KSÜ Tarım ve Doğa Derg 23 (6): 1608-1615, 2020
KSU J. Agric Nat 23 (6): 1608-1615, 2020
DOI:10.18016/ksutarimdoga.v23i54846.722592

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

Esra Nermin ERTEKİN[1], İbrahim ERTEKİN[2], Mehmet BİLGEN[3]
1,3Akdeniz Üniversitesi, Ziraat Fakültesi, Tarla Bitkileri Bölümü, Antalya, Türkiye, 2Hatay Mustafa Kemal Üniversitesi, Ziraat Fakültesi, Tarla Bitkileri Bölümü, Hatay, Türkiye
[1]https://orcid.org/0000-0002-5397-2239, [2]https://orcid.org/0000-0003-1393-8084 , [3]https://orcid.org/0000-0001-5671-2021
✉: bilgen@akdeniz.edu.tr

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×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.

Araştırma Makalesi

Makale Tarihçesi
Geliş Tarihi : 18.04.2020
Kabul Tarihi : 22.06.2020

Anahtar Kelimeler
Heavy metal
Germination
Seedling growth
Sorghum
Environment

Sorgumun Çimlenme ve Fide Gelişimi Üzerine Bazı Ağır Metallerin Etkisi

ÖZET

Topraklarda ağır metal kirlenmesi çoğu bitkinin tohum çimlenmesini ve fide gelişimini olumsuz etkileyebilir. Bu araştırma, Ni (nikel), Cd (kadmiyum), Pb (kurşun), Cr (krom) ve Hg (civa)' nın farklı dozlarının (0, 100, 200, 400 and 800 mg L^{-1}) sorgumun çimlenme ve fide gelişimi üzerine etkilerini belirlemek amacıyla yürütülmüştür. Araştırma, 2017 yılında Akdeniz Üniversitesi Ziraat Fakültesi'nde laboratuvar koşullarında yürütülmüştür. N48×Early Sumac sorgum çeşidi bitki materyali olarak kullanılmıştır. Bu araştırmada ağır metallerin etkisini belirlemek için çimlenme oranı (ÇO), nispi çimlenme indeksi (NÇİ), ortalama çimlenme süresi (OÇS), nispi canlılık indeksi (NCİ), nispi kök uzunluğu (NKU), nispi sap uzunluğu (NSU), kök yaş ağırlığı (KYA) ve sap yaş ağırlığı (SYA) özellikleri incelenmiştir. Araştırma sonuçları ağır metallerin hem çimlenme hem de fide özelliklerini olumsuz etkilediğini göstermiştir. Ayrıca, kadmiyumun çimlenme özellikleri üzerine olumsuz etkisi sınırlı düzeydeyken, fide özellikleri üzerinde ciddi olumsuz etkileri olmuştur. Ağır metal dozlarındaki artış da incelenen özellikleri olumsuz etkilemiştir. Sonuçta, bu çalışmada kullanılan ağır metallerin sorgumun incelenen özellikler üzerinde olumsuz etkiye sahip olmakla birlikte, özellikle Hg ve Cd diğerlerinden daha fazla olumsuz etkiye neden olmuştur.

Research Article

Article History
Received : 18.04.2020
Accepted : 22.06.2020

Keywords
Ağır metal
Çimlenme
Fide gelişimi
Sorgum
Çevre

To Cite : Ertekin EN, Ertekin İ, Bilgen, M 2020. Effects of Some Heavy Metals on Germination and Seedling Growth of Sorghum. KSÜ Tarım ve Doğa Derg 23 (3): 1608-1615. DOI: 10.18016/ksutarimdoga.v23i54846.722592

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 toxicity for human, animal and plant health (Järup, 2003; Azevedo 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; Rahman 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; Morzck and Funiccli, 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. Sorgum is extensively grown as a forage crops and becoming increasingly importance in many regions of the world (Miron et al., 2006; Yosef et al., 2009; 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 c 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.

Table 1. Knowledge about plant material and heavy metals.
Çizelge 1. Bitki materyali ve ağır metaller hakkında bilgiler.

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 / $Pb(NO_3)_2$	331.2	Riedel
Mercury / $Hg(NO_3)_2 \times H_2O$	342.62	Merck
Cadmium / $Cd(NO_3)_2 \times 4H_2O$	308.49	Panreae
Chromium / $Cr(NO_3)_3 \times 9H_2O$	400.15	Merck
Nickel / $Ni(NO_3)_2 \times 6H_2O$	290.81	Merck

Seed Germination

Seeds were sterilized with 5% H_2O_2 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 this study were given below.

$$GR\ (\%) = \text{number of germinating seeds} / \text{total seeds in each petri dishes} \quad (1)$$

$$MGT\ (day) = \sum D \times n / \sum n \quad (2)$$

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

$$RGI\ (\%) = GI_{heavy\ metals} / GI_{control} \times 100 \quad (3)$$

here, $GI = \sum Gt / Dt$ here, Gt is the number of germinated seeds in t days; Dt is the number of corresponding germination days

$$RVI\ (\%) = VI_{heavy\ metals} / VI_{control} \times 100 \quad (4)$$

here, $VI = GI \times S$ here, S means shoot length.

$$RRL \text{ or } RSL\ (\%) = \text{root or shoot length}_{heavy\ metals} / \text{root or shoot length}_{control} \times 100 \quad (5)$$

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

F 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
Çizelge 2. Bu çalışmada incelenen tüm özelliklerin F değerleri

Source of Variance *(Varyasyon Kaynağı)*	GR	RGI	MGT	RVI	RRL	RSL	SFW	RFW
Heavy Metals *(Ağır Metaller)*	2.2$^{n.s.}$	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 x 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 decreased the germination index of the turnip plant (Siddiqui et al., 2014).

Table 3. Effects of different heavy metals and doses on GR of sorghum
Çizelge 3. Sorgumun çimlenme oranı üzerine farklı ağır metallerin etkisi

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	95.0^{a}	88.3^{abcd}	88.3^{abcd}	89.2^{abcd}	91.7^{abc}	90.5
Cd	88.3^{abcd}	89.2^{abcd}	92.5^{ab}	91.7^{abc}	78.3^{cd}	88.0
Pb	95.0^{a}	88.3^{abcd}	90.8^{abc}	94.2^{ab}	93.3^{ab}	92.3
Cr	90.8^{abc}	90.8^{abc}	89.2^{abcd}	90.8^{abc}	89.2^{abcd}	90.2
Hg	97.5^{a}	94.2^{ab}	95.8^{a}	80.8^{bcd}	75.8^{d}	88.8
Dose Avg. *(Dozlar Ort.)*	93.3^{A}	90.2^{A}	91.3^{A}	89.3^{AB}	85.7^{B}	

Ni, nickel; Cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury
AB and abcd Mean in the same row or column with different superscript letters differ significantly from each other ($p<0.05$).

Table 4. Effects of different heavy metals and doses on RGI of Sorghum plant
Çizelge 4. Sorgumun nispi çimlenme indeksi üzerine farklı ağır metallerin etkisi

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	100.0^{ab}	92.1^{ab}	92.7^{ab}	94.0^{ab}	95.3^{ab}	94.8^{C}
Cd	100.0^{ab}	104.1^{a}	107.3^{a}	102.3^{a}	83.6^{b}	99.4^{A}
Pb	100.0^{ab}	94.7^{ab}	96.8^{ab}	99.2^{ab}	93.5^{ab}	96.8^{AB}
Cr	100.0^{ab}	101.8^{a}	101.0^{a}	103.6^{a}	100.0^{ab}	101.3^{A}
Hg	100.0^{ab}	93.3^{ab}	97.3^{ab}	64.9^{c}	58.1^{c}	82.7^{D}
Dose Avg. *(Dozlar Ort.)*	100.0^{A}	97.2^{AB}	99.0^{A}	92.8^{B}	86.1^{C}	

Ni, nickel; Cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury
ABC and abc Mean in the same row or column with different superscript letters differ significantly from each other ($p<0.05$).

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 Atis (2018) reported that the effect of nickel on MGT of perennial ryegrass was more pronounced than cadmium. Akıncı 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.

Table 5. Effects of different heavy metals and doses on MGT of Sorghum plant
Çizelge 5. Sorgumun ortalama çimlenme süresi üzerine farklı ağır metallerin etkisi

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	1.1^{cde}	1.2^{cde}	1.1^{cde}	1.1^{cde}	1.1^{cde}	1.1^{BC}
Cd	1.2^{cde}	1.1^{cde}	1.1^{cde}	1.3^{bcde}	1.3^{bcd}	1.2^{B}
Pb	1.2^{cde}	1.1^{cde}	1.1^{cde}	1.2^{cde}	1.4^{bc}	1.2^{B}
Cr	1.1^{cde}	1.1^{cde}	1.0^{e}	1.0^{de}	1.1^{cde}	1.0^{C}
Hg	1.1^{cde}	1.2^{cde}	1.2^{cde}	1.6^{ab}	1.7^{a}	1.4^{A}
Dose Avg. *(Dozlar Ort.)*	1.1^{BC}	1.1^{BC}	1.1^{C}	1.2^{AB}	1.3^{A}	

Ni, nickel; Cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury
ABC and abcde Mean in the same row or column with different superscript letters differ significantly from each other ($p<0.05$).

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 Kıran, 2005; Gyawali and Lekhak, 2006; Ayhan et al., 2007; He et al., 2014; Muhammad et al., 2015; Gedik et al., 2015; Akar and Atış, 2019).

Table 6. Effects of different heavy metals and doses on RVI of sorghum plant
Çizelge 6. Sorgumun canlılık indeksi oranı üzerine farklı ağır metallerin etkisi

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	100.0^{a}	94.6^{a}	78.1^{abc}	68.9^{abc}	41.3^{bcde}	76.6^{B}
Cd	100.0^{a}	75.7^{abc}	63.3^{abcd}	39.6^{cde}	12.3^{e}	58.2^{C}
Pb	100.0^{a}	81.7^{ab}	94.4^{a}	98.1^{a}	82.3^{ab}	91.3^{A}
Cr	100.0^{a}	90.8^{a}	103.7^{a}	84.9^{a}	87.8^{a}	93.4^{A}
Hg	100.0^{a}	101.8^{a}	82.8^{ab}	22.5^{de}	16.5^{e}	64.7^{BC}
Dose Avg. *(Dozlar Ort.)*	100.0^{A}	88.9^{AB}	84.5^{B}	62.8^{C}	48.0^{D}	

Ni, nickel; Cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury
ABCD and abcde Mean in the same row or column with different superscript letters differ significantly from each other ($p<0.05$).

Table 7. Effects of different heavy metals and doses on RRL of Sorghum plant
Çizelge 7. Sorgumun nispi kök uzunluğu üzerine farklı ağır metallerin etkisi

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	100.0^{ab}	66.3^{cde}	34.4^{gh}	9.7^{i}	4.3^{i}	42.9^{B}
Cd	100.0^{ab}	41.9^{efgh}	19.9^{hi}	4.4^{i}	2.2^{i}	33.7^{B}
Pb	100.0^{ab}	102.7^{a}	77.7^{bcd}	79.1^{abcd}	26.0^{ghi}	77.0^{A}
Cr	100.0^{ab}	91.5^{ab}	87.3^{abc}	82.0^{abcd}	59.5^{def}	84.1^{A}
Hg	100.0^{ab}	50.5^{efg}	35.5^{fgh}	7.3^{i}	4.3^{i}	39.5^{B}
Dose Avg. *(Dozlar Ort.)*	100.0^{A}	70.6^{B}	50.8^{C}	36.5^{D}	19.2^{E}	

Ni, nickel; Cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury
ABCDE and abcdefghi Mean in the same row or column with different superscript letters differ significantly from each other ($p<0.05$).

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; Ayhan et al., 2007).

Means of SFW 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; Gyewali and Lekhak 2006; Ayçiçek 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 $planlet^{-1}$. 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; Gyewali and Lekhak 2006; Ayçiçek et al., 2008).

Table 8. Effects of different heavy metals and doses on RSL of Sorghum plant
Çizelge 8. Sorgumun nispi sap uzunluğu üzerine farklı ağır metallerin etkisi

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	100.0^{a}	102.6^{a}	84.3^{ab}	73.2^{abcd}	43.1^{cdef}	80.6^{BC}
Cd	100.0^{a}	72.5^{abcd}	58.7^{bcde}	38.9^{def}	14.8^{f}	57.0^{D}
Pb	100.0^{a}	86.9^{ab}	98.2^{a}	99.4^{a}	87.9^{ab}	94.5^{A}
Cr	100.0^{a}	88.8^{ab}	102.4^{a}	81.5^{abc}	87.1^{ab}	92.0^{AB}
Hg	100.0^{a}	109.8^{a}	85.6^{ab}	34.6^{def}	28.5^{ef}	71.7^{C}
Dose Avg. *(Dozlar Ort.)*	100.0^{A}	92.1^{AB}	85.8^{B}	65.5^{C}	52.3^{D}	

Ni, nickel; Cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury
ABCD 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
Çizelge 9. Sorgumun sap yaş ağırlığı üzerine farklı ağır metallerin etkisi

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	39.2^{ab}	47.6^{a}	42.2^{ab}	32.0^{abcde}	17.3^{efg}	36.7^{AB}
Cd	47.0^{a}	42.2^{ab}	34.3^{abcd}	20.4^{cefg}	8.4^{g}	30.5^{B}
Pb	39.6^{ab}	35.7^{abcd}	40.8^{ab}	43.8^{ab}	33.9^{abcd}	38.7^{A}
Cr	41.6^{ab}	36.8^{abc}	41.2^{ab}	37.3^{ab}	37.9^{ab}	39.0^{A}
Hg	30.4^{abcdef}	46.0^{a}	37.2^{ab}	21.5^{cdefg}	15.5^{fg}	30.2^{B}
Dose Avg. *(Dozlar Ort.)*	39.5^{A}	41.6^{A}	39.2^{A}	31.0^{B}	22.6^{C}	

Ni, nickel; Cd, cadmium; Pb, lead; Cr, chromium; Hg, mercury
ABC and abcdefg 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
Çizelge 10. Sorgumun kök yaş ağırlığı üzerine farklı ağır metallerin etkisi

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	9.9^{b}	7.7^{bcde}	5.9^{cde}	1.0^{f}	1.0^{f}	5.1^{C}
Cd	14.5^{a}	8.2^{bcde}	5.6^{de}	1.0^{f}	1.0^{f}	6.1^{BC}
Pb	10.8^{ab}	8.9^{bcd}	9.1^{bcd}	9.0^{bcd}	4.4^{e}	8.4^{A}
Cr	7.4^{bcde}	7.0^{bcde}	8.2^{bcde}	5.7^{cde}	4.7^{e}	6.6^{B}
Hg	9.6^{bc}	7.2^{bcde}	6.0^{cde}	1.0^{f}	1.0^{f}	4.7^{C}
Dose Avg. *(Dozlar Ort.)*	10.4^{A}	7.8^{B}	7.0^{B}	3.5^{C}	2.4^{C}	

Ni, nickel; 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 effected 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.

ACKNOLEDGEMENT

This study was conducted as MSc thesis. It was also supported by Akdeniz University Scientific Research Projects Coordination Unit with the number of FYL-2017-2009.

Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

REFERENCES

Ahmad I, Akhtar MJ, Asghar HN, Zahir ZA 2013. Comparative efficacy of growth media in causing cadmium toxicity to wheat at seed germination stage. International Journal of Agriculture and Biology, 15: 517-522.

Akar M, Atis I 2018. The effects of priming pretreatments on germination and seedling growth in perennial ryegrass exposed to heavy metal stress. Fresenius Environmental Bulletin, 27(10): 6677-6685.

Akar M, Atış İ 2019. Priming uygulamalarının kadmiyum ve nikel stresine maruz bırakılan kırmızı yumağın çimlenme ve fide gelişimi üzerine etkisi. Gümüşhane Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 9: 26-36.

Akinci IE, Akinci S 2010. Effect of chromium toxicity on germination and early seedling growth in melon (*Cucumis melo* L.). African Journal of Biotechnology, 9: 4589-4594.

Akıncı İE, Çalışkan Ü 2010. Kurşunun bazı yazlık sebzelerde tohum çimlenmesi ve tolerans düzeyleri üzerine etkisi. Ekoloji, 19: 164-172.

Almansouri M, Kinet JM, Lutts S 2001. Effect of salt and osmotic stresses on germination in durum wheat (*Triticum durum* Desf.). Plant and Soil, 231: 243-254.

Amooaghaie R, Nikzad K 2013. The role of nitric oxide in priming-induced low-temperature tolerance in two genotypes of tomato. Seed Science Research, 23: 123-131.

Atis I, Konuskan O, Duru M, Gozubenli H, Yilmaz S 2012. Effect of harvesting time on yield, composition and forage quality of some forage sorghum cultivars. International Journal of Agriculture and Biology, 14: 879–886.

Ayçiçek M, Kaplan O, Yaman M 2008. Effect of cadmium on germination, seedling growth and metal contents of sunflower (*Helianthus annus* L.). Asian Journal of Chemistry, 20: 2663-2672.

Ayhan B, Ekmekçi Y, Tanyolaç D 2007. Erken fide evresindeki bazı mısır çeşitlerinin ağır metal (kadmiyum ve kurşun) stresine karşı dayanıklılığının araştırılması. Anadolu Üniversitesi Bilim ve Teknoloji Dergisi, 8: 411-422.

Azevedo RA, Lea PJ 2005. Toxic metals in plants. Brazilian Journal of Plant Physiology, 17: 1-1.

Beri A, Setia RC 1995. Assessment of growth and yield in *Lens culinaris* Medic var. Massar 9-12 treated with heavy metals under N-supplied conditions. Journal of the Indian Botanical Society, 74: 293-297.

Dabhi MS, Bhanderi P, Vyas AV 2005. Chromium toxicity study in fenugreek seedlings. Emerging trends in plant physiology, Ahmdabad. pp. 14.

Davies FT, Puryear JD, Newton RJ, Egilla JN, Grossi JAS 2002. Mycorrhizal fungi increase chromium uptake by sunflower plants: influence on tissue mineral concentration, growth, and gas exchange. Journal of Plant Nutrition, 25: 2389-2407.

Ellis RH, Roberts EH 1981. The quantification of ageing and survival in orthodox seeds. Seed Science and Technology, 9: 373-409.

Ertekin İ, Yılmaz Ş, Atak M, Can E 2018. Effects of different salt concentrations on the germination properties of Hungarian vetch (*Vicia pannonica* Crantz.) cultivars. Turkish Journal of Agricultural and Natural Sciences, 5: 175-179.

Ertekin İ, Yılmaz Ş, Atak M, Can E, Çeliktaş N 2017. Tuz stresinin bazı yaygın fiğ (*Vicia sativa* L.) çeşitlerinin çimlenmesi üzerine etkileri. Mustafa Kemal Üniversitesi Ziraat Fakültesi Dergisi, 22: 10-18.

Fang Z, Hu Z, Zhao H, Yang L, Ding C, Lou L, Cai Q 2017. Screening for cadmium tolerance of 21 cultivars from Italian ryegrass (*Lolium multiflorum* Lam) during germination. Grassland Science, 63: 36-45.

Farooqi ZR, Zafar-Iqbal M, Kabir M, Shafiq M 2009. Toxic effects of lead and cadmium on germination and seedling growth of *Albizia lebbeck* (L.) Benth. Pakistan Journal of Botany, 41: 27-33.

Gedik O, Kıran Y, Şahin A 2015. Kadmiyum'un *Vicia peregrina* L. tohumlarının çimlenmesi, kök gelişimi ve kök ucu hücreleri üzerindeki mitotik etkileri. Karaelmas Science and Engineering Journal, 5: 9-15.

Guo J, Dai X, Xu W, Ma M 2008. Over expressing GSHI and AsPCSI simultaneously increases the tolerance and accumulation of cadmium and arsenic in *Arabidopsis thaliana*. Chemosphere, 72: 1020-1026.

Güvercin D 2017. Sorgum tohumlarında ağır metal stresi etkilerinin hafifletilmesinde bazı bitki büyüme regülatörlerinin rolü. Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 21: 886-893.

Gyawali R, Lekhak HD 2006. Chromium tolerance of rice (*Oryza sativa* L.) cultivars from Kathmandu Valley, Nepal. Scientific World, 4: 102-108.

He J, Ren Y, Chen X, Chen H 2014. Protective roles of nitric oxide on seed germination and seedling growth of rice (*Oryza sativa* L.) under cadmium stress. Ecotoxicology and Environmental Safety, 108: 114-119.

Hossain M, Arefin M, Khan B, Rahman M 2005. Effects of seed treatments on germination and seedling growth attributes of horitaki (*Terminalia chebula* Retz.) in the nursery. Research Journal of Agriculture and Biological Sciences, 1: 135-141.

Huffman EWD Jr., Allaway HW 1973. Chromium in plants: distribution in tissues, organelles, and extracts and availability of bean leaf Cr to animals. Journal of Agricultural and Food Chemistry, 21: 982-986.

Järup L 2003. Hazards of heavy metal contamination. British Medical Bulletin, 68: 167-182.

Kabir M, Iqbal MZ, Muhammad M, Farooqi ZR 2008. Reduction in germination and seedling growth of *Thespesia populnea* L., caused by lead and cadmium treatments. Pakistan Journal of Botany, 40: 2419-2426.

Li CX, Feng SL, Shao Y, Jiang LN, Lu XY, Hou XL 2007. Effects of arsenic on seed germination and physiological activities of wheat seedlings. Journal of Environmental Sciences, 19: 725-732.

Miron J, Solomon R, Adin G, Nir U, Nikbachat M, Yosef E, Carmi A, Winberg ZG, Kipnis T, Zuckerman E, Ben-Ghedalia D 2006. Effects of harvest stage and re-growth on yield, composition, ensilage and in vitro digestibility of new forage sorghum varieties. Journal of the Science of Food and Agriculture, 86: 140–147.

Mishra A, Choudhuri MA 1998. Amelioration of lead and mercury effects on germination and rice seedling growth by antioxidants. Biologia Plantarum, 41: 469-473.

Mohanpuria P, Rana NK, Yadav SK 2007. Cadmium induced oxidative stress influence on glutathione metabolic genes of *Camella sinensis* (L.). O Kuntze. Environ. Toxicol., 22: 368-374.

Moosavi SA, Gharineh MH, Afshari RT, Ebrahimi A 2012. Effects of some heavy metals on seed germination characteristics of canola (*Brassica napus*), wheat (*Triticum aestivum*) and safflower (*Carthamus tinctorious*) to evaluate phytoremediation potential of these crops. Journal of Agricultural Science, 4: 11-19.

Morzck E Jr., Funicclli NA 1982. Effect of lead and on germination of *Spartina alterniflora* Losiel. seeds at various salinities. Environmental and Experimental Botany, 22: 23-32.

Muhammad ZI, Maria KS, Mohammad A, Muhammad S, Zia-Ur-Rehman F, Muhammad K 2015. Effect of mercury on seed germination and seedling growth of Mungbean (*Vigna radiata* (L.) Wilczek). Journal of Applied Sciences and Environmental Management, 19: 191-199.

Munzuroglu O, Geckil H 2002. Effects of metals on seed germination, root elongation, and coleoptile and hypocotyl growth in *Triticum aestivum* and *Cucumis sativus*. Archives of Environmental Contamination and Toxicology, 43: 203-2013.

Peralta JR, Gardea-Torresdey JL, Tiemann KJ, Gomez E, Arteaga S, Rascon E, Parsons JG 2001. Uptake and effects of five heavy metals on seed germination and plant growth in alfalfa (*Medicago sativa* L.). Bulletin of Environmental Contamination and Toxicology, 66: 727-734.

Rahman H, Sabreen S, Alam S, Kawai S 2005. Effects of nickel on growth and composition of metal micronutrients in barley plants grown in nutrient solution. Journal of Plant Nutrition, 28: 393-404.

Şahin A, Kıran Y 2005. The effects of the lead on the seed germination, root growth, and root tip cell mitotic divisons of *Lens culinaris* Medik. Gazi Üniversitesi Fen Bilimleri Dergisi, 18: 17-25.

Shafiq M, Iqbal MZ, Mohammad A 2008. Effect of lead and cadmium on germination and seedling growth of *Leucaena leucocephala*. Journal of Applied Sciences and Environmental Management, 12: 61-68.

Sharma P, Dubey RS 2005. Lead toxicity in plants. Brazilian Journal of Plant Physiology, 17: 35-52.

Siddiqui MM, Abbasi BH, Ahmad N, Ali M, Mahmood T 2014. Toxic effects of heavy metals (Cd, Cr and Pb) on seed germination and growth and DPPH-scavenging activity in *Brassica rapa* var. *turnip*. Toxicology and Industrial Health, 30: 238-249.

Soudek P, Katrusakova A, Selacek L, Petrova S, Koci V, Marsik P, Griga M, Vanek T 2010. Effect of heavy metals on inhibition of root elongation in 23 cultivars of falx (*Linum usitatissimum* L.). Archives of Environmental Contamination and Toxicology, 59: 194-203.

Subrahmanyam D 2008. Effects of chromium toxicity on leaf photosynthetic characteristics and oxidative changes in wheat (*Triticum aestivum* L.). Photosynthetica, 46: 339-345.

Verma S, Dubey RS 2003. Lead toxicity induces lipid peroxidation and alters the activities of antioxidant enzymes in growing rice plants. Plant Science, 164: 645-655.

Wang Y, Li L, Cui W, Xu S, Shen W, Wang R 2011. Hydrogen sulfide enhances alfalfa (*Medicago sativa*) tolerance against salinity during seed germination by nitric oxide pathway. Plant Soil, 351: 107-119.

Yosef E, Carmi A, Nikbachat M, Zenou A, Umiel N, Miron J 2009. Characteristics of tall versus short-type varieties of forage sorghum grown under two irrigation levels, for summer and subsequent fall harvests, and digestibility by sheep of their silages. Animal Feed Science and Technology, 152: 1–11

Zhou ZS, Huang SQ, Guo K, Mehta SK, Zhang PC, Yang ZM 2007. Metabolic adaptations to mercury-induced oxidative stress in roots of *Medicago sativa* L. Journal of Inorganic Biochemistry, 101: 1-9.