Isparta Uygulamalı Bilimler Üniversitesi
Ziraat Fakültesi Dergisi
ISSN 1304-9984

Research Article/Araştırma Makalesi

Ziraat Fakültesi Dergisi,
Cilt 17, Sayı 2,
Sayfa 119-128, 2022

Journal of the Faculty of Agriculture
Volume 17, Issue 2,
Page 119-128, 2022

Improvement of Rice *(Oryza sativa)* Germination and Seedling Growth Under Cadmium Stress Conditions Using Different Seed Priming Agents

Samet KARATAŞ[1], Ömer KONUŞKAN*[2]

Abstract: The non-essential heavy metal cadmium (Cd) prevents rice seed germination and seedling growth when it is present in micromolar concentrations. To mitigate the effects of Cd toxicity on rice, seed priming, a pre-germinated seedling approach, may improve seed and seedling performance. In 2019, an experiment was conducted in Turkey to evaluate seed germination and seedling growth of rice. The experiment was comprised of five concentrations of Cd stress (0, 50, 100, 200 and 400 ppm) on three rice cultivars (Osmancık 97, Halilbey, and Kızıltan) and three seed priming techniques such as hydropriming, priming using 2% KNO_3 (potassium nitrate), and priming using 100 mg/L salicylic acid. The complete randomized design was arranged to be conducted with three replications in this investigation. The findings demonstrated that each Cd dose had detrimental effects on seed germination and seedling growth in all rice varieties. All varieties showed different reactions to priming treatments. Hydropriming showed the most positive impact on germination, while priming with KNO_3 exhibited negative effects for all rice varieties. The Cd content of plant roots were higher than the shoots. It was observed that the lowest Cd content was detected in the shoots and roots of plants which were pre-treated with SA as compared to other priming applications. More than 50 ppm of cadmium was harmful because it lowered morphological features. However, seed hydropriming partially corrected these effects. For Cd stress resistance, the rice genotype Kızıltan continued to outperform the other cultivars studied.

Keywords: Cadmium, germination, *Oryza sativa*, KNO_3, salicylic acid

Kadmiyum Stres Koşullarında Farklı Priming Uygulamalarında Çeltiğin Çimlenme ve Fide Gelişimi

Öz: Bir ağır metal olan kadmiyum (Cd), çok düşük konsantrasyonlarda çeltiğin çimlenme ve fide gelişimini engeller. Kadmiyumun çeltiğin üzerine olan etkilerini azaltmak için, priming uygulamaları, tohum ve fide performansını iyileştirebilir. 2019 yılında yapılan bu çalışmada çeltiğin çimlenme ve fide gelişiminin değerlendirilmiştir. Deneme, tesdüf parselleri deneme deseninde üç faktörlü olarak (üç çeltik çeşidi (Osmancık 97, Halilbey ve Kızıltan), beş Cd konsantrasyonu (0, 50, 100, 200 ve 400 ppm) ve üç priming farklı uygulaması (hidropriming, %2 KNO_3, salisilik asit) yürütülmüştür. Araştırma sonuçları, her bir Cd dozunun tüm çeltik çeşitlerinde tohum çimlenmesi ve fide büyümesi üzerinde zararlı etkileri olduğunu göstermiştir. Tüm çeşitler, priming uygulamasına farklı tepkiler göstermiştir. Hidropriming; çimlenme üzerinde en olumlu etkiyi gösterirken, KNO_3 uygulaması tüm çeltik çeşitleri için olumsuz etkiler göstermiştir. Bitki köklerinin Cd içeriği sürgünlerden daha yüksek bulunmuştur. Salisilik asit uygulamasında köklerdeki kadmiyum içerikleri diğer priming uygulamalarına göre daha düşük bulunmuştur. 50 ppm'den fazla kadmiyum dozlarında morfolojik özellikler daha fazla etkilenmiştir. Bununla birlikte, hidropriming bu etkileri kısmen düzeltmiştir. Cd stresi altında, Kızıltan çeltik çeşidini en iyi performans göstermiştir.

Anahtar Kelimeler: Kadmiyum, çimlenme, *Oryza sativa*, KNO_3, salisilik asit

***Sorumlu yazar (Corresponding author)**
okonuskan@mku.edu.tr

Alınış (Received): 05/09/2022
Kabul (Accepted): 05/10/2022

[1]Hatay Mustafa Kemal University, Institute of Natural and Applied Sciences, Hatay, Türkiye.

[2]Hatay Mustafa Kemal University, Faculty of Agriculture, Department of Field Crops, Hatay, Türkiye.

 DOI: 10.54975/isubuzfd.1171385

1. Introduction

Rice (*Oryza sativa* L.) is one of the most essential cereal crops, and it is a staple food for more than half of the world's population. Around 90% of the world's rice is grown in Asian countries (Al-Ashkar et al., 2016; Das et al., 2018; Anis et al., 2019; Hossain et al., 2021). Worldwide, rice fulfils around 80% of the requisite calories for its people (Monsur et al., 2020). Worldwide rice production is significantly impacted by abiotic and biotic stressors. (Jamshidian and Talat, 2017; Wasaya et al., 2022). Drought, salinity, cold, flooding, high temperatures, and heavy metal contamination are the main abiotic stress factors for rice (Datta et al., 2021). Fe, Cu, Mn, Co, Ni, Zn, Cd, Hg, and arsenic are considered to be the major heavy metals found in soil, and some of these metals are essential micronutrients responsible for many regular processes in plants. The common detrimental influences of heavy metals are distorted nutrient assimilation, chlorosis, and reduction in growth and photosynthesis. These result in lower biomass accumulation and senescence, and finally lead to the death of plants (Ali et al., 2011).

Cadmium (Cd) is considered to be one of the major heavy metal toxic pollutants (Jarup and Akesson, 2009). It finds its way to the environment through waste produced as a result of industrial processes, urban activities, indiscriminate use of fertilizers, and sewage sludge (Liu et al., 2007; Parlakova Karagöz and Dursun, 2020). Generally, the concentration of Cd in the natural environment is very low, but even at low concentrations, it may cause toxicity because of its non-essential role in plants (White and Brown 2010; Farah et al., 2020). Cd in soil interferes with germination and has a detrimental effect on cereal seedling growth (Gözübenli, 2010). Ultimately, this leads to poor seedling establishment which results in lower grain yields and reduced efficacy in the utilization of farm resources. The main causes for the rise in Cd concentrations in soils are a variety of human activities, such as zinc mining and smelting as well as the use of chemical fertilizers and pesticides (Li et al., 2006). The natural protective responses for plants under heavy metal toxicity stress include activation of several antioxidative defence mechanisms and a decrease in absorption (Shahid et al., 2015).

Seed priming is a straightforward method for pre-germinating seeds. It can be used to boost seed and seedling performance and alleviate various abiotic stresses, such as heavy metal exposure (Iqbal et al., 2015a,b; Akar and Atis, 2018; Akar and Atis, 2019). It is a low-cost hydration technique in which seeds are soaked in a priming solution followed by drying the seeds. This initiates germination related processes without radicle emergence (Iqbal et al., 2015c; Nyoni et al., 2020; Choudhary et al., 2021). Different priming agents such as potassium nitrate (KNO_3) and ascorbic acid (AsA) and hormones like salicylic acid (SA) and gibberellic acid (GA_3) are used as priming agents in seed priming techniques which can greatly promote better germination and establishment of field crops such as rice, wheat, and maize under different stress conditions (Iqbal, 2015). Among priming agents, SA is a phytohormone that is effective against various stresses in plants (Arfan, 2009).

Seed priming works by regulating the amount of hydration in seeds. In turn, this controls the metabolic activity required for radical emergence. (Iqbal et al., 2015b; Anwar et al., 2021). The initiation of radical emergence usually takes place in the presence of high seed water content. To meet this requirement, seeds sown in field conditions usually take time to absorb a sufficient amount of water from the soil (Iqbal, 2015a). Hence, priming agents, especially hydropriming (soaking seeds in sterilized water), are supposed to reduce the time taken to germination (Iqbal et al., 2015a; Ali et al., 2016; Mamum et al., 2018). Nawaz et al., (2013) found that the promotion of pre-germination metabolic activity prior to the emergence of the radicle and plumule is the underlying mechanism behind priming and imparting tolerance against stress. Even in normal conditions, seed priming led to robust seedling growth, and ideal seedling establishment increased the grain yield of transplanted rice, as reported by Mamun et al., (2018); Iqbal (2015a), and Waraich et al., (2021). In wheat, Shakirova et al., (2016) reported that seed priming with SA decreased the negative effect of Cd toxicity.

The world's population is growing, and this increases the need for industrial products. It is anticipated that the problem of heavy metal toxicity will worsen in the future and have a significant impact on crop output, especially rice. Zhao et al., (2018) reported that the area of agricultural soil in China that is polluted by heavy metals through sewage irrigation was nearly 20% of the total agricultural land, and the area of agricultural soil polluted by cadmium was 1.133×107 hm^2 . Shao et al., (2004) observed that Cd stress greatly affects the seedling growth of rice, and there were significant differences in seedling growth and antioxidant enzyme activities among different Cd tolerance rice genotypes. Jun-yu et al., (2008) found that higher Cd concentration damages humans through the food chain, in addition to having negative impacts on crop output and quality. Additionally, they stated that different rice cultivars responded differently to various Cd stress levels.

Turkey's Cd concentration is rising steadily. Data on how Turkish rice cultivars fare under various levels of Cd stress and which cultivars respond best to seed priming techniques are not yet available. The goal of the current study is to evaluate the effectiveness of various priming agents on seed germination of rice varieties and seedling growth under Cd stress.

2. Materials and Methods

2.1. Location and duration

The investigation was carried out in 2019 under controlled circumstances at the Field Crops Laboratory of Mustafa Kemal University in Hatay, Turkey.

2.2. Experimental treatments and design

The experimental design was a three factorial design arranged in a completely randomized design with three replications. The experiments examined five concentrations of Cadmium (Cd) stress (0, 50, 100, 200 and 400 ppm) on three rice cultivars (Osmancık 97, Halilbey and Kızıltan) and three seed priming techniques, such as priming using fresh water (hydropriming), priming using 2% potassium nitrate (2% KNO_3), and priming using 100 mg/L salicylic acid, to evaluate seed priming efficacy on germination and seedling growth under different Cd stress conditions. Cadmium stress was imposed using cadmium sulphate hydrate (3 Cd SO_4. $8H_2O$). The seeds of three rice cultivars were primed in a beher glass for 48 hours at 25 °C. Twenty-five seeds from each priming technique for each cultivar were placed in petri dishes containing three layers of filter paper (Anchor Paper Co., St. Paul, Minn.). The tests were performed by following the protocols suggested by ISTA (ISTA 1996). The papers were rolled, placed in a plastic container (21.5 x 32.5 x 5.5 cm), and incubated in a dark germinator at 25 °C for 10 days.

2.3. Data collection

Seed germination was measured every 24 hours up until the tenth day of incubation. A seed was considered germinated when the emerging radicle was at least 2 mm long. At the final count, seedlings were classified as either normal or abnormal.

Germination percentage was calculated using the following formula 1 (ISTA, 1996):

$$\text{Germination percentage} = \frac{\text{Number of normal seedlings at final count}}{\text{Number of seeds placed for germination}} x100 \quad (1)$$

The Germination Index (GI) was measured according to Ellis and Roberts (1980) using the following formula 2:

$$\text{GI} = \sum(\text{Gt}/\text{Tt}) \quad (2)$$

where Gt is the number of seeds germinated on the t^{th} day, and Tt is the number of days up to the t^{th} day.

Mean germination time (MGT) was measured according to the formula of Wang et al., (2004), formula 3:

$$\text{MGT} = \sum(\text{D x n})/\Sigma\text{n} \quad (3)$$

where n is the number of seeds germinated on each day, and D is the day of counting. The tolerance index (TI) was measured by using the formula of Çarpıcı et al., (2009), as shown formula 4:

$$\text{TI} = \sum(\text{Gt}/\text{Tt}) \quad (4)$$

where Gt is the number of seeds germinated on the t^{th} day, and Tt is the number of days up to the t^{th} day.

The isolated roots and the shoots were washed in distilled water, dried, and ground (≤05 mm). The Cd content was determined with inductively coupled plasma optic emission spectrometry (ICP-OES Agilent 5110) after dry-ashing (Wang et al., 2007).

2.4. Statistical analysis

All of the data were thoroughly examined for homogeneity before being divided into parts with the use of a computer for analysis using the MSTAT-C statistical program. The treatment means were compared using the least significant difference (LSD) test at the 5% probability level (Gomez and Gomez, 1984).

3. Results and Discussion

The findings showed that different priming techniques had diverse effects on crop development at various Cd concentrations (Table 1,2,3,4). In all of the conditions, the maximum values of germination and crop growth traits were recorded for Kızıltan with hydropriming (Table 5-9). The present study's findings unmistakably showed that priming improved the seedling growth metrics for rice root and shoot weights.

The findings showed that all rice germination features, as well as the interactions among varieties, priming methods, and Cd concentrations, were strongly impacted by the treatments (Table 1). The highest performance for germination rate, germination index, mean germination time, etc. was recorded by hydropriming as compared to rest of the priming treatments. Among rice cultivars, Kızıltan outperformed the rest of the cultivars, especially under the controlled conditions for germination indices, while increasing the level of Cd stress hampered germination related parameters. It might be inferred that superior genetic potential and seed invigoration with hydropriming enabled rice seeds to perform better in terms of germination indices under various Cd stress levels. Increased amylase activity, which is favourably connected with reserve mobilization and MGT in rice, may have contributed to the notable improvement in germination (Lee and Kim, 2000). Our results indicated that primed seeds emerged faster and decreased the MGT. Similar results were also found by Harris et al., (2001). The positive effect of priming treatments was most likely a result of the stimulatory effects of priming in the early stage of germination processes by the mediation of cell division in germinating seeds (Khafagy et al., 2017). These results are in line with those of Iqbal (2015) who concluded that hydropriming was successful in increasing cereal germination indices. It has also been revealed that priming seeds slowly provided water, and this allowed for a slow and controlled imbibition, prompting rehydration cell membrane repair mechanisms to operate efficiently and adequately (Mercado and Fernandez, 2002). According to several studies, hydropriming increases the rate of seedling emergence, seedling establishment, and early vigour (Iqbal et al., 2015a; Khafagy et al., 2017).

Cultivar, seed priming, and Cd stress all interacted to significantly affect rice seedling and root growth. Hydropriming remained effective in boosting root length and fresh weight along with seedling length and fresh weight compared to all other priming treatments, especially up to 100 ppm Cd stress, while higher levels of Cd stress reduced root and seedling growth of all rice cultivars. It was possible to conclude that the rice variety Kızıltan cultivar had greater genetic potential and responded favourably to water-soaked seed treatment when exposed to Cd stress. Similarly, following the trend, the greatest root and seedling dry weights were also recorded by Kızıltan cultivar seeds treated with hydropriming. In terms of the seedling and root growth parameters under study, the Osmancık-97 cultivar could not perform on par with the other cultivars, while priming with KNO_3 remained inferior compared to hydropriming. Our findings also depicted that increased Cd stress reduced root and seedling growth of all rice cultivars under investigation. Cd had detrimental consequences that were visible at the molecular, physiological, and biochemical levels. It led to amend structures and ultra-structures of photosynthetic apparatus, and thus the photosynthetic rate was reduced (Xue et al., 2013). The ability of seed priming to induce abiotic stress, such as metal toxicity tolerance in plants, was not diminished. (Farooq et al., 2019). Using different chemicals for seed priming improved the seedling growth of cereals (Farooq et al., 2019). Probably due to hormonal imbalance, priming therapy on seed germination increased fresh and dry weights of rice roots and seedlings and decreased the amount of growth-inhibiting chemicals such abscisic acid (Demir et al., 1999). Similar results were reported by Ruan et al., (2002) who reported significant improvement on seedling growth of hydroprimed seeds of cereals. The faster emergence rate after priming may be due to an increased rate of cell division in the root tips of seedlings from primed seeds, as reported in wheat (Basra et al., 2006). This result agrees with that of Tongma et al., (2001) and Farooq et al., (2006). It has been noted that priming has positive impacts on repairing and accumulating nucleic acids, triggering the creation of proteins, and repairing damaged membranes (Moradi et al., 2008).

In order to prevent the hazardous effects of Cd, determining the Cd concentrations in roots and seedlings is of great importance, in addition to rice cultivar performance in terms of root and seedling growth. The results showed that hydropriming remained effective in ameliorating Cd stress by reducing Cd uptake in both roots as well as seedlings. Hydroprimed seeds of Kızıltan recorded the least Cd contents in roots and seedlings, and less Cd was observed in the shoots as compared to the roots. The lowest Cd content was recorded in Kızıltan roots and shoots (Figure 1). The optimum availability of nutrients to seedlings following their emergence, which improved the early growth and consequently led to improved barley fresh and dry weight within the nutrient primed seed treatments, could also be responsible for the improvement in barley seedling fresh and dry weight. (Khafagy et al., 2017). In terms of the interactions between rice varieties and priming agents, the findings showed that nearly all interactions considerably improved rice germination and early seedling growth parameters.

Table 1. Seed priming alleviates cadmium stress during germination and early seedling growth stages of rice

Cd (ppm)	Priming	GR (%)	GI	MGT (day)	TI	RL (cm)	SL (cm)
	H_2O	78.67 b	9.88 d	4.02 b-e	100.00 d	15.88 e	34.91 e
0	KNO_3	14.83 ı	1.42 ı	2.73 f	27.93 ı	3.34 j	11.65 k
	SA	77.66 b	10.06 cd	4.25 a-d	100.00 d	12.87 f	32.09 f
	H_2O	82.50 a	11.39 a	3.40 ef	168.24 a	22.94 c	45.94 a
50	KNO_3	21.16 ı	2.38 k	3.69 c-e	34.00 g	6.39 h	15.84 ı
	SA	83.33 a	11.73 a	3.56 de	136.44 c	24.22 a	43.71 b
	H_2O	71.00 c	10.84 b	3.56 de	153.06 b	21.87 d	42.21 c
100	KNO_3	16.67 ı	1.86 jk	4.03 a-e	29.16 h	4.24 ı	12.14 j
	SA	65.00 d	8.10 f	3.99 b-e	137.26 c	23.45 b	36.06 d
	H_2O	71.33 c	10.47 cb	3.99 b-e	95.19 e	11.45 g	27.67 h
200	KNO_3	17.16 ı	1.93 ı	4.34 a-c	21.87 j	3.30 j	7.29 l
	SA	59.83 e	8.87 e	4.04 a-c	95.55 e	12.47 f	28.68 g
	H_2O	45.16 g	6.16 h	4.43 ab	0.00 k	0.00 k	12.29 j
400	KNO_3	3.50 j	0.37 j-l	4.75 a	0.00 k	0.00 k	0.00 m
	SA	48.33 f	6.81 g	3.82 b-e	0.00 k	0.00 k	12.54 j
LSD		2.50	0.441	0.727	0.890	0.209	0.414

GR: Germination rate, GI: germination index, MGT: Mean germination time, TI: Tolarance index, RL: Root length, SL: Seedling length

Table 2. Seed priming alleviates cadmium stress during germination and early seedling growth stages of rice

Cd (ppm)	Priming	RFW (mg)	SFW (mg)	RDW (mg)	SDW (mg)	RCdC (ppm)	SCdC (ppm)
	H_2O	14.85 e	22.12 d	14.80 d	21.58 e	0.00 h	0.00 j
0	KNO_3	3.90 k	6.72 ı	3.57 ı	6.72 ı	0.00 h	0.00 j
	SA	10.79 h	22.17 d	10.37 g	21.82 e	0.00 h	0.00 j
	H_2O	19.70 b	29.49 a	19.70 b	28.62 a	15.39 e	11.21 f
50	KNO_3	4.45 ı	8.47 h	4.34 h	8.24 h	5.50 g	3.81 ı
	SA	15.14 d	25.50 b	15.06 d	25.12 b	12.28 f	10.24 g
	H_2O	20.71 a	25.25 b	20.30 a	24.07 c	28.37 c	22.63 d
100	KNO_3	4.26 j	6.81 ı	4.00 h	6.54 ı	11.67 f	8.35 h
	SA	18.26 c	22.92 c	18.23 c	22.58 d	21.76 d	18.58 e
	H_2O	11.47 g	16.12 f	11.13 f	16.19 f	76.54 a	48.27 a
200	KNO_3	2.84 l	5.47 k	2.93 j	5.29 k	22.34 d	11.54 f
	SA	12.75 f	16.99 e	12.94 e	15.89 f	59.68 b	38.73 e
	H_2O	0.00 m	6.19 j	0.00 k	5.73 j	0.00 h	48.07 a
400	KNO_3	0.00 m	0.00 l	0.00 k	0.00 l	0.00 h	0.00 j
	SA	0.00 m	9.56 g	0.00 k	9.34 g	0.00 h	41.16 b
LSD		0.148	0.289	0.382	0.419	0.996	0.940

RFW: Root fresh weigth, SFW: Seedling fresh weigth, RDW: Root dry weigth, SDW: Seedling dry weigth, RCdC: Root cadmium, SCd C: Seedling cadmium

Table 3. Seed priming alleviates cadmium stress during germination and early seedling growth stages of rice

Cd (ppm)	Variety	GR (%)	GI	MGT (day)	TI	RL (cm)	SL (cm)
	Osmancık-97	49.67 a	5.63 g	3.23 e-f	66.67 ı	7.16 k	14.17 ı
0	Halilbey	45.33 g	5.60 g	3.91 c-e	66.67 ı	13.43 e	33.40 d
	Kızıltan	76.16 b	10.12 e	4.26 a-d	84.56 g	10.10 g	31.08 e
	Osmancık-97	54.17 d	7.32 f	4.91 a	94.69 e	8.77 ı	15.90 h
50	Halilbey	48.83 ef	5.83 g	3.06 f	133.01 a	18.56 c	33.94 e
	Kızıltan	84.0 a	12.35 a	3.70 c-f	110.99 d	26.22 a	55.64
	Osmancık-97	47.0 fg	6.98 f	3.97 c-d	84.98 g	7.61	12.45 k
100	Halilbey	32.5 h	4.42 h	3.85 c-e	118.63 b	16.93	31.42 e
	Kızıltan	73.17 c	9.02 d	4.42 a-c	115.86 c	25.06	46.54 b
	Osmancık-97	48.67 ef	6.91 f	4.17 b-d	49.76 j	5.30 l	10.24 m
200	Halilbey	26.33 ı	3.92 ı	3.19 ef	85.91 f	10.37 h	23.48 g
	Kızıltan	73.33 c	10.80 b	3.61 d-f	76.93 h	11.57 f	29.90 f
	Osmancık-97	20.33 j	2.38 k	4.83 ab	0.00 k	0.00 m	0.00 n
400	Halilbey	21.16 j	3.02 p	3.74 c-f	0.00 k	0.00 m	13.56 j
	Kızıltan	55.5 d	8.03 c	4.03 cd	0.00 k	0.00 m	11.27 l
LSD		2.5	0.441	0.727	0.890	0.209	0.414

GR: Germination rate, GI: germination index, MGT: Mean germination time, TI: Tolarance index, RL: Root length, SL: Seedling length

Table 4. Seed priming alleviates cadmium stress during germination and early seedling growth stages of rice

Cd (ppm)	Variety	RFW (mg)	SFW (mg)	RDW (mg)	SDW (mg)	RCdC (ppm)	SCdC (ppm)
	Osmancık-97	6.68 j	9.31 ı	5.94 ı	8.87 j	0.00 g	0.00 ı
0	Halilbey	13.31 d	19.01 e	13.32 c	18.88 e	0.00 g	0.00 ı
	Kızıltan	9.54 g	22.68 c	9.48 f	5.80 l	0.00 g	0.00 ı
	Osmancık-97	9.31 h	13.42	8.99 g	12.61 h	8.84 f	6.81 h
50	Halilbey	16.54 c	21.33.d	16.51 b	21.23 d	8.15 f	5.99 h
	Kızıltan	13.45 d	28.71 a	13.60 c	28.14 a	16.18 de	12.46 g
	Osmancık-97	8.62 ı	11.77 h	8.05 h	11.35 ı	15.23 e	13.77 f
100	Halilbey	17.07 b	16.74 f	17.08 a	16.24 g	16.97 d	13.34 fg
	Kızıltan	17.54 a	26.49 b	17.40 a	25.61 b	29.60 c	12.46 g
	Osmancık-97	5.43 k	6.51 j	5.12 j	6.34 k	47.34 b	41.08 b
200	Halilbey	11.25 e	13.23 g	11.30 d	12.84 h	47.84 b	22.64 e
	Kızıltan	10.39 f	18.84 e	10.48 e	18.11 f	63.38 a	22.47 d
	Osmancık-97	0.00 l	0.00 l	0.00 k	0.00 m	0.00 g	41.08 b
400	Halilbey	0.00 l	6.21 k	0.00 k	5.80 l	0.00 g	37.36 c
	Kızıltan	0.00 l	9.54 ı	0.00 k	9.28 j	0.00 g	51.87 a
LSD		0.148	0.248	0.382	0.419	0.996	0.940

RFW: Root fresh weigth, SFW: Seedling fresh weigth, RDW: Root dry weigth, SDW: Seedling dry weigth, RCdC: Root cadmium content, SCd C: Seedling cadmium content

Table 5. Interaction effects between priming and varieties

	RFW (mg)			SFW (mg)			RDW (mg)		
	H_2O	KNO_3	SA	H_2O	KNO_3	SA	H_2O	KNO_3	SA
Osmancık-97	9.05 e	0.00 g	8.98 e	15.46 e	0.00 g	10.15 f	8.57 ef	0.00 g	8.29 f
Halilbey	19.03 a	0.00 g	16.87 b	22.97b	0.00 g	22.94 b	17.89 a	0.00 g	16.99 b
Kızıltan	12.96 c	9.27 d	8.33 f	22.60 c	16.49 d	24.68 a	13.02 c	8.91 d	8.65 cd
LSD		0.115			0.1928			0.296	
	SDW (mg)			RCdC (ppm)			SCdC (ppm)		
Osmancık-97	13.79 e	0.00 g	9.73 f	24.10 ab	0.00 e	18.74 d	20.60 d	0.00 g	16.38 c
Halilbey	22.34 b	0.00 g	22.66 b	24.77 a	0.00 e	19.01 d	26.53 c	0.00 g	21.07 d
Kızıltan	21.59 c	16.1 d	24.44 a	23.31 e	23.70 be	18.48 d	30.98 a	14.22 f	22.78 b
LSD		0.325			0.771			0.728	

RFW: Root fresh weigth, SFW: Seedling fresh weigth, RDW: Root dry weigth, FRW: Fresh root length, RCdC: Root cadmium content, SCdC: Seedling cadmium content

Table 6. Interaction effects between priming and varieties

Cd (ppm)	PM	GR (%)			GI			MGT (day)		
		Osmancık -97	Halilbey	Kızıltan	Osmancık -97	Halilbey	Kızıltan	Osmancık -97	Halilbey	Kızıltan
	H_2O	73h-j	69 j-l	95 a-b	6.97 n	8.80 k	13.44 e	5.54 ab	4.09 dk	3.65 f-m
0	KNO_3	0 v	2 uv	43 op	0.00 u	0.13 u	4.12 f	0.00 n	2.75 ı-m	5.43 abc
	SA	77fu	66 l	91 bc	9.94 ıj	7.44 ln	12.81 ef	4.16 d-k	4.89 b-f	3.70 e-m
	H_2O	78 eg	74 gı	97 a	10.10 ı	7.75 km	15.28 a	4.23 c-k	4.53 b-j	3.22 k-m
50	KNO_3	5 u	2 uv	59 m	0.00 u	0.00 u	4.12 f	6.50 a	0.00 n	4.58 b-ı
	SA	81 e-f	73 h-j	97 a	11.49 gh	8.69 k	15.01 ab	4.00 d-l	4.66 b-h	3.31 j-m
	H_2O	70 ı-k	54 n	90 c	10.96 h	7.75 k-m	12.69 e	3.34 ı-m	3.66 e-m	3.68 e-m
100	KNO_3	4 uv	2 uv	45 o	0.37 u	0.16 u	6.77 b	4.92 b-e	3.50 h-m	4.61 b-h
	SA	68 kl	43 op	85 d	9.61 ıj	5.34 o	9.35 ık	3.67 e-m	4.38 b-k	4.98 b-d
	H_2O	71 t	47 o	97 a	11.06 h	7.09 mn	14.38 c	3.32 j-m	3.42 h-m	3.45 h-m
200	KNO_3	19 t	1 uv	32 r	1.80 t	0.10 u	3.88 gh	5.50 ab	2.50 m	4.08 d-k
	SA	56 mn	31 r	92 bc	7.91 l	4.57 p	14.14 cd	3.70 e-m	3.65 f-m	3.33 ı-m
	H_2O	17 v	37 q	82 de	1.87 t	5.34 o	11.58 f	4.65 b-h	3.71 e-m	3.71 e-m
400	KNO_3	5 u	2 uv	4 uv	0.44 u	0.21 u	0.47 q-s	5.50 ab	3.88 d-l	4.88 b-g
	SA	40 p-q	25 s	81 de	4.84 op	3.53 q	12.06 ef	4.32 b-k	3.63 g-m	3.50 h-m
LSD			4.345			0.764			1.259	

Table 7. Interaction effects of Cd, priming, and varieties of some germination parameters

Cd (ppm)	PM	TI			RL (cm)			SL (cm)		
		Osmancık -97	Halilbey	Kızıltan	Osmancık -97	Halilbey	Kızıltan	Osmancık -97	Halilbey	Kızıltan
	H_2O	100.00 o	100.00 o	100.00 o	9.97 pq	21.29 f	16.37 ı	20.72 t	52.26 e	31.77 n
0	KNO_3	0.00 v	0.00 v	83.78 r	0.00 u	0.00 u	10.02 pq	0.00 y	0.00 y	34.96 l
	SA	100.00 o	100.00 o	69.88 t	11.52 n	18.99 h	6.60 t	21.80 r	47.95 g	26.51 p
	H_2O	163.54 e	224.29 a	116.88 k	10.19 p	34.84 b	23.78 e	25.78 q	53.29 d	58.74 b
50	KNO_3	0.00 v	0.00 v	102.00 n	0.00 u	0.00 u	19.18 h	0.00 y	0.00 y	47.52 g
	SA	120.51 j	174.73 c	114.09 l	16.11 j	20.83 g	35.71 a	21.92 r	48.55 f	60.66 a
	H_2O	147.20 f	167.94 d	144.03 g	11.23 o	21.47 f	32.90 c	21.22 s	47.85 g	57.54 c
100	KNO_3	0.00 v	0.00 v	87.47 p	0.00 u	0.00 u	12.72 l	0.00 y	0.00 y	47.52 g
	SA	107.75 m	187.95 b	116.09 k	11.59 n	29.32 d	29.55 d	16.14 v	46.41 h	45.64 ı
	H_2O	78.83 s	126.99 ı	79.75 o	7.47 s	14.66 k	12.23 m	16.42 v	36.12 k	30.45 o
200	KNO_3	0.00 v	0.00 v	70.45 t	0.00 u	0.00 u	9.91 q	0.00 y	0.00 y	21.86 r
	SA	107.75	130.76	85.43 q	8.41 r	16.44 ı	12.58 l	14.32 x	34.33 m	37.37 j
	H_2O	0.00 v	0.00 v	0.00 v	0.00 u	0.00 u	0.00 u	0.00 y	21.67 rs	15.22 w
400	KNO_3	0.00 v	0.00 v	0.00 v	0.00 u	0.00 u	0.00 u	0.00 y	0.00 y	0.00 y
	SA	0.00 v	0.00 v	0.00 v	0.00 u	0.00 u	0.00 u	0.00 y	19.02 u	18.60 l
LSD			1.028			0.241			0.478	

TI: Tolarance index, RL: Root length, SL: Seedling length

DOI: 10.54975/isubuzfd.1171385

Table 8. Interaction effects of Cd, priming, and varieties of some germination parameters

Cd (ppm)	PM	RFW (mg)			SFW (mg)			RDW (mg)		
		Osmancık -97	Halilbey	Kızıltan	Osmancık -97	Halilbey	Kızıltan	Osmancık -97	Halilbey	Kızıltan
0	H_2O	8.57 t	20.46 e	15.51 ı	24.71 h	28.10 e	22.77 j	8.25 s	20.15 e	15.98 h
	KNO_3	0.00 w	0.00 w	11.69 q	0.00 y	0.00 y	20.15 m	0.00 v	0.00 v	10.70 p
	SA	11.47 r	19.47 f	1.42 v	15.54 r	28.92 c	25.14 g	9.55 o	19.80 e	14.75 k
50	H_2O	14.54 k	30.07 a	14.50 k	24.71 h	33.86 a	29.89 e	14.03 k	30.28 q	14.80 j
	KNO_3	0.00 w	0.00 w	13.35 m	0.00 y	0.00 y	25.40 g	0.00 v	0.00 v	13.03 ım
	SA	13.39 m	19.55 r	12.51 o	13.72 s	30.12 c	30.84 b	12.95 ım	19.25 f	12.98 ım
100	H_2O	13.73 l	23.72 d	24.68 c	21.60 k	24.15 ı	30.05 c	12.90 m	28.25 d	24.95 c
	KNO_3	0.00 w	0.00 w	12.78 n	0.00 y	0.00 y	20.45 l	0.00 v	0.00 v	12.00 n
	SA	12.13 p	27.49 b	15.15 j	13.72 s	26.08 f	28.96 d	11.45 n	26.98 b	15.25 ı
200	H_2O	8.40 t	15.92 h	10.12 s	10.52 u	20.28 ım	20.18 ı-n	7.38 st	16.13 h	9.38 q
	KNO_3	0.00 w	0.00 w	8.51 t	0.00 y	0.00 y	16.42 q	0.00 v	0.00 v	8.80 r
	SA	7.89 u	17.84 g	12.54 o	9.02 w	19.43 o	19.92 n	8.48t	17.78 g	13.28 ı
400	H_2O	0.00 w	0.00 w	0.00 w	0.00 y	8.47 x	10.11 v	0.00 v	0.00 v	0.00 v
	KNO_3	0.00 w	0.00 w	0.00 w	0.00 y	0.00 y	0.00 y	0.00 v	0.00 v	0.00 v
	SA	0.00 w	0.00 w	0.00 w	0.00 y	10.17 v	18.52 p	0.00 v	0.00 v	0.00 v
LSD			0.171			0.287			0.441	

RFW: Root fresh weigth, SFW: Seedling fresh weigth, RDW: Root dry weigth

Table 9. Interaction effects of Cd, priming, and varieties of some germination parameters

Cd (ppm)	PM	SDW (mg)			RCdC (ppm)			SCdC (ppm)		
		Osmancık -97	Halilbey	Kızıltan	Osmancık -97	Halilbey	Kızıltan	Osmancık -97	Halilbey	Kızıltan
0	H_2O	14.55 o	27.83 e	22.35 ı	0.00 p	0.00 p	0.00 p	0.00 t	0.00 t	0.00 t
	KNO_3	0.00 v	0.00 v	20.15 k	0.00 p	0.00 p	0.00 p	0.00 t	0.00 t	0.00 t
	SA	12.05 q	28.83 d	24.58 g	0.00 p	0.00 p	0.00 p	0.00 t	0.00 t	0.00 t
50	H_2O	23.23 b	33.80 a	28.83 d	13.76 n	13.68 n	18.74 l	10.69 pq	9.50 rs	13.44 o
	KNO_3	0.00 v	0.00 v	28.83 d	0.00 p	0.00 p	16.49 m	0.00 t	0.00 t	12.52 o
	SA	14.60 o	29.89 c	30.88 b	12.75 n	10.78 o	13.31 n	9.73 qr	0.00 t	12.52 o
100	H_2O	20.97 j	22.50 ı	28.75 d	26.96 ı	28.77 h	29.37 h	22.33 l	22.62 l	22.95 l
	KNO_3	0.00 v	0.00 v	19.63 l	0.00 p	0.00 p	35.00 g	0.00 t	0.00 t	25.05 k
	SA	13.08 p	26.23 f	28.45 d	18.73 l	22.13 k	24.43 j	18.97 m	17.39 n	19.39 nı
200	H_2O	10.20 n	19.35 l	18.73 m	79.79 b	81.40 a	68.44 c	70.00 c	35.95 h	38.87 g
	KNO_3	0.00 v	0.00 v	15.88 n	0.00 p	0.00 p	67.02 d	0.00 t	0.00 t	34.62 ı
	SA	9.90 t	19.98 m	19.83 kl	62.23 e	62.12 e	54.59 f	53.24 e	31.96 j	31.01 j
400	H_2O	0.00 v	7.53 u	8.28 st	0.00 p	0.00 p	0.00 p	0.00 t	64.58 d	79.63 a
	KNO_3	0.00 v	0.00 v	0.00 v	0.00 p	0.00 p	0.00 p	0.00 t	0.00 t	0.00 t
	SA	0.00 v	9.88 s	18.55 m	0.00 p	0.00 p	0.00 p	0.00 t	47.50 f	75.99 b
LSD			0.484			1.151			1.086	

SDW: Seedling

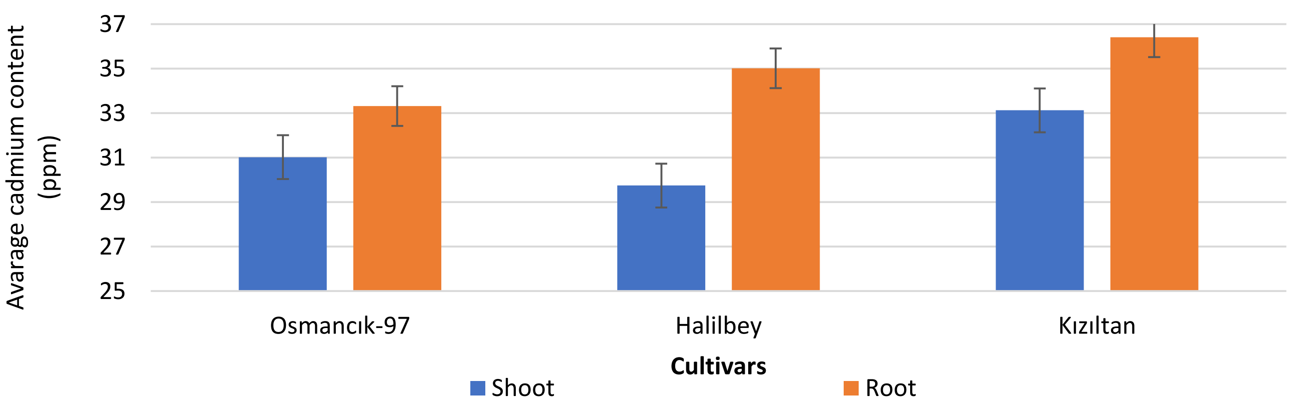

Figure 1. Cadmium content of shoots and roots of the three rice cultivars

4. Conclusions

The results of the current study supported the suggested hypothesis because different rice cultivars responded differently to seed priming agents when exposed to varied levels of Cd stress. It was established that, compared to other pre-treatments, the amount of cadmium found was much lower in the roots and shoots of plants made up of seeds pre-treated with salicylic acid. According to the results of the current study, the most Cd-sensitive variety is osmancık, whereas the most Cd-resistant variety is Kızıltan. Additionally, rice growers can be advised to use hydropriming, which was found to be the most successful method of increasing germination indices and seedling growth parameters. Nevertheless, more synthetic and natural growth regulators need to be tested because they might perform better in terms of rice germination and seedling growth, resulting in increased rice productivity.

Author contributions

Samet Karataş: Methodology, Resource, Investigation.
Ömer Konuşkan: Rewiew and Editing, Software, Supervision.

Conflict of interest

As the authors of this study, we declare that we do not have any conflict of interest statement.

Ethics Committee Approval

As the authors of this study, we declare that we do not have any ethics committee approval.

References

Akar, M., & Atış, 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), 6677-668.

Akar, M., & Atış, I. (2019). The effects of priming treatments on germination and seedling growth of red fescue under nickel and cadmium stress. *Gümüşhane Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 9*(1), 26-36.

Al-Ashkar, I. M., Zaazaa, E. I., El Sabagh, A., & Barutçular, C. (2016). Physio-biochemical and molecular characterization for drought tolerance in rice genotypes at early seedling stage. *Journal of Experimental Biology and Agricultural Sciences, 4*(6), 675-687. http://dx.doi.org/10.18006/2016.4(Issue6).675.687

Ali, A. A., Iqbal, A., & Iqbal., M. A. (2016). Forage maize (Zea mays L.) germination, growth and yield get triggered by different seed invigoration techniques. *World Journal of Agricultural Sciences, 12*(2), 97-104.

Ali, S., Bai, P., Zeng, F., Cai, S., & Shamsi, I. H. (2011). The ecotoxicological and interactive effects of chromium and aluminum on growth, oxidative damage and antioxidant enzymes on two barley genotypes differing in Al tolerance. *Environmental and Experimental Botany, 70*(2-3), 185-191. https://doi.org/10.1016/j.envexpbot.2010.09.002.

Anis, G., Hassan, H., El-Sherif, A., Saneoka, H., & El Sabagh, A. (2019). Evaluation of new promising rice hybrid and its parental lines for floral, agronomic traits and genetic purity assessment. *Pakistan Journal of Agricultural Sciences, 56*(3), 567-576. https://doi.org/10.21162/PAKJAS/19.7297.

Anwar, M. P., Khalid, M. A. I., Islam, A. M., Yeasmin, S., Shari, A., Hadifa, A., Ismail, A. I., Hossain, A., & El Sabagh, A. (2021). Potentiality of Different Seed Priming Agents to Mitigate Cold Stress of Winter Rice Seedling. *Phyton-Internatıonal Journal of Experımental Botany, 90*(5), 1491-1506. https://doi.org/10.32604/phyton.2021.015822.

Arfan, M. (2009). Exogenous application of salicylic acid through rooting medium modulates ion accumulation and antioxidant activity in spring wheat under salt stress. *International Journal of Agriculture & Biology, 11*(4), 437-442.

Basra, S. M. A., Farooq, M., Afzal, I., & Hussain, M. (2006). Influence of osmopriming on the germination and early seedling growth of coarse and fine rice. *International Journal of Agriculture and Biology, 8*: 19-21.

Choudhary, S. K., Kumar, V., Singhal, R. K., Bose, B., Chauhan, J., Alamri, S., & Sabagh, A. E. (2021). Seed priming with Mg $(NO_3)_2$ and $ZnSO_4$ salts triggers the germination and growth attributes synergistically in wheat varieties. *Agronomy, 11*(11), 2110. https://doi.org/10.3390/agronomy11112110.

Çarpıcı, E. B., Celik, N., & Bayram, G. (2009). Effects of salt stress on germination of some maize (Zea mays L.) cultivars. *African Journal of Biotechnology, 8*(19), 4918-4922.

Das, S., Ali, M. M., Rahman, M. H., Khan, Mr., & Hossain, A. (2018). Soil test based with additional nutrients increased the fertility and productivity of wheatmungbean-T. Aman rice cropping pattern in the high Ganges river floodplain soils of Bangladesh. *Bulgarian Journal of Agricultural Science, 24*(6), 992-1003.

Datta, J., Monsur, M. B., Chakraborty, P., Chakrabarty, S., Sabagh, A. E., Hossain, A., & Mondal, M. F. (2021). Obstacle in controlling major rice pests in Asia: insecticide resistance and the mechanisms to confer insecticide resistance. In: Fahad S, Sönmez O, Saud S, Wang D, Wu C, Adnan M, Arif M, Amanullah (eds) Engineering tolerance in crop plants against abiotic stress. CRC Press, Boca Raton. https://doi.org/10.1201/9781003160717-5

Demir, I., & Van De Venter, H. A. (1999). The effect of priming treatments on the performance of watermelon (Citrullus lanatus (Thunb.) Matsum and Nakai) seeds under temperature and osmotic stress. *Seed Science and Technology, 27*(3), 871-875.

Ellis, R. H., & Roberts, E. H. (1980). Towards a rational basis for seed testing seed quality. In: Hebblethwaitei P., ed. Seed Production: Butterworths, London.

Farah, G., Muhammad, A., Muhammad, S., & Basra, S. M. A. (2020). Salicylic acid seed priming modulates morphology, nutrient relations and photosynthetic attributes of wheat grown under cadmium stress. *International Journal of Agriculture and Biology, 23*(1), 197-204.

Farooq, M., Basra, S. M. A., Tabassum, R., & Afzal, I. (2006). Enhancing the performance of direct seeded fine rice by seed priming. *Plant Production Science, 9*(4), 446-456. https://doi.org/10.1626/pps.9.446.

Farooq, M., Usman, M., Nadeem, F., Rehman, H., Wahid, A., Basra, S. M. A., & Siddique, K. H. M. (2019). Seed priming in field crops-potential benefits, adoption and challenges. *Crop and Pasture Science, 70*(9), 731-771. https://doi.org/10.1071/CP18604.

Gomez, K. A., & Gomez, A. A. (1984). Statistical procedure of agricultural research: John Wiley and Sons. New York, USA.

Gözubenli, H. (2010). Seed vigorof maize grown on the contaminated soils by cadmium. *Asian Journal of Plant Sciences, 9*(3), 168-171. https://doi.org/10.3923/ajps.2010.168.171

Harris, D., Pathan, A. K., Gothkar, P., Joshı, A., Chivasa, W., & Nyaniudeza, P. (2001). On-farm seed priming using parricipatory methods to revive and refine a key technology. *Agricultural Systems, 69*(1-2), 151-164. https://doi.org/10.1016/S0308-521X(01)00023-3

Hossain, A., Sabagh, A. E., Bhatt, R., Farooq, M., & Hasanuzzaman, M. (2021). Consequences of Salt and Drought Stresses in Rice and Their Mitigation Strategies through Intrinsic Biochemical Adaptation and Applying Stress Regulators. In Sustainable Soil and Land Management and Climate Change; CRC Press: Boca Raton, FL, USA, 2021; pp. 1-15.

ISTA, (1996). International rules for seed testing rules. Seed Science and Technology, 24. Supplement.

Iqbal, M. A. (2015). Improving germination and seedling vigour of cowpea (Vigna unguiculata L.) with different priming techniques. *American-Eurasian Journal of Agricultural & Environmental Sciences, 15*(2), 265-270.

Iqbal, M. A., Ahmad, T., Ahmad, Z., Saleem, A. M., & Ahmad, B. (2015b). Overviewing comparative efficacy of different germination enhancement techniques for cereal crops. *American-Eurasian Journal of Agricultural & Environmental Sciences, 15*(9), 1790-1802.

Iqbal, M. A., Cheema, Z. A., & Afzal, M. I. (2015a). Evaluation of forage soybean (Glycine max L.) germination and seedling growth enhancement by seed priming techniques. *American-Eurasian Journal of Agricultural & Environmental Sciences, 15*(6), 1198-1203.

Iqbal, M. A., Saleem, A. M., Ahmad, B. (2015c). Effect of seed invigoration techniques on germination and seedling growth of Chinese sweet sorghum. *Journal of Advanced Botany and Zoology, 2*(2), 1-4.

Jamshidian, Z., & Talat, F. (2017). Effects of seed priming on morphological and phonological characteristics of the coriander (Coriandrumsativum L.). *Advances in Plants & Agriculture Research, 7*(6), 411-415. http://dx.doi.org/10.15406/apar.2017.07.00275.

Jarup, L., & Akesson, A. (2009). Current status of cadmium as an environmental health problem. *Toxicology and Applied Pharmacology, 238*(3), 201-208. https://doi.org/10.1016/j.taap.2009.04.020.

Jun-yu, H., Yan-fang, R., Cheng, Z., & De-an, J. (2008). Effects of Cadmium stress on seed germination, seedling growth and seed amylase activities in rice (Oryza sativa). *Rice Science, 15*(4), 319-325. https://doi.org/10.1016/S1672-6308(09)60010-X.

Khafagy, M. A., Mohamed, Z. A. A., Farouk, S., & Amrajaa Hanan, K. (2017). Effect of pre-treatment of barely grain on germination and seedling growth under drought stress. *Advances in Applied Science, 2*(3), 33-42. https://doi.org/10.11648/j.aas.20170203.12.

Lee, S. S., & Kim, J. H. (2000). Total sugars, α-amylase activity, and emergence after priming of normal and aged rice seeds. *Korean Journal of Crop Science, 45*(2), 108-111.

Li, J., Xie, Z. M., Xu, J. M., & Sun, Y. F. (2006). Risk assessment for safety of soils and vegetables around a lead/zinc mine. *Environmental Geochemistry and Health, 28*: 37-44. https://doi.org/10.1007/s10653-005-9009-x.

Liu, J., Qian, M., Cai, G., Yang, J., & Zhu, Q. (2007). Uptake and translocation of Cd in different rice cultivars and the relation with Cd accumulation in rice grain. *Journal of Hazardous Materials, 143*(1-2), 443-447. https://doi.org/10.1016/j.jhazmat.2006.09.057.

Mamun, A. A., Naher, U. A., & Ali, M. Y. (2018). Effect of seed priming on seed germination and seedling growth of modern rice (Oryza sativa L.) varieties. *The Agriculturalist 16*(1), 34-43. https://doi.org/10.3329/agric.v16i1.37532.

Mercado, M. F. O., & Fernandez, P. G. (2002). Solid matrix priming of soybean seeds. *Philippine Journal of Crop Science, 27*(2), 27-35.

Monsur, M. B., Ivy, N. A., Haque, M. M., Hasanuzzaman, M., El Sabagh, A., & Rohman, M. (2020). Oxidative stress tolerance mechanism in rice under salinity. *Phyton-International Journal of Experimental Botany, 89*(3), 497-517. https://doi.org/10.32604/phyton.2020.09144.

Moradi Dezfuli, P., Sharıf-Zadeh, F., & Janmohammadi, M. (2008). Influence of priming techniques on seed germination behavior of maize inbred lines (Zea mays L.). *ARPN Journal of Agricultural and Biological Science, 3*(3), 22-25.

Nawaz, J., Husssain, M., Jabbar, A., Naddem, G. A., Sajid, M., Substain, M., & Shabbir, I. (2013). Seed priming a technique. *International Journal of Agriculture and Crop Sciences, 6*(20), 1373-1381.

Nyoni, N., Ndlovu, E., & Maphosa, M. (2020). Effect of priming regimes on seed germination of field crops. *African Crop Science Journal, 28*(2), 169-176. https://doi.org/10.4314/acsj.v28i2.3.

Parlakova Karagoz, F., & Dursun, A. (2020). Effects of chemical fertilizer and some bacterial formulations on growing medium and plant heavy metal content in poinsettia cultivation. *Alinteri Journal of Agriculture Sciences, 35*(1), 84-92. http://dx.doi.org/10.28955/alinterizbd.739438.

Ruan, S., Zue, Q., & Thylokowska, K. (2002). Effects of seed priming on germination and health of ricen (Oryza sativa L.) seeds. *Seed Science and Technology, 30*(2), 451-458.

Shahid, M., Khalid, S., Abbas, G., Shahid, N., & Nadeem, M. (2015). Heavy metal stress and crop productivity. In: K.R. Hakeem (ed.), Crop Production and Global Environmental Issues. Springer International Publishing Switzerland. pp. 1-25. https://doi.org/10.1007/978-3-319-23162-4_1.

Shakirova, F. M., Allagulova, C. R., Maslennikova, D. R., Klyuchnikova, E. O., Avalbaev, A. M., & Bezrukova, M. V. (2016). Salicylic acid-induced protection against cadmium toxicity in wheat plants. *Environmental and Experimental Botany, 122*: 19-28. https://doi.org/ 10.1016/j.envexpbot.2015.08.002.

Shao, G. S., Muhammad, J. H., Zhang, X. F., & Zhang, G. P. (2004). Effects of cadmium stress on plant growth and antioxidative enzyme system in different rice genotypes. *Chinese Journal of Rice Science, 18*(3), 239-244. (in Chinese with English abstract).

Tongma, S., Kobayashi, K., & Usui, K. (2001). Allelopathic activity of Mexican sunflower [Tithonia diversifolia (Hemsl.) A. Gray] in soil under natural field conditions and different moisture conditions. *Weed Biology and Management, 1*(2), 115-119. https://doi.org/10.1046/j.1445-6664.2001.00020.x.

Wang, M., Zou, J., Duan, X., Jiang, W., & Liu, D. (2007). Cadmium accumulation and its effects on metal uptake in maize (Zea mays L.). *Bioresource Technology, 98*(1), 82-88. https://doi.org/10.1016/j.biortech.2005.11.028.

Wang, Y. R., Yu, L., Nan, Z. B., & Liu, Y. L. (2004). Vigor tests used to rank seed lot quality and predict field emergence in four forage species. *Crop Science, 44*(2), 535-541. https://doi.org/10.2135/cropsci2004.5350.

Waraich, E. A., Ahmad, M., Soufan, W., Manzoor, M. T., Ahmad, Z., Habib-ur-rahman, M., & Sabagh, A. E. (2021). Seed priming with sulfhydral thiourea enhances the performance of Camelina sativa L. under heat stress conditions. *Agronomy, 11*(9), 1875. https://doi.org/ 10.3390/agronomy11091875.

Wasaya, A., Yasir, T. A., Sarwar, N., Mubeen, K., Rajendran, K., Hadifa, A., & Sabagh, A. E. (2022). Climate Change and Global Rice Security. In Modern Techniques of Rice Crop Production (pp. 13-26). Springer, Singapore. https://doi.org/10.1007/978-981-16-4955-4_2.

White, P. J., & Brown, P. H. (2010). Plant nutrition for sustainable development and global health. *Annals of Botany, 105*(7), 1073-1080. https://doi.org/10.1093/aob/ mcq085

Zhao, Q. G., Zhou, B. Z., & Yang, H. (2018). Environmental quality and agricultural safety in Jiangsu Province. *Soils, 1*(1), 1-8. (in Chinese with English abstract).

Xue, C., Gao, H. Y., & Zhang, L. T. (2013). Effects of cadmium on growth, photosynthetic rate and chlorophyll content in leaves of soybean seedlings. *Biologia Plantarum, 57*(3), 587-590. https://doi.org/10.1007/s10535-013-0318-0.