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

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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.

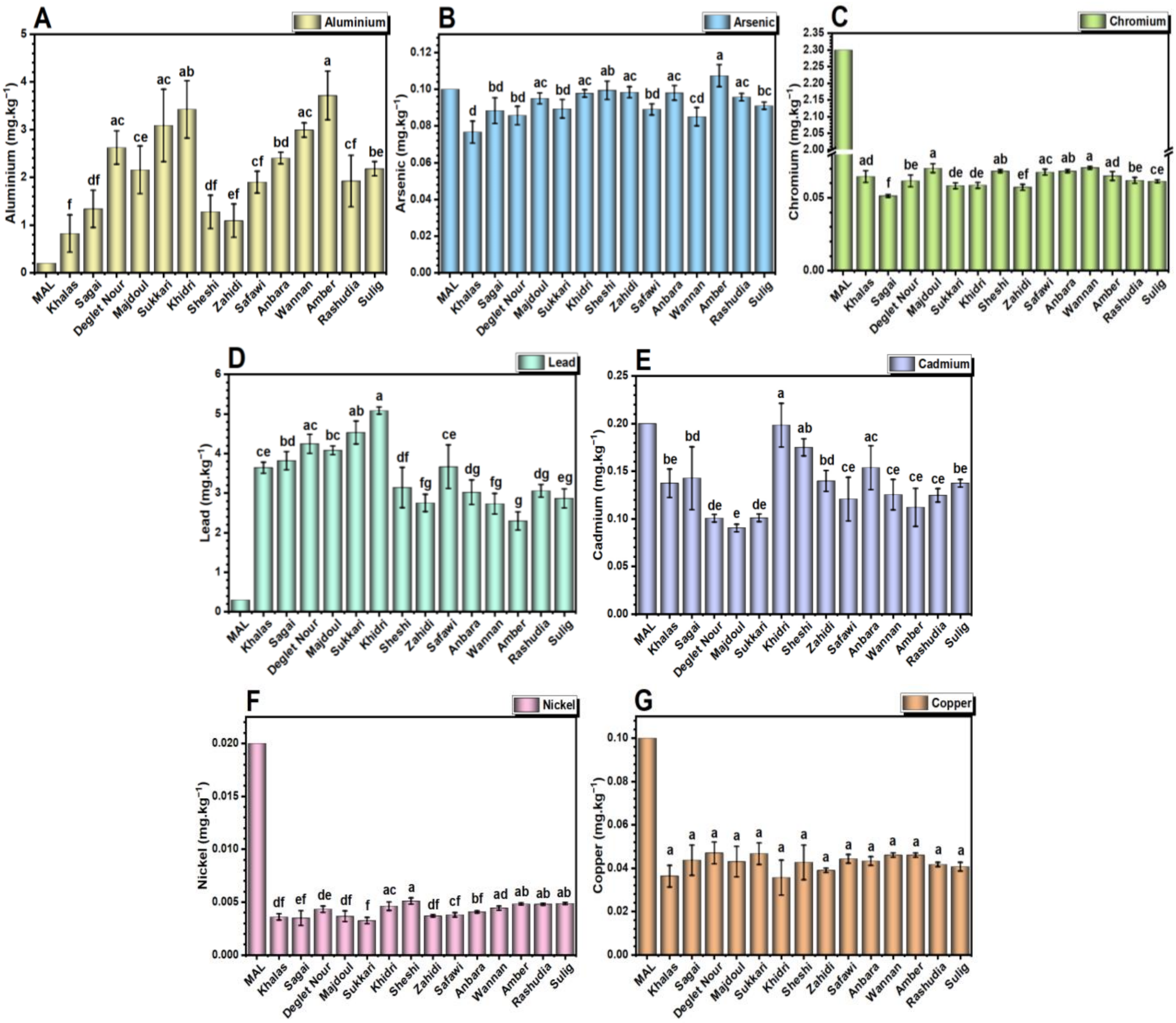

Fig. 1. Concentration of toxic heavy metals in date palm cultivars. Similar letters show non-significant difference at 5% level of probability (p<0.05). MAL is the abbreviation for maximum allowed limit (mg kg^{-1}) prescribed by FAO/WHO. Y-bars indicate the standard deviation within replicates.

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.

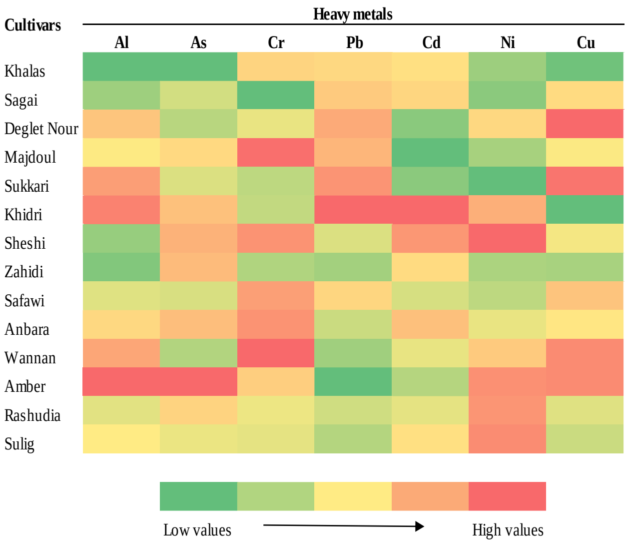

Fig. 2. Heatmap showing the values of heavy metals; Aluminium (Al), Arsenic (As), Chromium (Cr), Lead (Pb), Cadmium (Cd), Nickel (Ni), and Copper (Cu) found in fourteen date palm cultivars.

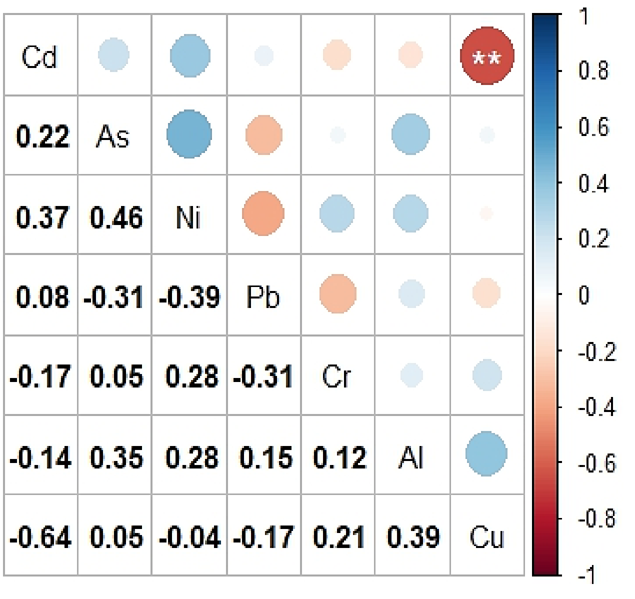

Fig. 3. Path coefficient correlation computed by Pearson-method for heavy metals; Aluminium (Al), Arsenic (As), Chromium (Cr), Lead (Pb), Cadmium (Cd), Nickel (Ni), and Copper (Cu) of date palm cultivars. ** represents significant correlation between the heavy metals at $p \leq 0.01$.

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.

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