Pak. J. Bot., 57(1): DOI: http://dx.doi.org/10.30848/PJB2025-1(30)

COMPARATIVE ASSESSMENT OF HEAVY METALS CONTAMINATION IN SELECTED DATE PALM CULTIVARS AND ITS SIGNIFICANCE FOR FOOD SAFETY

MUHAMMAD MUNIR[1*], ABDUL GHAFOOR[2], NASHI ALQAHTANI[1,3] AND ZAFAR IQBAL[4]

[1]*Date Palm Research Center of Excellence, King Faisal University, Al-Ahsa, Saudi Arabia*
[2]*Water and Environmental Study Center, King Faisal University, Al-Ahsa, Saudi Arabia*
[3]*Department of Food and Nutrition Sciences, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa, Saudi Arabia*
[4]*Cental Laboratories, King Faisal University, Al-Ahsa, Saudi Arabia*
** Corresponding author's email: mmunir@kfu.edu.sa*

Abstract

Date fruits, famous for their unique flavor and rich in minerals, may contain heavy metals and contaminants during on-farm and off-farm practices, leading to health risks to consumers. The current study examined hazardous heavy metals (Aluminium, Arsenic, Chromium, Lead, Cadmium, Nickel, and Copper) in fourteen commercial cultivars of date palm (Khalas, Sagai, Deglet Nour, Majdoul, Sukkari, Khidri, Sheshi, Zahidi, Safawi, Anbara, Wannan, Amber, Rashudia, and Sulig) purchased from the Al-Ahsa local market, Kingdom of Saudi Arabia. All date cultivars had safe maximum allowable limits for most heavy metals, except for aluminium (0.20 mg kg^{-1}) and lead (0.30 mg kg^{-1}). The concentration of aluminium and lead were present in cvs. Khalas (0.82 and 3.64 mg kg^{-1}), Sagai (1.34 and 3.82 mg kg^{-1}), Deglet Nour (2.62 and 4.25 mg kg^{-1}), Majdoul (2.16 and 4.09 mg kg^{-1}), Sukkari (3.09 and 4.53 mg kg^{-1}), Khidri (3.42 and 5.09 mg kg^{-1}), Sheshi (1.28 and 3.14 mg kg^{-1}), Zahidi (1.09 and 2.75 mg kg^{-1}), Safawi (1.90 and 3.67 mg kg^{-1}), Anbara (2.40 and 3.02 mg kg^{-1}), Wannan (2.99 and 2.73 mg kg^{-1}), Amber (3.71 and 2.30 mg kg^{-1}), Rashudia (1.92 and 3.06 mg kg^{-1}), and Sulig (2.18 and 2.87 mg kg^{-1}). The estimated daily intake of lead was exceeded the provisional tolerable daily intake (214 µg/person/day/100 g) in all date cultivars. Although, the daily intake of aluminium exceeded the maximum allowable limits, but it is still within the safe limit (8571 µg/person/day/100 g). We also calculated a hazard risk index from the estimated daily intake data, predicting that only lead had more than one health risk index.

Key words: Date palm cultivars, Heavy metals, Fruit contamination, Health risk index, Toxicity.

Introduction

Date palm (*Phoenix dactylifera* L.), a renowned evergreen fruit-bearing tree cultivated globally, plays a crucial role in agriculture and food security due to its historical significance. Date palm fruit contains functional compounds and therapeutic bioactive agents, potentially improving human health (Soomro *et al*., 2023). It is deeply rooted in the culture and traditions of the Arabian Peninsula, Middle East, and North Africa. Approximately 5,000 distinct date palm cultivars have been cultivated in 34 countries. They are diverse, with each cultivar having distinctive morphological characteristics, nutritional composition, and commercial significance (Nadeem *et al*., 2019). The categorization of cultivars is determined by the attributes of the fruit, including its color, texture, size, and taste (Hadrami & Hadrami, 2009). Saudi Arabia's hot and dry climate is ideal for date palm cultivation, making it one of the largest global plantations. The region with the highest date palm production is Riyadh, followed by Qassim and the Eastern region. The Kingdom grows around 400 cultivars of date palm, with only 50-60 cultivars being commercially available (Aleid *et al*., 2015). It is used as a biomonitor in Saudi Arabia, Kuwait, Turkey, and Jordan (Bu-Olayan & Thomas, 2002; Al-Khlaifat & Al-Khashman, 2007; Salama *et al*., 2019) to assess ecosystem health and pollutants based on their sensitivity to environmental factors or their capacity to accumulate specific substances (Jafari *et al*., 2023).

Heavy metals such as lead, aluminium, chromium, arsenic, copper, cadmium, nickel, zinc, boron, and metalloids, pose significant health and agricultural risks. These compounds have the potential to induce toxicity in living tissues and can result in the development of cancer at high levels of exposure. Environmental factors such as vehicular emissions, mining, waste incineration, industrial emissions, agricultural practices, metallurgical operations, atmospheric deposition, and non-biodegradation of metals increase heavy metal levels, causing abiotic stress in plants and accumulating in fruits, causing negative effects (Abeywickrama & Wansapala, 2019; Siddiqa & Faisal, 2020). Monitoring heavy metal levels in date palm trees is crucial due to their adaptability to various climates and susceptibility to contaminants in residential, rural, and industrial areas (Abass *et al*., 2015).

Sewage water often contains various contaminants, including heavy metals, that originate from domestic, industrial, and commercial sources. The sewage water is sometimes mixed with groundwater for the purpose of irrigating date palm farms. This practice, however, can lead to the build-up of heavy metals in the water and soil, which in turn can pose a risk of toxicity (Al-Busaidi *et al*., 2015). Date palm trees, when irrigated with this water, can absorb heavy metals through their roots, leading to accumulation in plant tissues and potential toxicity issues as these metals interfere with the physiological processes of the plant. These metals also accumulate in edible parts of food crops, leading to a range of health issues in humans and animals globally (Akensous *et al*., 2022). Heavy metals, which are ingested or inhaled by humans, can lead to various diseases if their concentrations exceed the maximum allowable limits (MALs) approved by Food and Agriculture Organization (FAO) and World Health Organization (WHO). These risks include compromised physical well-being, cirrhosis, brain and kidney function impairment, skeletal disorders, heart conditions, excessive bleeding, cognitive decline, systemic cancer, particularly gastrointestinal cancer, and reduced sperm motility. Heavy metals can damage macromolecular structures, damaging DNA, proteins, and delicate biological tissues. Therefore, assessing the safety of date palms requires analyzing heavy metal levels and comparing results with acceptable thresholds (Mansour, 2014; Vardhan *et al*., 2019; Ajani *et al*., 2022).

Cadmium, and lead have been found in the dust of major cities in Saudi Arabia, with concentrations varying based on traffic and industrial activities (Alghamdi *et al*., 2022; Al-Swadi *et al*., 2022). Date fruits from fourteen Riyadh city locations showed high levels of cadmium and lead, but their values were within WHO/FAO permitted limits (Aldjain *et al*., 2011). Salama *et al*., (2019) found that Al, Cr, and Sb in seven date palm cultivars are safe, except for As, Pb, and Cd, which could pose hazards to consumers. Similarly, Ali and Al-Qahtani (2012) found that cereals, fruits, and vegetables grown in Saudi Arabia's industrial and urban cities contain heavy metals exceeding WHO/FAO MALs. Therefore, the present study aims to determine the presence of heavy metals in the fruits of different date palm cultivars available in local markets and calculate their health hazard index for humans.

Material and Methods

In 2022, the present study carried out at the Date Palm Research Center of Excellence, located at King Faisal University in the Kingdom of Saudi Arabia. One-kilogram ripe Tamar fruits of fourteen commercial date palm cultivars (Khalas, Sagai, Deglet Nour, Majdoul, Sukkari, Khidri, Sheshi. Zahidi, Safawi, Anbara, Wannan, Amber, Rashudia, and Sulig) were purchased from a local market of Al-Ahsa, Kingdom of Saudi Arabia. The fruits were washed with tap-water, followed by air drying. Subsequently, they were carefully placed in polyethylene bags and stored in the Biochemistry Laboratory at the Date Palm Research Center of Excellence, King Faisal University, at a temperature of 4 °C in a refrigerator.

The seeds were removed manually from the fruits of each cultivar, and the pulp was then mashed individually to obtain a uniform sample. One-gram sample from each cultivar was subjected to digestion using a 12 mL mixture (2:1 v/v) of concentrated hydrochloric acid and nitric acid. The mixture underwent microwave-assisted heating for 45 minutes in a reaction system, at 180°C and 200 psi pressure (Jin *et al*., 2002; Salama *et al*., 2019). After the digestion process was finished, the solution was filtered through a Whatman No. 42 filter paper. Then, a 25 mL volume was prepared by adding deionized water. The samples were kept in conical glass flasks at 4°C until analysis. The heavy metal analysis was conducted following the AOAC protocols, using atomic absorption spectrometer (Thermo Fisher Scientific Inc., USA) and employing the wet digestion technique. Reference analytes for quantitative estimation and quality assurance of heavy metals (Aluminium, Arsenic, Chromium, Lead, Cadmium, Nickel, and Copper) were obtained from Merck KGaA, Germany. These standards were utilized to calibrate and ensure the accuracy of each analyte. To prepare the working standard solutions, the initial stock solutions with a concentration of 1000 mg kg^{-1} were diluted. The resulting working standard solutions had concentrations ranging from 5 mg kg^{-1} to 20 mg kg^{-1}. Subsequently, these solutions were stored at of 4°C and were maintained at an acidity level of 0.1% nitric acid. A calibration curve was constructed by plotting the measured absorbance against the concentration. The measurements were conducted using a standard cathode lamp for the elements Al, As, Cr, Pb, Cd, Ni, and Cu, as described in the AOAC (2005), Meena *et al*. (2010), and Kulhari *et al*., (2013).

The daily consumption of heavy metals (mg/person/day) was determined by multiplying the concentration of a certain metal by the per capita daily consumption of dates and then dividing by the average body weight of an adult human (Khan *et al*., 2008). The assessment of the daily consumption of heavy metals from eating date fruits was calculated and compared to the recommended values set by WHO/FAO (2011). Al-Mssallem (2018) stated that the average daily consumption of dates per person among Saudi Arabian adults is approximately 100 grams of wet weight, with an average body weight of 71 kg (Mohamed *et al*., 2017). The daily intake assessment values of heavy metals were employed to calculate the health risk index of heavy metals in the dates. As described by Khan *et al*., (2008), the health risk index (HRI) was determined by dividing the daily intake of metals in date palm cultivars by the oral reference dose. The HRI more than one for any heavy metal means that the health of consumer is at risk.

The collected data was analyzed using the one-way analysis of variance (ANOVA) method using GenStat, version 18, software developed by VSN International Ltd., Hemel Hempstead, UK. The separation of treatment means was determined using the least significant difference (LSD) test at a 5% probability level. The heatmap and correlation analysis was done using R programming, version R 4.3.2. (R Core Development Team, The R Foundation, Vienna, Austria).

Results

Figure 1 indicated the mean concentration of heavy metals in date palm cultivars, Khalas, Sagai, Deglet Nour, Majdoul, Sukkari, Khidri, Sheshi. Zahidi, Safawi, Safawi, Anbara, Wannan, Amber, Rashudia, and Sulig. The concentration of all heavy metals (aluminium, arsenic, chromium, lead, cadmium, and nickel) except copper was significant (p<0.05) varied with the cultivars. Among the tested date palm cultivars, Amber exhibited the highest aluminium concentration, followed by cvs. Khidri, Sukkari, Wannan, and Deglet Nour, whereas it was lowest in cv. Khalas. All these cultivars had high allowable aluminium limit (0.20 mg kg^{-1}). Cultivar Amber had maximum concentration of arsenic, followed by cvs. Sheshi, Khidri, Zahidi, Anbara, Rashudia, and Majdoul. It was significantly reduced in cv. Khalas. Arsenic was below allowed limit (0.10 mg kg^{-1}) in all date palm cultivars except cv. Amber. Similarly, maximum concentration of chromium was found in cvs. Majdoul and Wannan, followed by Sheshi, Safawi, and Anbara. It was minimum in cv. Sagai. All date palm cultivars had well below allowable chromium limit (2.30 mg kg^{-1}). The lead concentration was highest in cv. Khidri, followed by cvs. Sukkari and Deglet Nour, whereas it was lowest in cv. Amber. The lead concentration in all date palm cultivars was higher than the allowable limit (0.30 mg kg^{-1}). Cultivar Khidri displayed relatively high cadmium concentration, followed by cv. Khidri, followed by Sheshi and Anbara. It was lower in cv. Majdoul. The nickel concentration was maximum in cv. Sheshi, followed by cvs. Amber, Rashudia, Sulig, Khidri, and Wannan, whereas it was minimum in cv. Sukkari. In contrast, there was a non-significant difference in copper concentration among all date palm cultivars. Allowable limits for cadmium (0.20 mg kg^{-1}), nickel (0.02 mg kg^{-1}), and copper (0.10 mg kg^{-1}) were significantly lower in in all date palm cultivars.

Table 1 displays the estimated daily intake of heavy metals of different date palm cultivars, as well as the provisional tolerable daily intake based on consuming 100 g of date palm per day for an adult in Saudi Arabia. Cultivar Amber exhibited the highest estimated daily intake of Al (371.33 µg/person/day/100 g) and As (10.73 µg/person/day/100 g), whereas cv. Wannan had the highest estimated daily intake of Cr (7.07 µg/person/day/100 g). Similarly, cvs. Khidri (19.83 µg/person/day/100 g), Sheshi (0.51 µg/person/day/100 g), and Deglet Nour (4.70 µg/person/day/100 g) had highest estimated daily intake of Cd, Ni, and Cu, respectively. Nevertheless, the quantity of these elements remains within the provisional tolerable daily intake. The highest estimated daily intake of Al, As, Cr, Cd, Ni, and Cu were below the provisional tolerable daily intake values. It revealed that Saudi dates consumers are not exposed to any health hazards due to the presence of Al, As, Cr, Cd, Ni, and Cu in different cultivars of date palm. However, the estimated daily intake for Pb showed that all date palm cultivars are exceeding the provisional tolerable daily intake value (214 µg/person/day/100 g). Cultivar Khidri had the highest estimated daily intake (508.70 µg/person/day/100 g), followed by Sukkari (453.10 µg/person/day/100 g), Deglet Nour (424.83 µg/person/day/100 g), and Majdoul (408.53 µg/person/day/100 g). Compared to provisional tolerable daily intake value, the estimated daily intake values of Pb were 58% (Khidri), 53% (Sukkari), 50% (Deglet Nour), 48% (Majdoul), 44% (Sagai), 42% (Safawi), 41% (Khalas), 32% (Sheshi), 30% (Rashudia), 29% (Anbara), 25% (Sulig), 22% (Zahidi and Wannan), and 7% (Amber) higher in the mentioned date palm cultivars.

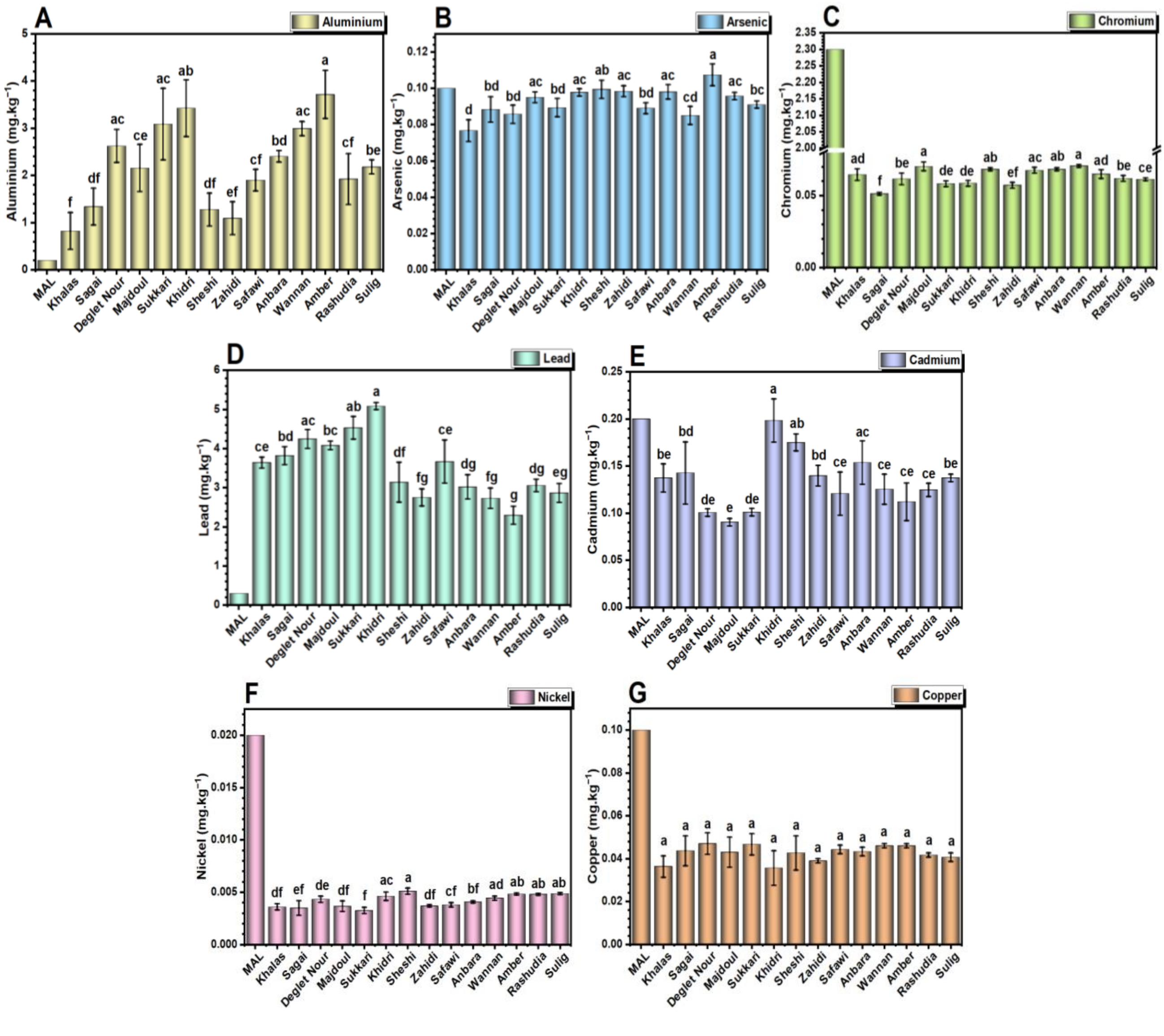

Fig. 1. Concentration of toxic heavy metals in date palm cultivars. Similar letters show non-significant difference at 5% level of probability (p<0.05). MAL is the abbreviation for maximum allowed limit (mg kg^{-1}) prescribed by FAO/WHO. Y-bars indicate the standard deviation within replicates.

Table 1. Comparison of estimated daily intake of heavy metals of different date palm cultivars with provisional tolerable daily intake (PTDI).

Date palm cultivars	Al	As	Cr	Pb	Cd	Ni	Cu
	(µg/person/day/100 g)						
Khalas	82.33	7.67	6.47	364.40	13.73	0.36	3.63
Sagai	133.93	8.83	5.13	382.33	14.27	0.35	4.37
Deglet Nour	262.23	8.57	6.17	424.83	10.07	0.43	4.70
Majdoul	215.67	9.50	7.03	408.53	9.03	0.37	4.30
Sukkari	308.70	8.93	5.83	453.10	10.10	0.33	4.67
Khidri	342.40	9.77	5.87	508.70	19.83	0.46	3.57
Sheshi	127.67	9.93	6.83	314.23	17.50	0.51	4.27
Zahidi	109.33	9.83	5.73	275.33	13.97	0.37	3.90
Safawi	190.00	8.90	6.77	367.00	12.07	0.38	4.43
Anbara	240.33	9.80	6.83	302.33	15.37	0.41	4.33
Wannan	299.00	8.50	7.07	273.33	12.53	0.44	4.60
Amber	371.33	10.73	6.50	230.00	11.20	0.48	4.60
Rashudia	192.33	9.57	6.20	306.00	12.47	0.48	4.17
Sulig	218.00	9.10	6.13	287.00	13.73	0.49	4.07
PTDI	8571	25.2	6000	214	60	100	3000

Table 2. Health risk index (HRI) associated with heavy metals present in date palm cultivars.

Date palm cultivars	Al	As	Cr	Pb	Cd	Ni	Cu
	(mg kg^{-1})						
Khalas	0.03	0.36	0.00006	1.47	0.19	0.00025	0.0010
Sagai	0.04	0.41	0.00005	1.54	0.20	0.00025	0.0012
Deglet Nour	0.09	0.40	0.00006	1.71	0.14	0.00031	0.0013
Majdoul	0.07	0.45	0.00007	1.64	0.13	0.00026	0.0012
Sukkari	0.10	0.42	0.00005	1.82	0.14	0.00023	0.0013
Khidri	0.11	0.46	0.00006	2.05	0.28	0.00033	0.0010
Sheshi	0.04	0.47	0.00006	1.26	0.25	0.00036	0.0012
Zahidi	0.04	0.46	0.00005	1.11	0.20	0.00026	0.0011
Safawi	0.06	0.42	0.00006	1.48	0.17	0.00027	0.0012
Anbara	0.08	0.46	0.00006	1.22	0.22	0.00029	0.0012
Wannan	0.10	0.40	0.00007	1.10	0.18	0.00031	0.0013
Amber	0.12	0.50	0.00006	0.93	0.16	0.00034	0.0013
Rashudia	0.06	0.45	0.00006	1.23	0.18	0.00034	0.0012
Sulig	0.07	0.43	0.00006	1.15	0.19	0.00034	0.0011
RfD	0.043	0.0003	1.5	0.004	0.001	0.02	0.05

RfD: Oral reference dose (mg kg^{-1} day^{-1}) prescribed by FAO/WHO; HRI more than 1 for any heavy metal is at health risk

The estimated daily intake and oral reference dose of each heavy metal for each date palm cultivar were used to calculate the health risk index values, which were then used to evaluate the hazards associated to health (Table 2). The findings demonstrated that consuming date palm cultivars does not provide any health risks for Al, As, Cr, Cd, Ni, and Cu. However, all cultivars of date palm have potential health threat for Pb since the health risk index values exceed one. Among these cultivars, cv. Khidri (2.05 mg kg^{-1})., had the highest Pb health risk index, followed by Sukkari (1.82 mg kg^{-1}), Deglet Nour (1.71 mg kg^{-1}), Majdoul (1.64 mg kg^{-1}), Sagai (1.54 mg kg^{-1}), Safawi (1.48 mg kg^{-1}), Khalas (1.47 mg kg^{-1}), Sheshi (1.26 mg kg^{-1}), Rashudia (1.23 mg kg^{-1}), Anbara (1.22 mg kg^{-1}), Sulig (1.15 mg kg^{-1}), Zahidi (1.11 mg kg^{-1}), Wannan (1.10 mg kg^{-1}), and Amber (0.93 mg kg^{-1}).

The heatmap (Fig. 2) indicated the low (green) to high (red) values of heavy metals (Al, As, Cr, Pb, Cd, Ni, and Cu) in different date palm cultivars (Khalas, Sagai, Deglet Nour, Majdoul, Sukkari, Khidri, Sheshi, Zahidi, Safawi, Anbara, Wannan, Amber, Rashudia, and Sulig). The heavy metal spectrum regarding Al was lower in cvs. Khalas, Sheshi, and Zahidi, whereas As was lowest in cv. Khalas. The lowest value of Cr was in cv. Sagai, while Pb was lowest in cv. Amber. The heavy metal Cd was minimal in cvs. Majdoul, Deglet Nour, and Sukkari, Ni in cvs. Sukkari, Sagai, Khalas, and Majdoul, and Cu in cvs. Khalas and Khidri. The date palm cultivars also exhibit higher values of heavy metals such as Al (Amber, Khidri, Wannan, and Sukkari), As (Amber), Cr (Majdoul, Wannan, Anbara, Sheshi, and Safawi), Pb (Khidri, Sukkari, and Deglet Nour), Cd (Khidri and Sheshi), Ni (Sheshi, Amber, Rashudia, and Sulig), and Cu (Deglet Nour, Sukkari, Wannan, and Amber). The lower Pb values on the heatmap are linked to a higher health risk index, similar to the higher values. Consequently, the presented data illustrates a fluctuating trend in Pb levels, but it does not indicate the safe values. The heatmap provides a visual representation of the heavy metal levels across different date palm cultivars, allowing for simple comparison and analysis. This information can be valuable for decision-making purposes, such as cultivar selection or management strategies.

The heavy metals correlation graph in Fig. 3 provides insights into the relationship between different heavy metals (Al, As, Cr, Pb, Cd, Ni, and Cu) in date palm cultivars (Khalas, Sagai, Deglet Nour, Majdoul, Sukkari, Khidri, Sheshi, Zahidi, Safawi, Anbara, Wannan, Amber, Rashudia, and Sulig). A significant negative correlation was found between Cd and Cu heavy metals, while a non-significant negative correlation was observed among Cd, Cr, and Al; As and Pb; Ni, Pb, and Cu; and Pb, Cr, and Cu heavy metals. A non-significant positive correlation was observed among Cd, As, Ni, and Pd; As, Ni, Al, and Cu; Ni, Cr, Al, and Cu; Pb and Al; Cr, Al, and Cu; and Al and Cu heavy metals.

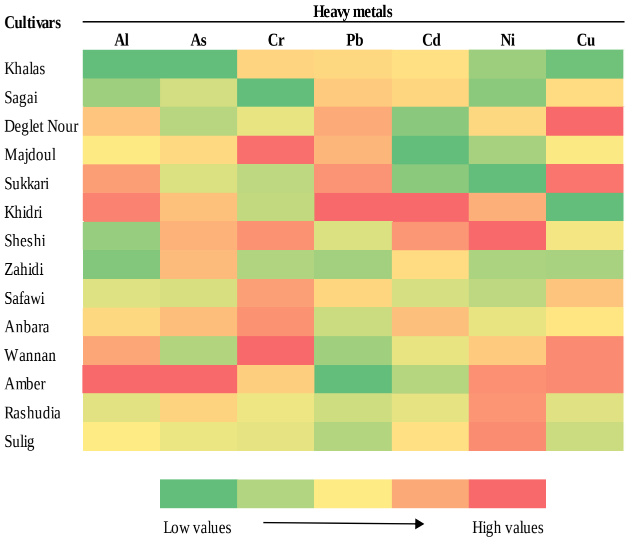

Fig. 2. Heatmap showing the values of heavy metals; Aluminium (Al), Arsenic (As), Chromium (Cr), Lead (Pb), Cadmium (Cd), Nickel (Ni), and Copper (Cu) found in fourteen date palm cultivars.

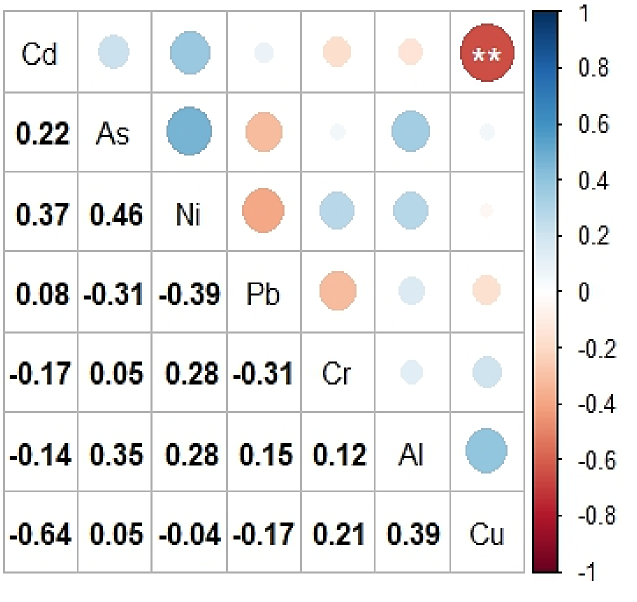

Fig. 3. Path coefficient correlation computed by Pearson-method for heavy metals; Aluminium (Al), Arsenic (As), Chromium (Cr), Lead (Pb), Cadmium (Cd), Nickel (Ni), and Copper (Cu) of date palm cultivars. ** represents significant correlation between the heavy metals at $p \leq 0.01$.

Discussion

Global environmental degradation is a significant environmental issue that poses a critical challenge. Heavy metals enter the environment through various pathways, becoming involved in biochemical cycles and entering the human body and food chain. They transform into hazardous substances or harmless metabolites, posing a severe health threat (Cimboláková *et al*., 2019; Vareda *et al*., 2019; Abdullahi *et al*., 2021). Food safety is a worldwide public health issue because of increasing concerns about food pollution caused by heavy metals, toxic pollutants, and pesticides, which has led to new investigations into these problems (Shaheen *et al*., 2016). This study, conducted on randomly selected date fruits from the local market, lacks previous literature studies, leaving the exact cause of heavy metal contaminations in fruits unclear. Our findings found that the concentrations of heavy metals (arsenic, chromium, cadmium, nickel, and copper) in the fruits of fourteen date palm cultivars were below the maximum allowable limit, making them safe to consume. Heavy metals aluminium and lead in all date palm cultivars exceed the maximum allowable limit, however, date fruits having higher maximum allowable limit of aluminium are safe to consume because it is lower than the provisional tolerable daily intake.

Heavy metal accumulation in fruits is influenced by factors such as soil heavy metals concentration, root uptake efficiency, transpiration rate, metal distribution within plant tissues, and translocation through xylem and phloem (Abass *et al*., 2016; Zouari *et al*., 2016). The xylem transports water and dissolved minerals, including heavy metals, from the roots to the plant's aboveground parts. As the water is pulled up through the xylem by transpiration, heavy metals can be carried along with it. Phloem, on the other hand, transports organic compounds such as sugars and amino acids from leaves to plant parts, including fruits, and can also transport heavy metals along with these compounds (Page & Feller, 2015; Shahid *et al*., 2017; White & Ding, 2023). Date palm trees' root systems, facilitated by root hairs, absorb water and nutrients from soil. Plant roots absorb heavy metals through root uptake, which occurs through both passive and active mechanisms. Passive uptake is driven by concentration gradients, where higher soil concentrations cause metals to move into roots. Active uptake involves specialized transport proteins in root cell membranes, which actively transport heavy metals into roots, even against concentration gradients (Mitra *et al*., 2014; Thakur *et al*., 2016; Podar & Maathuis, 2022).

Heavy metals can be found in soil through natural processes or human activities like pesticides, industrial pollution or fertilizer use (Akensous *et al*., 2022). Heavy metal contamination in dates can pose severe health risks, including kidney and bone damage, as well as brain cell degeneration (Salama *et al*., 2019; Bharti & Sharma, 2022). The findings of present study revealed significant variations in heavy metal concentrations in date palm cultivars due to factors such as soil composition (Wang *et al*., 2015; Roba *et al*., 2016), environmental conditions (Kooner *et al*., 2014; Einolghozati *et al*., 2023), and cultivation practices (Fang & Zhu, 2014; Chen *et al*., 2021). The high concentration of aluminium in Amber cultivar might be attributed to its specific genetic characteristics (Savvas *et al*., 2010) or the soil conditions (Wang *et al*., 2015; Roba *et al*., 2016) in which it was cultivated. The lower concentration of aluminium in Khalas cultivar suggests that it may have mechanisms to regulate or exclude aluminium uptake (Yan *et al*., 2022). These variations in aluminium concentration among cultivars are important from a food safety perspective, as excessive aluminium intake can have detrimental effects on human health. Aluminium damage brain cells, bones, and causes anemia in hemodialysis patients. It also causes toxic effects in stems, leaves, and roots, leading to stunted growth and wilting (Williams *et al*., 2005; Blamey *et al*., 2021; Rahman & Upadhyaya, 2021). The slightly higher arsenic content in cv. Amber suggests the need for its careful consumption. It could be due to the use of arsenic-containing pesticides and fertilizers (Jayasumana *et al*., 2015; Upadhyay *et al*., 2019), contaminated irrigation water (Rahaman *et al*., 2013; Sandil *et al*., 2021), soil composition (Zakir *et al*., 2022), and environmental conditions (Hussain *et al*., 2019). Arsenic in palms can lead to wilting, necrotic lesions, stunted growth, and phytotoxicity (Al-Shayeb & Seaward, 2000). The primary factors contributing to the rise in lead levels in fruits are automobiles and applying chemicals containing lead for crop protection. Factors such as air dust, pollution, distance from roadside, traffic loads, and exposure time for sale influence lead deposit on crops' edible tissues (Le *et al*., 2019; Ankush *et al*., 2023). Salama *et al*., (2019) found high levels of lead in date palm cvs. Sakay Mabroum, Sakay Normal, Rashadya, Kadary, Barny, Safawy, and Eklas, while cvs. Sakay Normal, Kadary, Safawy, and Eklas had a high arsenic concentration compared to the maximum allowable limits. Similarly, Radwan & Salama (2006) revealed a higher lead concentration in certain Egyptian dates. Khan *et al*., (2019) reported that date palm fruits from Pakistan's diverse regions contained higher concentrations of heavy metals (Ni, Fe, and Zn), exceeding WHO standards. Forage plants used as livestock feed contain high levels of heavy metals like Cu, Co, Fe, Zn, and Mn (Khan *et al*., 2021). The current study elucidated the presence of elevated lead concentrations, hence revealing the ability of the date palm plants to uptake and accumulate heavy metals.

Conclusion

The majority of the cultivars contained heavy metals within safe maximum allowable limits, except for aluminium and lead. The highest concentrations of aluminium were found in Sukkari, Khidri, Amber, and Wannan cultivars, while lead levels were highest in Sukkari, Khidri, Majdoul, and Amber cultivars. The daily aluminium intake exceeded the maximum allowable limits, but it remains within the safe limits of the provisional maximum tolerable daily intake. The estimated daily intake of lead exceeded the provisional tolerable daily intake in all date cultivars. The study also calculated a hazard risk index, revealing lead contamination as the most significant health risk among the analyzed heavy metals. Lead contamination in date fruits is primarily caused by human activities, particularly the combustion of fossil fuels in vehicles using leaded gasoline or diesel fuel. The findings of present research emphasize the importance of implementing effective measures to minimize heavy metal contamination in date palm cultivation, processing, and distribution. Future prospects involve research and development to identify sources of heavy metal contamination in date palm cultivation, such as soil, water, air pollution, fertilizers, and pesticides. This understanding can lead to targeted interventions to reduce and prevent heavy metal accumulation in date fruits. Innovative agricultural practices, such as efficient irrigation systems, organic farming, and sustainable land and water management, can be explored to improve soil and water quality for date palm cultivation.

Acknowledgments

The authors extend their gratitude to the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Kingdom of Saudi Arabia, for funding the publication of this work under the Ambitious Researcher program (Proposal No. KFU241358).

References

Abass, M.H., J.D. Neama and K. Al-Jabary. 2016. Biochemical responses to cadmium and lead stresses in date palm (*Phoenix dactylifera* L.) plants. *Adv. Agric. Bot.*, 8(3): 92-110.

Abass, M.H., Z.K. Hassan and K.M. Al-Jabary. 2015. Assessment of heavy metals pollution in soil and date palm (*Phoenix dactylifera* L.) leaves sampled from Basra/Iraq governorate. *Adv. Environ. Sci*., 7(1): 52-59.

Abdullahi, A., M.A. Lawal and A.M. Salisu. 2021. Heavy metals in contaminated soil: source, accumulation, health risk and remediation process. *Bayero J. Pure Appl. Sci*., 14(1): 1-12.

Abeywickrama, C.J. and J. Wansapala. 2019. Review of organic and conventional agricultural products: Heavy metal availability, accumulation and safety. *Int. J. Food Sci. Nutr.,* 4(1): 77-88.

Ajani, M.B., P.P. Maleka, S. Penabei and I.T. Usman. 2022. Health risk assessment of heavy metals concentration from soil; a case study of the Mayo-Dallah in Southern area of Chad. *J. Rad. Res. Appl. Sci*., 15(1): 130-138.

Akensous, F.Z., M. Anli and A. Meddich. 2022. Biostimulants as innovative tools to boost date palm (*Phoenix dactylifera* L.) performance under drought, salinity, and heavy metal (Oid)s' stresses: A concise review. *Sustainability*, 14(23): 15984.

Al-Busaidi, A., B. Shahroona, R. Al-Yahyai and M. Ahmed. 2015. Heavy metal concentrations in soils and date palms irrigated by groundwater and treated wastewater. *Pak. J. Agric. Sci.,* 52(1): 129-134.

Aldjain, I.M., M.H. Al-Whaibi, S.S. Al-Showiman and M.H. Siddiqui. 2011. Determination of heavy metals in the fruit of date palm growing at different locations of Riyadh. *Saudi J. Biol. Sci*., 18: 175-180. DOI:10.1016/j.sjbs.2010.12.001.

Aleid, S.M., J.M. Al-Khayri and A.M. Al-Bahrany. 2015. Date Palm Status and Perspective in Saudi Arabia. In: (Eds.): Al-Khayri, J., S. Jain and D. Johnson. *Date Palm Genetic Resources and Utilization*. Springer, Dordrecht. pp. 49-95. DOI:10.1007/978-94-017-9707-8_3

Alghamdi, A.G., M.H. El-Saeid, A.J. Alzahrani and H.M. Ibrahim. 2022. Heavy metal pollution and associated health risk assessment of urban dust in Riyadh, Saudi Arabia. *PLoS One*, 17(1): e0261957.

Ali, M.H.H. and K.M. Al-Qahtani. 2012. Assessment of some heavy metals in vegetables, cereals and fruits in Saudi Arabian markets. *Egypt. J. Aquat. Res*., 38: 31-37. DOI:10.1016/j.ejar.2012.08.002.

Al-Khlaifat, A.L. and O.A. Al-Khashman. 2007. Atmospheric heavy metal pollution in Aqaba city, Jordan, using *Phoenix dactylifera* L. leaves. *Atmos. Environ*., 41(39): 8891-8897. DOI:10.1016/j.atmosenv.2007.08.028

Al-Mssallem, M.Q. 2018. Consumption of dates among Saudi adults and its association with the prevalence of type 2 diabetes. *Asian J. Clin. Nutr*., 10(2): 58-64. DOI:10.3923/ajcn.2018.58.64.

Al-Shayeb, S.M. and M.R.D. Seaward. 2000. The date palm (*Phoenix dactylifera* L.) fibre as a biomonitor of lead and other elements in arid environments. *Asian J. Chem*., 12(4): 954-966.

Al-Swadi, H.A., A.R. Usman, A.S. Al-Farraj, M.I. Al-Wabel, M. Ahmad and A. Al-Faraj. 2022. Sources, toxicity potential, and human health risk assessment of heavy metals-laden soil and dust of urban and suburban areas as affected by industrial and mining activities. *Sci. Rep*., 12(1): 8972.

Ankush, S. Lamba, Ritambhara, A. Diwedi, S. Kumar and V. Singh. 2023. Source and distribution of lead in soil and plant-A Review. In: (Eds.): Kumar, N. and A.K. Jha. *Lead Toxicity: Challenges and Solution. Environmental Science and Engineering*. Springer, Cham. pp. 3-16. DOI:10.1007/978-3-031-37327-5_1

AOAC. 2005. *Official Methods of Analysis of AOAC International*. Horwitz W. and G.W. Latimer Jr. (Eds.), 18th Edition. Maryland. USA.

Bharti, R. and R. Sharma. 2022. Effect of heavy metals: An overview. *Mater. Today Proc*., 51: 880-885. DOI:10.1016/j.matpr.2021.06.278

Blamey, F.P.C., P.M. Kopittke, J.B. Wehr and N.W. Menzies. 2021. *Aluminum*. In: (Eds.): Barker, A.V. and D.J. Pilbeam. *Handbook of Plant Nutrition*. Second Edition. CRC Press, Taylor and Francis Group, Boca Raton, NY, USA. pp. 567-606.

Bu-Olayan, A.H. and B.V. Thomas. 2002. Biomonitoring studies on the effect of lead in date palm (*Phoenix dactylifera*) in the arid ecosystem of Kuwait. *J. Arid Environ*., 51(1): 133-139. DOI:10.1006/jare.2001.0916

Chen, Z., I. Muhammad, Y. Zhang, W. Hu, Q. Lu, W. Wang, B. Huang and M. Hao. 2021. Transfer of heavy metals in fruits and vegetables grown in greenhouse cultivation systems and their health risks in Northwest China. *Sci. Total Environ*., 766: 142663.

Cimboláková, I., I. Uher, K.V. Laktičová, M. Vargová, T. Kimáková and I. Papajová. 2019. Heavy metals and the environment. In: (Eds.): Uher, I. *Environmental Factors Affecting Human Health*. IntechOpen, London, UK. pp. 29-58. DOI:10.5772/intechopen.86876

Einolghozati, M., E. Talebi-Ghane, M. Khazaei and F. Mehri. 2023. The level of heavy metal in fresh and processed fruits: a study meta-analysis, systematic review, and health risk assessment. *Biol. Trace Elem. Res*., 201(5): 2582-2596.

Fang, B. and X. Zhu. 2014. High content of five heavy metals in four fruits: evidence from a case study of Pujiang County, Zhejiang Province, China. *Food Control*, 39: 62-67.

Hadrami, I.E. and A.E. Hadrami. 2009. Breeding date palm. In: (Eds.): Jain S.M. and P.M. Priyadarshan. *Breeding Plantation Tree Crops: Tropical Species*. Springer, New York, USA. pp. 191-216.

Hussain, S., Z. Rengel, M. Qaswar, M. Amir and M. Zafar-ul-Hye. 2019. Arsenic and heavy metal (cadmium, lead, mercury and nickel) contamination in plant-based foods. In: (Eds.): Ozturk, M. and K.R. Hakeem. *Plant and Human Health, Volume 2: Phytochemistry and Molecular Aspects*. Springer, Cham. pp. 447-490. DOI:10.1007/978-3-030-03344-6_20

Jafari, K., M.R. Ghalhari, R. Hayati, Z. Baboli, K. Zeider, M.D. Ramírez-Andreotta, A. Sorooshian, A. De Marco, D. Namdar-Khojasteh, M. Goudarzi and M.G. Ghozikali. 2023. Using date palm (*Phoenix dactylifera* L.) as bio-monitors of environmental quality for exposure assessment and pollution source tracking. *Atmos. Environ*., 313: 120055.

Jayasumana, C., S. Fonseka, A. Fernando, K. Jayalath, M. Amarasinghe, S. Siribaddana, S. Gunatilake and P. Paranagama. 2015. Phosphate fertilizer is a main source of arsenic in areas affected with chronic kidney disease of unknown etiology in Sri Lanka. *SpringerPlus*, 4: 90. DOI:10.1186/s40064-015-0868-z

Jin, T., M. Nordberg, W. Frech, X. Dumont, A. Bernard, T.T. Ye, Q. Kong, Z. Wang, P. Li, N.G. Lundström and Y. Li. 2002. Cadmium biomonitoring and renal dysfunction among a population environmentally exposed to cadmium from smelting in China (ChinaCad). *Biometals*, 15: 397-410.

Khan, A., M.I. Khattak, R. Jabeen, S.K. Laghari and Y. Arafat. 2019. Study of trace elements in fruits of dates at Turbat-Punjgur region of Balochistan with reference to medicinal and environmental pollution. *Pak. J. Bot*., 51(5): 1769-1774.

Khan, S., Q. Cao, Y.M. Zheng, Y.Z. Huang and Y.G. Zhu. 2008. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environ. Pollut*., 152: 686-692. DOI:10.1016/j.envpol.2007.06.056.

Khan, Z.I., I. Ugulu, A. Zafar, N. Mehmood, H. Bashir, K. Ahmad and M. Sana. 2021. Biomonitoring of heavy metals accumulation in wild plants growing at soon valley, Khushab, Pakistan. *Pak. J. Bot*., 53(1): 247-252.

Kooner, R., B.V.C. Mahajan and W.S. Dhillon. 2014. Heavy metal contamination in vegetables, fruits, soil and water–A Critical Review. *Int. J. Agric., Environ. Biotechnol*., 7(3): 603-612.

Kulhari, A., A. Sheorayan, S. Bajar, S. Sarkar, A. Chaudhury and R.K. Kalia. 2013. Investigation of heavy metals in frequently utilized medicinal plants collected from environmentally diverse locations of north western India. *SpringerPlus*, 2: 676. DOI:10.1186/2193-1801-2-676

Le, Q.H., D.D. Tran, Y.C. Chen and H.L. Nguyen. 2019. Risk of lead exposure from transport stations to human health: a case study in the highland province of Vietnam. *Toxics*, 7(3): 48.

Mansour, S.A. 2014. Heavy metals of special concern to human health and environment. In: (Eds.): Bhat, R. and V.M. Gómez-López. *Practical Food Safety: Contemporary Issues and Future Directions*. Wiley Publishing Company, John Wiley & Sons Inc., New Jersey, USA. pp. 213-233. DOI:10.1002/9781118474563.ch12

Meena, A.K., P. Bansal, S. Kumar, M.M. Rao and V.K. Garg. 2010. Estimation of heavy metals in commonly used medicinal plants: A market basket survey. *Environ. Monit. Assess*., 170(1): 657-660.

Mitra, A., S. Chatterjee, S. Datta, S. Sharma, V. Veer, B.H. Razafindrabe, C. Walther and D.K. Gupta. 2014. Mechanism of metal transporters in plants. In: (Eds.): Gupta and D.K. and S. Chatterjee. *Heavy Metal Remediation: Transport and Accumulation in Plants*. Nova Science Publishers, Inc. NY, USA. pp. 1-28.

Mohamed, H., P.I. Haris and E.I. Brima. 2017. Estimated dietary intakes of toxic elements from four staple foods in Najran city, Saudi Arabia. *Int. J. Environ. Res. Public Health*, 14: 1575. DOI:10.3390/ijerph14121575.

Nadeem, M., T.M. Qureshi, I. Ugulu, M.N. Riaz, Q.U. An, Z.I. Khan, K. Ahmad, A. Ashfaq, H. Bashir and Y. Dogan. 2019. Mineral, vitamin and phenolic contents and sugar profiles of some prominent date palm (*Phoenix dactylifera*) varieties of Pakistan. *Pak. J. Bot*., 51(1): 171-178.

Page, V. and U. Feller. 2015. Heavy metals in crop plants: transport and redistribution processes on the whole plant level. *Agronomy*, 5(3): 447-463.

Podar, D. and F.J. Maathuis. 2022. The role of roots and rhizosphere in providing tolerance to toxic metals and metalloids. *Plant Cell Environ*., 45(3): 719-736.

Radwan, M.A. and A.K. Salama. 2006. Market basket survey for some heavy metals in Egyptian fruits and vegetables. *Food Chem. Toxicol*., 44: 1273-1278. DOI:10.1016/j.fct.2006.06.020.

Rahaman, S., A.C. Sinha, R. Pati and D. Mukhopadhyay. 2013. Arsenic contamination: a potential hazard to the affected areas of West Bengal, India. *Environ. Geochem. Health*, 35: 119-132.

Rahman, R. and H. Upadhyaya. 2021. Aluminium toxicity and its tolerance in plant: A review. *J. Plant Biol*., 64(2): 101-121.

Roba, C., C. Roşu, I. Piştea, A. Ozunu and C. Baciu. 2016. Heavy metal content in vegetables and fruits cultivated in Baia Mare mining area (Romania) and health risk assessment. *Environ. Sci. Pollut. Res*., 23: 6062-6073.

Salama, K.F., M.A. Randhawa, A.A. Al Mulla and O.A. Labib. 2019. Heavy metals in some date palm fruit cultivars in Saudi Arabia and their health risk assessment. *Int. J. Food Prop*., 22(1): 1684-1692. DOI:10.1080/10942912.2019.1671453

Sandil, S., M. Óvári, P. Dobosy, V. Vetési, A. Endrédi, A. Takács, A. Füzy and G. Záray. 2021. Effect of arsenic-contaminated irrigation water on growth and elemental composition of tomato and cabbage cultivated in three different soils, and related health risk assessment. *Environ. Res*., 197: 111098.

Savvas, D., G. Colla, Y. Rouphael and D. Schwarz. 2010. Amelioration of heavy metal and nutrient stress in fruit vegetables by grafting. *Sci. Hort*., 127(2): 156-161.

Shaheen, N., N.M. Irfan, I.N. Khan, S. Islam, M.S. Islam and M.K. Ahmed. 2016. Presence of heavy metals in fruits and vegetables: Health risk implications in Bangladesh. *Chemosphere*, 152: 431-438.

Shahid, M., C. Dumat, S. Khalid, E. Schreck, T. Xiong and N.K. Niazi. 2017. Foliar heavy metal uptake, toxicity and detoxification in plants: A comparison of foliar and root metal uptake. *J. Hazard. Mater*., 325: 36-58.

Siddiqa, A. and M. Faisal. 2020. Heavy metals: source, toxicity mechanisms, health effects, nanotoxicology and their bioremediation. In: (Eds.): Naeem, M., A.A. Ansari and S.S. Gill. *Contaminants in Agriculture: Sources, Impacts and Management*, Springer, Cham. pp. 117-141. DOI:10.1007/978-3-030-41552-5_6

Soomro, A.H., A. Marri and N. Shaikh. 2023. Date Palm (*Phoenix dactylifera*): A Review of economic potential, industrial valorization, nutritional and health significance. In: (Eds.): Ismail, T., S. Akhtar and C.E. Lazarte. *Neglected Plant Foods of South Asia: Exploring and Valorizing Nature to Feed Hunger*. Springer, Cham. pp. 319-350. DOI:10.1007/978-3-031-37077-9_13

Thakur, S., L. Singh, Z.A. Wahid, M.F. Siddiqui, S.M. Atnaw and M.F.M. Din. 2016. Plant-driven removal of heavy metals from soil: uptake, translocation, tolerance mechanism, challenges, and future perspectives. *Environ. Monit. Assess*., 188: 1-11.

Upadhyay, M.K., A. Shukla, P. Yadav and S. Srivastava. 2019. A review of arsenic in crops, vegetables, animals and food products. *Food Chem*., 276: 608-618.

Vardhan, K.H., P.S. Kumar and R.C. Panda. 2019. A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives. *J. Mol. Liq*., 290: 111197.

Vareda, J.P., A.J. Valente and L. Durães. 2019. Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. *J. Environ. Manag*., 246: 101-118.

Wang, Q., J. Liu and S. Cheng. 2015. Heavy metals in apple orchard soils and fruits and their health risks in Liaodong Peninsula, Northeast China. *Environ. Monit. Assess*., 187: 1-8.

White, P.J. and G. Ding. 2023. Long-distance transport in the xylem and phloem. In: (Eds.): Rengel, Z., I. Cakmak and P.J. White. *Marschner's Mineral Nutrition of Plants*. Fourth Edition. Academic Press. MA, USA. pp. 73-104. DOI:10.1016/C2019-0-00491-8

WHO/FAO. 2011. Joint FAO/WHO Expert Committee on Food Additives. Compendium of Food Additive Specifications, 74th Meeting. Rome, Italy.

Williams, J.R., A.E. Pillay, M.O. El Mardi, S.M.H. Al-Lawati and A. Al-Hamdi. 2005. Levels of selected metals in the Fard cultivar (date palm). *J. Arid Environ*., 60(2): 211-225. DOI:10.1016/j.jaridenv.2004.04.005.

Yan, L., M. Riaz, J. Liu, M. Yu and J. Cuncang. 2022. The aluminium tolerance and detoxification mechanisms in plants; recent advances and prospects. *Crit. Rev. Environ. Sci. Technol*., 52(9): 1491-1527.

Zakir, H.M., Q.F. Quadir, A. Bushra, S. Sharmin. A. Sarker. M.H. Rashid and A. Rahman. 2022. Human health exposure and risks of arsenic from contaminated soils and brinjal fruits collected from different producers and retailers levels. *Environ. Geochem. Health*, 44(12): 4665-4683.

Zouari, M., N. Elloumi, C.B. Ahmed, D. Delmail, B.B. Rouina, F.B. Abdallah and P. Labrousse. 2016. Exogenous proline enhances growth, mineral uptake, antioxidant defense, and reduces cadmium-induced oxidative damage in young date palm (*Phoenix dactylifera* L.). *Ecol. Eng*., 86: 202-209.

(Received for publication 22 December 2023)