Effects of Some Heavy Metals on Germination and Seedling Growth of Sorghum

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ABSTRACT

Heavy metal contamination in soils can adversely affect seed germination and seedling growth of most plants. This research was conducted to determine the effects of different doses (0, 100, 200, 400 and 800 mg L⁻¹) of Ni (nickel), Cd (cadmium), Pb (lead), Cr (chromium) and Hg (mercury) on seed germination and seedling growth of sorghum. The study was conducted in laboratory conditions at the Agricultural Faculty of Akdeniz University in 2017. Sorghum cv. N48 x Early Sumac was used as the plant material. In the research, germination rate (GR), relative germination index (RGI), mean germination time (MGT), relative vigor index (RVI), relative root length (RRL), relative shoot length (RSL), root fresh weight (RFW) and shoot fresh weight (SFW) were measured during germination and seedling growth to determine the effects of heavy metals. The results showed that both germination and seedling growth properties were adversely affected by heavy metals. In addition, while the negative effect of cadmium on germination properties was limited, it had serious negative effects on seedling characteristics of sorghum. Increasing heavy metal doses adversely affected all investigated properties. In conclusion, all heavy metals including Hg and Cd had negative effect on germination and seedling growth of sorghum in the study.

Keywords

Heavy metal
Germination
Seedling growth
Sorghum
Environment

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INTRODUCTION

Heavy metals are regularly released into the biosphere by volcanoes, natural precipitations, and industrial activities such as mining, burning fossil fuels (Munzuroglu and Geckil, 2002; Shafiq et al., 2008). Heavy metals are toxic for human, animal and plant health (Jarup, 2003; Azvedo and Lea, 2005). The adjacencies of Turkey has been contaminated swiftly since two decades because of various of pollutants such as fossil fuels, agricultural fertilizers and pesticides, energy plants and factories related to heavy metals affecting of plant germination and growth. The intense accumulation of heavy metals in nature is becoming increasingly problematic for all types of organisms, especially plants. Heavy metals are the major abiotic stress factors causing stress on the plant (Akar and Atis, 2018).

Lead, cadmium, mercury, chromium and nickel are very important for plant life (Sharma and Dubey, 2005; Rahaman et al., 2005; Zhou et al., 2007; Guo et al., 2008; Subrahmanyam, 2008). Lead is one of the most common elements in the soil and have been reported to limit germination of some plants (Nakos, 1979; Morzek and Funiclì, 1982). Mercury is one of the most toxic elements for all organisms. Mercury toxicity causes wounds and physiological disorders on plants (Zhou et al., 2007). Plants grown on soils with high cadmium levels may have visible symptoms (such as chlorosis, decreasing root and stem growth and high doses can cause even death) (Mohanpuria et al., 2007). Although some plants are unaffected by the low level of chromium and nickel, many plants adversely affect due to high chromium and nickel levels (Huffman and Allaway, 1973; Davies et al., 2002; Rahman et al., 2005).

To provide for sufficient germination in seedbed in the cultured fields, the adequate attention should be given after seed sowing (Almansouri et al., 2001). Therefore, knowing the effect of plant species on germination and seedling forming ability of heavy metals existing in germination environment is very important at this point (Akar and Atış, 2019). Sorghum that is commonly cultivated in arid and semi-arid areas to meet nutritional needs for livestock production in Turkey was choose as plant material. Sorghum is extensively grown as a forage crops and becoming increasingly importance in many regions of the world (Miron et al., 2006; Yosef et al., 2008; Atis et al., 2012). This study was carried out to determine effects of some heavy metals on germination and seedling growth of sorghum.

MATERIAL and METHODS

The research was conducted in laboratory in the Field Crops Department of the Akdeniz University Faculty of Agriculture. The seeds of sorghum (Sorghum bicolor (L.) Moench.) were used as plant material. Five different heavy metals (Lead (Pb), Mercury (Hg), Cadmium (Cd), Chromium (Cr) and Nickel (Ni)) were used as stress factor during germination and seedling growth. Knowledge about plant material and heavy metals were given in Table 1.

| Plant (Bitki) | Cultivar (Çeşit) | Registered institutions or organizations (Kayıt ettiren kuruluş) |
|--------------|-----------------|---------------------------------------------------------------|
| Sorghum (Sorghum bicolor (L.) Moench.) | N48×Early Sumac | West Mediterranean Agricultural Research Institute |
| Heavy metals / Compound Formulas (Ağır metaller / Bileşik formülleri) | Molecular Weight g mol⁻¹ (Moleküler ağırlığı) | Manufacturers (Üreticiler) |
| Lead / Pb(NO₃)₂ | 331.2 | Riedel |
| Mercury / Hg(NO₃)₂×H₂O | 342.62 | Merck |
| Cadmium / Cd(NO₃)₂×4H₂O | 308.49 | Panreae |
| Chromium / Cr(NO₃)₃×9H₂O | 400.15 | Merck |
| Nickel / Ni(NO₃)₂×6H₂O | 290.81 | Merck |

Seed Germination

Seeds were sterilized with 5% H₂O₂ for 3 min and rinsed five times with sterilized and distilled water. Thirty seeds had uniform size were selected and sown evenly in each petri dish (9 cm diameter) filled with two layers of filter papers. 8 ml of the stock solution prepared in doses of 100, 200, 400, 800 mg L⁻¹ of heavy metals (previously prepared as 1 L stock solution) and distilled water was used as a control treatment. Each treatment had three replicates. During the seed germination stage, the petri dishes were covered with parafilm to avoid moisture loss. All the petri dishes were placed in an incubator. Germination and seedling growth period of sorghum were maintained for 10 days with 30 ± 1 °C in 12 h light/12 h dark photoperiod under 70% relative humidity (Ertekin et al., 2017; Ertekin et al., 2018).

Germination Test and Germination Index Determination

Seeds were considered germinated when emerging radicle elongated over than 2 mm. The germinated
seeds were counted daily from the beginning to finishing of germination. Then, the root length (RL) and shoot length (SL) of thirteen seedlings in each petri dish were measured. The inhibition rate of root or shoot elongation was calculated according to the method described by Soudek et al. (2010). Germination rate (GR) was measured according to Wang et al. (2011). Germination percentages were defined when the mean daily germination reached its peak (Hossain et al., 2005). The GI and VI were expressed by using relative values to compare the differences among the treatments under heavy metal stress. Germination index (GI) and vigor index (VI) were calculated using methods described by Amooaghaie and Nikzad (2013) and Li et al. (2007), respectively. Mean germination time (MGT) was calculated using method reported by Ellis and Roberts (1981). RL and SL were measured by using a ruler. RL and SL was calculated as relative values. All those parameters were calculated by the following equations germination rate (GR), relative germination index (RGI), relative vigor index (RVI), relative root length (RRL) and relative shoot length (RSL). It was also evaluated root fresh weight (RFW) and shoot fresh weight (SFW). The formulas used in this study were given below.

\[ GR(\%) = \frac{\text{number of germinating seeds}}{\text{total seeds in each petri dishes}} \times 100 \]  
\[ MGT(\text{day}) = \sum D \times n \sum n \]  

here, D is the days counted from the beginning of the germination test. n is the number of seeds germinated on D day

\[ RGI(\%) = \frac{GI_{\text{heavy metal}} - GI_{\text{control}}}{GI_{\text{control}}} \times 100 \]  
\[ RVI(\%) = \frac{VI_{\text{heavy metal}} - VI_{\text{control}}}{VI_{\text{control}}} \times 100 \]  
\[ RRL \text{ or } RSL(\%) = \frac{\text{root or shoot length}_{\text{heavy metal}} - \text{root or shoot length}_{\text{control}}}{\text{root or shoot length}_{\text{control}}} \times 100 \]  

Statistical Analysis

Data were stated as the means of three replications. Statistical analyses were performed using SAS JMP Statistical Package Version 13.0. Data under different heavy metals were subjected to a one-way analysis of variance (ANOVA). The means and interactions were considered significant when P<0.05. Differences analyses of groups were subjected to one-way ANOVA according to Tukey’s multiple range test.

RESULTS and DISCUSSION

P values of investigated properties obtained was given in Table 2. As seen in Table 2, treatments significantly affected the observed most of parameters of sorghum. The effect of heavy metals on SFW was significant at the p<0.01 while the effect of heavy metals on GR was not significant. All other parameters examined were affected at the significance level of 0.001 by experimental factors and interactions.

Table 2. F values of investigated all features in this research

| Source of Variance (Varyasyon Kaynağı) | GR | GRI | MGT | RVI | RRL | RSL | SFW | RFW |
|----------------------------------------|----|-----|-----|-----|-----|-----|-----|-----|
| Heavy Metals (Ağır Metaller)           | 2.9*| 55.2***| 23.8***| 29.5***| 98.4***| 26.8***| 7.8**| 20.7***|
| Doses (Dozlar)                         | 6.4***| 16.8***| 12.4***| 37.5***| 238.5***| 36.6***| 37.7***| 120.8***|
| Heavy Metals × Doses (Ağır Metaller × Dozlar) | 4.2***| 8.5***| 4.0***| 5.8***| 13.0***| 5.8***| 7.3***| 9.9***|

***: P<0.001 **: P<0.01 : P<0.05 n.s.: not significant (önemli değil)

GR values obtained in the research were given in Table 3. GR values were ranged 75.8% to 97.5% in term of heavy metal kinds. RGR value of Hg was lower than those of Cd, Pb and Cr. Also, RGR values of Hg and Ni were statistically similar. GR values were determined as 95.0%, 88.3%, 88.3%, 89.2% and 91.7% depending on the increasing doses (respectively for 0, 100, 200, 400 and 800 mg L⁻¹). A continuous decrease in the GR due to increased heavy metal doses was observed. Although, GR determined at control was statistically similar with doses of 100, 200, 400 mg L⁻¹. The GR determined at doses of 400 and 800 mg L⁻¹ were statistically not different from each other. The lowest GR for interactions was obtained from Hg×800 mg L⁻¹, while the highest value was found in Hg×Control mg L⁻¹.

When the interactions were evaluated overall, the highest effect on sorghum germination rate was Hg heavy metal. As a result of the application of Pb to the sorghum plant during germination stage, it was reported that the germination rate decreased due to increasing lead doses (Güvercin, 2017). In another study, Ayhan et al. (2007) reported that there was no significant change in the germination rates of maize cultivars due to the increase of cadmium and lead doses at the germination stage.

Means of RGI obtained were given in Table 4. The interaction values ranged from 58.1 to 107.3. While the heavy metal average values for RGI ranged from 82.7 to 101.3, the dose averages ranged from 86.1 to 100.0. The lowest RGI in terms of interactions was obtained from Hg×800 mg L⁻¹, while the highest was achieved in Cd×200 mg L⁻¹ treatment. He et al., 2014 reported that the germination index under cadmium stress
significantly restricted at 100 µM compared to control. In a study in which twenty-one commercial Italian ryegrass cultivars were examined under cadmium toxicity, it was reported that the relative germination index decreased due to increasing cadmium doses (Fang et al., 2017). As the doses increased from 0, 2.5 to 5 g L⁻¹, Cd, Cr and Pb heavy metals increased the germination index of the turnip plant (Siddiqui et al., 2014).

| Heavy Metals (Ağır Metaller) | Heavy Metal Doses (Ağır Metal Dozları) (mg L⁻¹) | Heavy Metals Avg. (Ağır Metaller Ort.) |
|-----------------------------|-----------------------------------------------|--------------------------------------|
| Control (Kontrol)           | 100   | 200   | 400   | 800   | Ni (Ni) | Cd (Cd) | Pb (Pb) | Cr (Cr) | Hg (Hg) |
| Ni                           | 95.0a | 88.3abcd | 89.2abcd | 91.7abcd | 90.5  |
| Cd                           | 88.3abcd | 89.2abcd | 92.5ab  | 91.7ab  | 88.0  |
| Pb                           | 95.0a | 88.3abcd | 90.8abc  | 94.2ab  | 92.3  |
| Cr                           | 90.8abcd | 90.8abc  | 90.8abcd | 90.8abcd | 90.2  |
| Hg                           | 97.5a | 94.2ab   | 95.8a    | 80.8abcd | 88.8  |

Dose Avg. (Dozlar Ort.) 93.3A 90.2A 91.3A 89.3AB 85.7B

Ni, nickel; Cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury

**Table 3. Effects of different heavy metals and doses on GR of sorghum**

MGT values were given in Table 5. MGT interaction values ranged from 1.0 to 1.7 day, while the heavy metal and dose average ranged from 1.0 to 1.4 and from 1.1 to 1.3 day, respectively. The highest value for interactions was obtained from Hg×800 mg L⁻¹, but the lowest value was obtained from Cr×200 mg L⁻¹ treatment. Especially as the Hg dose increased, MGT of sorghum plant during germination stage significantly increased. Akinci and Akinci (2011) found that the MGT in spinach extended with increasing nickel dose from 0 to 800 mg L⁻¹. In addition, Akar and Atia (2018) reported that the effect of nickel on MGT of perennial ryegrass was more pronounced than cadmium. Akinci and Çalışkan (2010) reported that as the lead dose increased from 0 to 800 mg L⁻¹, mean germination times of pepper, eggplant, cucumber, pumpkin, watermelon, melon, okra and bean extended. Ahmad et al. (2013) reported that MGT of wheat plant under lead stress during germination stage increased.

| Heavy Metals (Ağır Metaller) | Heavy Metal Doses (Ağır Metal Dozları) (mg L⁻¹) | Heavy Metals Avg. (Ağır Metaller Ort.) |
|-----------------------------|-----------------------------------------------|--------------------------------------|
| Control (Kontrol)           | 100   | 200   | 400   | 800   | Ni (Ni) | Cd (Cd) | Pb (Pb) | Cr (Cr) | Hg (Hg) |
| Ni                           | 1.1bcde | 1.2cde   | 1.1cde  | 1.1cde  | 1.1bcde | 1.2B   |
| Cd                           | 1.2cde | 1.1cde  | 1.1cde  | 1.3cde  | 1.3cde  | 1.2B   |
| Pb                           | 1.2cde | 1.1cde  | 1.1cde  | 1.2cde  | 1.4bc   | 1.2B   |
| Cr                           | 1.1cde | 1.1cde  | 1.0c    | 1.0bc   | 1.1cde  | 1.0c   |
| Hg                           | 1.1cde | 1.2cde  | 1.2cde  | 1.6ab   | 1.7c    | 1.4A   |

Dose Avg. (Dozlar Ort.) 1.1BC 1.11BC 1.1C 1.2AB 1.3A

Means of RVI were given in Table 6. The averages of heavy metal ranged from 58.2 to 93.4 while the averages of dose ranged from 48.0 to 100.0 %. The interaction values ranged from 12.3 to 103.7. When the values were evaluated overall, RVI of Hg and Cd was lower than other heavy metals. Kabir et al. (2008)
reported that as the Pb and Cd dose increased, RGI of *Thespesia populnea* L. decreased. Farooqi et al. (2009) reported that Pb and Cd decreased seed vigor index in *Albizia lebbeck* (L.) Benth. It was also reported that as the Pb and Cd concentration increased, the seed vigor of wheat, safflower and canola plants decreased (Moosavi et al., 2012).

Means of RRL were given in Table 7. Means of heavy metal average ranged from 33.7 to 84.1 % while the means of dose average ranged from 19.2 to 100.0 %. The means of interaction ranged from 2.2 to 100.0 %.

The highest value of interactions was obtained from Pb×100 mg L⁻¹ treatment (102.7 %) whereas the lowest was found in Cd×800 mg L⁻¹. When the interaction values were evaluated overall, Cd, Hg and Ni heavy metals had more negative effects on RRL than others. Similar to our findings, the negative effects of heavy metals on root growth have been reported by other researchers (Mishra and Choudhuri, 1998; Peralta et al., 2001; Verma and Dubey, 2003; Dabhi et al., 2005; Şahin and Kırân, 2005; Gyawali and Lekhak, 2006; Ahyan et al., 2007; He et al., 2014; Muhammad et al., 2015; Gedik et al., 2015; Akar and Atiş, 2019).

### Table 6. Effects of different heavy metals and doses on RVI of sorghum plant

| Heavy Metals (Ağır Metaller) | Heavy Metal Doses (Ağır Metal Dozları) (mg L⁻¹) | Heavy Metals Avg. (Ağır Metal Ort. Dozları) |
|------------------------------|-----------------------------------------------|---------------------------------------------|
| Ni                           | Control (Kontrol) 100 | 100.0a | 94.6a | 78.1abc | 68.9abc | 41.3bcde | 76.6B |
| Cd                           | 100.0a | 75.7abc | 63.3abcd | 39.6bcde | 12.3b | 58.2C |
| Pb                           | 100.0a | 81.7ab | 94.4a | 98.1a | 82.3ab | 91.3A |
| Cr                           | 100.0a | 90.8a | 103.7a | 84.9a | 87.8a | 93.4A |
| Hg                           | 100.0a | 101.8a | 82.8abc | 22.5de | 16.5b | 64.7BC |
| Dose Avg. (Dozlar Ort.)      | 100.0A | 88.9AB | 84.5B | 62.8C | 48.0D |

Means of RSL were given in Table 8. The heavy metal averages of RSL ranged from 57.0 to 100.0 % while the dose averages ranged from 19.2 to 100.0 %. When the interaction values were evaluated overall, Cd had more negative effects on RSL than others. Many studies on different heavy metals during germination stage and seedling growth were reported that as the heavy metal concentrations increased, shoot length of studied plants decreased (Beri and Setia, 1995; Mishra and Choudhuri, 1998; Peralta et al., 2001; Verma and Dubey, 2003; Dabhi et al., 2005; Gyawali and Lekhak, 2006; Ahyan et al., 2007).

Means of RFW obtained from this study were given in Table 9. The heavy metal averages ranged from 30.2 to 39.0 mg plantlet⁻¹ while the dose averages ranged from 22.6 to 41.6 mg plantlet⁻¹. The means of interactions ranged from 8.4 to 47.6 mg plantlet⁻¹. When the interaction values were evaluated overall, Cd was more restricted to SFW of sorghum than other heavy metals. It was reported that some heavy metals had adverse effects on shoot fresh weight of maize, fenugreek and rice plants (Dabhi et al., 2005; Gyawali and Lekhak 2006; Aycıçek et al., 2008). Means of RFW were given in Table 10. The heavy metal averages ranged from 4.7 to 8.4 mg plantlet⁻¹ while the dose averages ranged from 2.4 to 10.4 mg plantlet⁻¹. The means of interaction ranged from 1.0 to 14.5 mg plantlet⁻¹. When the interaction values were evaluated overall, the 400 and 800 mg L⁻¹ doses of Cd, Ni and Hg seriously reduced root fresh weight. The effect of Pb and Cr on root fresh weight was more limited than other heavy metals. It was reported that some heavy metals had an adverse effect on root fresh weight of maize, fenugreek and rice plants (Dabhi et al., 2005; Gyawali and Lekhak 2006; Aycıçek et al., 2008).

### Table 7. Effects of different heavy metals and doses on RRL of Sorghum plant

| Heavy Metals (Ağır Metaller) | Heavy Metal Doses (Ağır Metal Dozları) (mg L⁻¹) | Heavy Metals Avg. (Ağır Metal Ort. Dozları) |
|------------------------------|-----------------------------------------------|---------------------------------------------|
| Ni                           | Control (Kontrol) 100 | 100.0ab | 66.3abc | 34.4gh | 9.7i | 4.3l | 42.9B |
| Cd                           | 100.0ab | 41.9gh | 19.9i | 4.3 | 2.2 | 33.7B |
| Pb                           | 100.0ab | 102.7a | 77.7bcd | 79.1abcd | 26.0ghi | 77.0A |
| Cr                           | 100.0ab | 91.5ab | 87.3abc | 82.0abcd | 59.5def | 84.1A |
| Hg                           | 100.0ab | 50.5fg | 35.5gh | 7.3i | 4.3l | 39.5B |
| Dose Avg. (Dozlar Ort.)      | 100.0A | 70.6B | 50.8C | 36.5D | 19.2E |

Means of RSL were given in Table 8. The heavy metal averages of RSL ranged from 57.0 to 92.0 % while the dose averages ranged from 52.3 to 100.0 %. Interaction values ranged from 14.8 to 109.8 %. When the interaction values were evaluated overall, Cd had more negative effects on RSL than others. Many studies on different heavy metals during germination stage and seedling growth were reported that as the heavy metal concentrations increased, shoot length of studied plants decreased (Beri and Setia, 1995; Mishra and Choudhuri, 1998; Peralta et al., 2001; Verma and Dubey, 2003; Dabhi et al., 2005; Gyawali and Lekhak, 2006; Ahyan et al., 2007).

Means of RFW obtained from this study were given in Table 9. The heavy metal averages ranged from 30.2 to 39.0 mg plantlet⁻¹ while the dose averages ranged from 22.6 to 41.6 mg plantlet⁻¹. The means of interactions ranged from 8.4 to 47.6 mg plantlet⁻¹. When the interaction values were evaluated overall, Cd was more restricted to SFW of sorghum than other heavy metals. It was reported that some heavy metals had adverse effects on shoot fresh weight of maize, fenugreek and rice plants (Dabhi et al., 2005; Gyawali and Lekhak 2006; Aycıçek et al., 2008). Means of RFW were given in Table 10. The heavy metal averages ranged from 4.7 to 8.4 mg plantlet⁻¹ while the dose averages ranged from 2.4 to 10.4 mg plantlet⁻¹. The means of interaction ranged from 1.0 to 14.5 mg plantlet⁻¹. When the interaction values were evaluated overall, the 400 and 800 mg L⁻¹ doses of Cd, Ni and Hg seriously reduced root fresh weight. The effect of Pb and Cr on root fresh weight was more limited than other heavy metals. It was reported that some heavy metals had an adverse effect on root fresh weight of maize, fenugreek and rice plants (Dabhi et al., 2005; Gyawali and Lekhak 2006; Aycıçek et al., 2008).
Table 8. Effects of different heavy metals and doses on RSL of Sorghum plant

| Heavy Metals (Ağır Metaller) | Heavy Metal Doses (Ağırlık Dozları) (mg L⁻¹) | Heavy Metals Avg. (Ağırlık Metaller Ort.) |
|-----------------------------|---------------------------------------------|-----------------------------------------|
|                             | Control (Kontrol) 100 200 400 800           |                                         |
| Ni                          | 100.0⁻      102.6⁻  84.3⁻  73.2⁻  43.1⁻  80.6⁻         |
| Cd                          | 100.0⁻      72.5⁻    58.7⁻    38.9⁻    14.8⁻    57.0⁻         |
| Pb                          | 100.0⁻      86.9⁻    98.2⁻    99.4⁻    87.9⁻    94.5⁻         |
| Cr                          | 100.0⁻      88.8⁻    102.4⁻   81.5⁻    87.1⁻    92.0⁻         |
| Hg                          | 100.0⁻      109.8⁻   85.6⁻    34.6⁻    28.5⁻    71.7⁻         |

Dose Avg. (Dozlar Ort.) 100.0⁻ 92.1⁻ 85.8⁻ 65.5⁻ 52.3⁻

Ni, cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury

ABC and abcdef Mean in the same row or column with different superscript letters differ significantly from each other (p<0.05).

Table 9. Effects of different heavy metals and doses on SFW of Sorghum plant

| Heavy Metals (Ağır Metaller) | Heavy Metal Doses (Ağırlık Dozları) (mg L⁻¹) | Heavy Metals Avg. (Ağırlık Metaller Ort.) |
|-----------------------------|---------------------------------------------|-----------------------------------------|
|                             | Control (Kontrol) 100 200 400 800           |                                         |
| Ni                          | 39.2⁻      47.6⁻  42.2⁻  32.0⁻  17.3⁻  36.7⁻         |
| Cd                          | 47.0⁻      42.2⁻    34.3⁻    20.4⁻    8.4⁻    30.5⁻         |
| Pb                          | 39.6⁻      35.7⁻    40.8⁻    43.8⁻    33.9⁻    38.7⁻         |
| Cr                          | 41.6⁻      36.8⁻    41.2⁻    37.3⁻    37.6⁻    39.0⁻         |
| Hg                          | 30.4⁻abcdef 46.0⁻ 37.2⁻ 21.5⁻ 15.5⁻ 30.2⁻         |

Dose Avg. (Dozlar Ort.) 39.5⁻ 41.6⁻ 39.2⁻ 31.0⁻ 22.6⁻

Ni, cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury

ABC and abcdef Mean in the same row or column with different superscript letters differ significantly from each other (p<0.05).

Table 10. Effects of different heavy metals and doses on RFW of Sorghum plant

| Heavy Metals (Ağır Metaller) | Heavy Metal Doses (Ağırlık Dozları) (mg L⁻¹) | Heavy Metals Avg. (Ağırlık Metaller Ort.) |
|-----------------------------|---------------------------------------------|-----------------------------------------|
|                             | Control (Kontrol) 100 200 400 800           |                                         |
| Ni                          | 9.9⁻       7.7⁻    5.9⁻     1.0⁻     1.0⁻     5.1⁻         |
| Cd                          | 14.5⁻      8.2⁻    5.6⁻     1.0⁻     1.0⁻     6.1⁻         |
| Pb                          | 10.8⁻      8.9⁻    9.1⁻     9.0⁻     4.4⁻     8.4⁻         |
| Cr                          | 7.4⁻bcde   7.0⁻bcde 8.2⁻cdefe 5.7⁻cdefe 4.7⁻f        |
| Hg                          | 9.6⁻bcdef  7.2⁻bcde 6.0⁻bcdefe 1.0⁻bcdefe 1.0⁻         |

Dose Avg. (Dozlar Ort.) 10.4⁻ 7.8⁻ 7.0⁻ 3.5⁻ 2.4⁻

Ni, cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury

ABC and abcdef Mean in the same row or column with different superscript letters differ significantly from each other (p<0.05).

CONCLUSION
In conclusion, the RGR, RGI, MGT and RVI properties of sorghum seeds and RRL, RSL, RFW and SFW characteristics for seedling growth evaluated in this study adversely affected under Ni, Cd, Pb, Cr and Hg heavy metal stress during germination stage. However, the effect of each heavy metal was different. The negative effect of Hg and Cd evaluated in this work was higher than other heavy metals.

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Statement of Conflict of Interest
Authors have declared no conflict of interest.

Author’s Contributions
The contribution of the authors is equal.

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