dose x variety was very significant ($p<0.01$). The cluster ratios of the varieties varied between 21.92% and 29.48% and the highest cluster ratio was obtained from the Akdarı variety, and the lowest cluster ratio was obtained from the Öğretmenoğle variety. All varieties were included in the different mean group.

When the effect of Ni doses on the cluster ratios of the plants was examined, the control group had the highest cluster ratio (33.12%) and formed the first mean group. 300 mg kg^{-1} Ni treatment created the second highest cluster ratio and formed the second mean group. 500 mg kg^{-1} Ni treatment formed the lowest cluster rate (22.35%) and took place in the same mean group as 100, 200 and 400 mg kg-1 treatments. When we look at the variety x dose interaction, the highest cluster rate (40.31%) was obtained in 0 mg kg^{-1} Ni/control treatment of Öğretmenoğlu variety, and the lowest cluster rate (16.74%) was obtained in 500 mg kg^{-1} Ni treatment of the same variety.

Among the sorghum varieties used, the cluster ratios of Beydarı and Öğretmenoğlu varieties were determined the highest in the control plant, that is, even the lowest Ni treatment caused a decrease in the cluster rate in these two varieties. The highest cluster rate was observed in the Akdarı variety at a dose of 300 mg kg^{-1}. When certain concentrations of Ni are applied to *Capsicum frutescens* L. (paprika) and *Lycopersicon esculentum* L. (tomato) plants, plant growth and development progress positively at levels up to 1 μg L^{-1}, but higher doses applied after 1 μg L^{-1} stress and doses higher than 1 μg L^{-1} have been reported to be toxic (Pais et al. 1969). It is also believed that an excess of Ni causes a true Fe deficiency by preventing the transport of Fe from the roots to the tops (Wyszkowska et al. 2007). Rombolà and Tagliavini (2006) stated that iron element significantly affects fruit/grain yield and quality. It is thought that the possibility of a deficiency of Fe element at doses where the nickel element is perceived as stress and this negativity may cause a decrease in the seed/cluster ratio.

Table 8. Averages of the Effect of Different Ni Doses on Cluster Ratio (%) of Grain Sorghum Varieties

	Varieties			
Ni dose (mg kg^{-1})	**Akdarı**	**Beydarı**	**Öğretmenoğlu**	**Mean**
0	30.15±0.25 BC**	28.89±0.34 C	40.31±0.53 A	**33.12 a****
100	28.79±2.11 C	23.09±1.95 DE	17.65±2.04 FG	**23.18 c**
200	30.01±1.56 BC	24.4±2 D	18.44±2.44 FG	**24.28 c**
300	32.78±1.01 B	27.77±1.16 C	20.72±1.3 EF	**27.09 b**
400	27.5±2.47 C	22.71±1.16 DE	17.61±0.63 FG	**22.61 c**
500	27.66±3.57 C	22.66±3.06 DE	16.74±0.85 G	**22.35 c**
Mean	**29.48 a****	**24.92 b**	**21.92 c**	

**: 1%, level of significance; capital letters show significant differences between the interactions of varieties and doses; small letters show significant differences between the averages of varieties and doses.

4. Conclusion

The effects of different Ni doses on some sorghum cultivars (Akdarı, Beydarı and Öğretmenoğlu) were investigated in terms of morphological characteristics. It was determined in 1987 as a result of researches that nickel is a plant nutrient that is needed for plants and also necessary for growth and development (Brown et al. 1987; Brown et al. 1990; Fageria 2009; Bolat and Kara 2017). However, whether the plants use such metals instead of plant nutrients or not, the intense accumulation of heavy metals in plant tissues adversely affects the vegetative and generative development of plants (Gür et al. 2004). In addition, this accumulation has a negative effect on product and yield values (Long et al. 2002). In this study, morphological properties of plants under Ni treatment were generally positively affected up to 200-300 mg kg^{-1} levels, but were negatively affected at higher doses. Considering the soil pH and the availability of other macro and micro elements in the soil, it has been observed that plants take Ni element as a plant nutrient element up to some concentrations and the element has a toxic effect after certain concentrations. It has been predicted that the morphological characteristics of the plants are therefore negatively affected. According to the soil analyzes to be made in the Ni-contaminated areas and the plant type, the doses that will be accepted by the plants as a heavy metal or plant nutrient element should be determined and a decision should be made to make cultivation in this direction.

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References

Ahmad, M.S.A., Hussain, M., Saddiq, R., & Alvi, A. K. 2007. Mungbean: a nickel indicator, accumulator or excluder?. *Bulletin of environmental contamination and toxicology*, *78*(5), 319-324.

Al Chami, Z., Amer, N., Al Bitar, L., & Cavoski, I. 2015. Potential use of Sorghum bicolor and Carthamus tinctorius in phytoremediation of nickel, lead and zinc. *International journal of environmental science and technology*, *12*(12), 3957-3970.

Banks, P. A., & Duncan, R. R. 1983. Weed-control evaluations in ratoon-cropped grain sorghum (*Sorghum bicolor*). *Weed Science*, *31*(2), 254-258.

Bazzaz, F. A., Carlson, R. W., & Rolfe, G. L. 1974. The effect of heavy metals on plants: Part I. Inhibition of gas exchange in sunflower by Pb, Cd, Ni and Tl. *Environmental Pollution (1970)*, *7*(4), 241-246.

Bolat, İ., & Kara, Ö. 2017. Bitki besin elementleri: Kaynakları, işlevleri, eksik ve fazlalıkları. *Bartın Orman Fakültesi Dergisi*, *19*(1), 218-228.

Brown, P. H., Welch, R. M., & Cary, E. E. 1987. Nickel: A micronutrient essential for higher plants. *Plant physiology*, *85*(3), 801-803.

Brown, P. H., Welch, R. M., & Madison, J. T. 1990. Effect of nickel deficiency on soluble anion, amino acid, and nitrogen levels in barley. *Plant and Soil*, *125*(1), 19-27.

Duda-Chodak, A., & Blaszczyk, U. 2008. The impact of nickel on human health. Journal of Elementology, 13(4), 685-693.

Eskew, D. L., Welch, R. M., & Cary, E. E. 1983. Nickel: an essential micronutrient for legumes and possibly all higher plants. *Science*, *222*(4624), 621-623.

Fageria, N. K. 2009. The use of nutrients in crop plants.,(CRC Press, Taylor and Francis Group: London).

Gough, L. P., LP, G., HT, S., & AA, C. 1979. Element concentrations toxic to plants, animals and man.

Gür N., Topdemir A., Munzuroğlu Ö., &Çobanoğlu D. 2004. Ağır Metal İyonlarının (Cu^{+2}, Pb^{+2}, Hg^{+2}, Cd^{+2}) *Clivia* sp. Bitkisi Polenlerinin Çimlenmesi ve Tüp Büyümesi Üzerine Etkileri. F.Ü. Fen ve Matematik Bilimleri Dergisi 16(2): 177-182.

Hamman, L., Dhuyvetter, K. C., & Boland, M. 2001. *Economic issues with grain sorghum*. Agricultural Experiment Station and Cooperative Extension Service, Kansas State University.

House L.R.1985. A guide to sorghum breeding. Second Edition. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. S. 212

Kabata-Pendias, A. 2011. Trace elements in soils and plants. 4th edn CRC Press. *Boca Raton*.

Kahvecioğlu, Ö., Kartal, G., Güven, A. and Timur, S. 2007. Metallerin Çevresel Etkileri –I. (erişim adresi: https://metalurji.org.tr/dergi/dergi136/d136_4753.pdf (erişim tarihi: 29.01.2019)

Long, X. X., Yang, X. E., & Ni, W. Z. 2002. Current status and perspective on phytoremediation of heavy metal polluted soils. *Journal of Applied Ecology*, *13*, 757-762.

Mengel, K., & Kirkby, E. A. 1982. Principles of Plant Nutrition. International Potash Institute. Worblaufen–Bern. s. 593.

Mishra, D., & Kar, M. 1974. Nickel in plant growth and metabolism. *The botanical review*, *40*(4), 395-452.

Pais, I., Somos, A., Duda, L., Tarjanyi, F., & Nagymihaly, F. 1969. Trace-element experiments with tomato and paprika. *Kertészet*, *62*, 25-40.

Reck, B. K., Müller, D. B., Rostkowski, K., & Graedel, T. E. 2008. Anthropogenic nickel cycle: Insights into use, trade, and recycling. *Environmental science & technology*, *42*(9), 3394-3400.

Rombolà, A. D., & Tagliavini, M. 2006. Iron nutrition of fruit tree crops. In *Iron nutrition in plants and rhizospheric microorganisms* (pp. 61-83). Springer, Dordrecht.

SAS 1999. SAS User's Guide: Statistic. Statistical Analysis Systems Institute Inc., Cary, NC.

Smith, C. W., & Frederiksen, R. A. (Eds.). 2000. *Sorghum: Origin, history, technology, and production* (Vol. 2). John Wiley & Sons.

Tiffin, L. O. 1972. Translocation of micronutrients in plants. En: Micronutrients in Agriculture. RC Dinauer (Ed.) Madison, WI. *Soil Science Society of America, Inc*, 199-228.

Tsui, C. 1955. Effect of seed treatment with micro-elements on the germination and early growth of wheat. Scientia Sinica (Peking)4: 129–135.

USDI. 2009. Mineral Commodity Summaries. USGS. http://minerals.usgs.gov/ minerals/pubs/mcs) (erişim tarihi: 11.12.2021).

Wyszkowska, J., Boros, E., & Kucharski, J. 2007. Effect of interactions between nickel and other heavy metals on the soil microbiological properties. *Plant Soil and Environment*, *53*(12), 544.

Zengin, K. F., & Munzuroğlu, Ö. 2005. Fasulye fidelerinin (*Phaseolus vulgaris* L. Strike) klorofil ve karotenoid miktarı üzerine bazı ağır metallerin (Ni^{+2}, Co^{+2}, Cr^{+3}, Zn^{+2}) etkileri. *FÜ Fen ve Mühendislik Bilimleri Dergisi*, *17*(1), 164-172.