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تلوث التمور بالمعادن الثقيلة: نظرة عامة

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Heavy Metal Contamination in the Fruit of Date Palm: An Overview

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الملخص:

للمعادن الثقيلة تأثير كبير على الخلايا والكائنات الحية لأنها تسبب عددًا من التأثيرات الضارة والسموم. وقد ثبت في السنوات الأخيرة أن بعض المعادن الثقيلة الملوثة تؤثر سلبًا على جودة المحاصيل، بما في ذلك نخيل التمر، مما يؤثر على صحة الإنسان كما الأمن الغذائي. فعلى سبيل المثال، وجد أن العديد من الأطعمة تحتوي على الكروم والكادميوم والنحاس والرصاص والزئبق. ويبدو أن هذه المكونات ملوثات بيئية في الطبيعية، وفقًا للأدلة. ونتيجة لذلك، يؤكد هذا التحليل على مخاطر تلوث نخيل التمر بالمعادن الثقيلة وتأثيراتها على صحة الإنسان. لذلك تم الحصول على المعلومات من مجموعة من قواعد البيانات، بما في ذلك Directory of Open Access Journals، وPubMed، وScience Direct، وGoogle Scholar. تسلط هذه النتائج الضوء على أهمية تنفيذ تقنيات فعالة لتخفيف اثار التلوث، مثل إعادة تأهيل التربة وتبني الممارسات المستدامة في الزراعة، للحد من امتصاص المعادن الثقيلة من قبل النباتات. وفي المستقبل، من الضروري تكثيف الجهود البحثية التي تركز على تحديد مصادر التلوث وتطوير الحلول المبتكرة والتي تتكيف مع السياقات البيئية. إن الجهود التعاونية بين العلماء وصناع السياسات والمجتمعات المحلية ضرورية لحل هذه المشكلة المعقدة. وبناءً على المعرفة المكتسبة من هذه الدراسة، يمكن لأصحاب المصلحة العمل على ضمان سلامة واستدامة زراعة النخيل، والحفاظ على البيئة وصحة الإنسان. ومع ذلك، فإن الآليات التي تمارس بها هذه المعادن الثقيلة تأثيراتها على صحة الإنسان ليست مفهومة بشكل جيد. وعلاوة على ذلك، فإن التأثيرات الإيجابية والسلبية للمعادن الثقيلة ليست راسخة جيداً، مما يشير للحاجة إلى مزيد من البحث.

الكلمات الدالة: التمور، المعادن الثقيلة، التلوث، صحة الانسان.

Abstract:

Heavy metals have a significant impact on living cells and organisms because they cause a number of harmful environmental impacts and toxicities. Certain heavy metal contaminants have been shown in recent years to negatively impact crop quality, including date palm, which impacts human health and food security. For instance, many foods were found to include chromium, cadmium, copper, lead, and mercury. These components appear to be environmental pollutants in natural foods, according to evidence. As a result, this analysis emphasizes the dangers of date

palm pollution by heavy metals and their effects on human health. The information was obtained from a variety of databases, including the Directory of Open Access Journals, PubMed, Science Direct, and Google Scholar. The results highlight the importance of implementing effective mitigation techniques, such as soil rehabilitation and adopting sustainable agricultural practices, to reduce the uptake of heavy metals by these plants. In the future, it is imperative to intensify research efforts focused on the identification of specific pollution sources and the development of innovative solutions adapted to different environmental contexts. Collaborative efforts between scientists, policy makers and local communities will take place essential to solve this complex problem. Based on the knowledge gained from this study, stakeholders can work to ensure the safety and sustainability of palm cultivation, preserving the environment and human health. However, the mechanisms by which these heavy metals exert their effects on human health are not well understood. Furthermore, the positive and negative effects of heavy metals are not well established, suggesting the need for more research.
Keywords: Heavy metals, Date palm, Contamination, Human health

1 .Introduction

The date palm, scientifically known as *Phoenix dactylifera*, is a crucial fruit-bearing tree that thrives in arid and semi-arid regions. Renowned for its nutritional and economic significance, the date palm has been cultivated for thousands of years, particularly in the Middle East and North Africa (Abul-Soad et al., 2017; Banadka et al., 2025). As a staple food source and a vital component of agricultural economies, the quality and safety of dates are of paramount importance (El Far et al., 2016; Elsherif & Aljaroushi, 2021). However, recent studies have raised concerns about the contamination of date palm fruits with heavy metals (Chamon et al., 2024; El Youssfi et al., 2024; Tamirat et al., 2024). Heavy metals are naturally occurring elements with high atomic weights and densities. While some heavy metals like iron, zinc, and copper are essential for biological processes in trace amounts, others such as lead, cadmium, and mercury pose significant health risks even at low concentrations (Engwa et al., 2019; Salem & Salem, 2023; Verma et al., 2016). These metals can enter the environment through various sources, including industrial activities, agricultural practices, and natural processes, leading to soil and water contamination (Hou, O'Connor, et al., 2020).Contamination of date palms with heavy metals can occur through the uptake of these metals from contaminated soils or irrigation water (Masindi & Muedi, 2018; Salama et al., 2019). The extent of contamination can vary widely based on geographical location, soil characteristics, and local environmental conditions (Al-Busaidi et al., 2015; Nagajyoti et al., 2010). Understanding the levels and sources of heavy metal contamination in date palms is crucial for ensuring food safety and protecting public health.

This literature review aims to provide an overview of heavy metal contamination in the fruit of date palms grown at different locations. It will explore the cultivation background of date palms, the definition and sources of heavy metals, and how these metals contaminate date palms. Additionally, the review will examine the geographical variations in contamination levels and discuss strategies for mitigating and managing heavy metal contamination in date palm cultivation.

2 .Date Palm Cultivation

The cultivation of date palms can be traced back to ancient Mesopotamia, highlighting their longstanding significance in Middle Eastern agriculture and culture (Abul-Soad et al., 2017; Amadou, 2016) These resilient plants played a crucial role in ancient trade routes and economies, serving as a staple food source for desert communities. Beyond their economic value, date palms hold symbolic and religious importance across various cultures (EL-Mously et al., 2023). In modern times, the economic impact of date palm cultivation remains substantial, supported by their adaptability to arid and semi-arid environments. This adaptability underscores their continued relevance in both historical and contemporary contexts. Date palm cultivation spans various regions globally, with significant concentrations in the Middle East, North Africa, and South Asia. These areas provide optimal climatic conditions critical to the growth and productivity of date palms. Economically, date palm cultivation sustains local economies, offering diverse varieties that thrive under specific regional conditions. Agricultural practices, deeply rooted in traditional knowledge, influence cultivation methods, yet these regions face challenges such as climate change and resource limitations (EL-Mously et al., 2023; Ramadan & Farag, 2022). Understanding these dynamics is crucial for maintaining the economic and cultural significance of date palms in these key locations.

3 .Economic and Nutritional Significance

Date palms serve as a cornerstone of economic stability in arid and semi-arid regions, contributing significantly to a global market valued at billions of dollars annually. The cultivation of date palms not only supports rural livelihoods and employment but also enhances food security in areas with limited agricultural diversity (Abul-Soad et al., 2023). Nutritionally, dates are rich in essential vitamins and minerals, high in dietary fiber for digestive health, and provide a quick energy boost due to their natural sugars (Elsherif & Aljaroushi, 2021; Mohamed et al., 2014). Furthermore, their antioxidant properties offer potential health benefits (Vayalil, 2013). The export of dates significantly bolsters the economies of producing countries, while innovative uses of date by-products add value and minimize waste (Subhash et al., 2024).

4 .Heavy Metal Contamination in Date Palms

Heavy metals are naturally occurring elements known for their high atomic weight and density, characterized by a specific gravity exceeding 5 g/cm³. Common examples include lead, mercury, cadmium, arsenic, and chromium (Mahurpawar, 2015). These metals possess distinct metallic properties and are notorious for their toxicity, even at low concentrations (Engwa et al., 2019). Found within the Earth's crust, they are released into the environment through both natural processes and human activities. As persistent environmental pollutants, heavy metals pose risks of bioaccumulation and biomagnification, leading to adverse effects on human health, ecosystems, and agriculture (Chan, 1998; Salem & Salem, 2023). Industrial activities, such as manufacturing and processing, often release heavy metals into the environment, posing a significant threat to agricultural areas. Agricultural practices can exacerbate this issue by using contaminated water or soil, while the application of pesticides and fertilizers further introduces heavy metals (Elsherif & Aljaroushi, 2021). Mining operations are another major contributor, contaminating both soil and water sources (Aly & El-soad, 2009). Additionally, atmospheric deposition from industrial emissions and waste disposal sites can lead to heavy metal accumulation. Urban runoff also plays a role by transporting contaminants into agricultural zones. Lastly, natural geological sources can release heavy metals, impacting soil and water quality (Okereafor et al., 2020).

Heavy metals, such as lead, cadmium, and mercury, can accumulate in human tissues over time through the consumption of contaminated food products, leading to chronic exposure that poses significant and far-reaching health risks. When these toxic substances enter the body, they can persist for extended periods, as the body's natural elimination processes are often inadequate to remove them efficiently. This bioaccumulation can result in gradual and cumulative damage to various organs and systems, with potentially severe consequences for human health. The health effects of heavy metal exposure are well-documented and diverse, affecting multiple systems within the body. Neurological disorders are among the most concerning outcomes, particularly for children, whose developing nervous systems are more susceptible to the toxic effects of these metals. Lead, for instance, has been shown to impair cognitive function, reduce IQ, and disrupt behavioral development in children. . Similarly, mercury exposure, often associated with the consumption of contaminated fish, can lead to neurological damage, including symptoms such as tremors, memory loss, and impaired vision. In addition to neurological effects, heavy metals can also cause significant damage to the kidneys, a critical organ for filtering waste from the blood. Cadmium, for example, is a known nephrotoxin that can lead to kidney dysfunction and, in severe cases, renal failure (Borowska & Brzóska, 2015). The immune system is another target for heavy metal toxicity, with exposure potentially leading to immunosuppression, making individuals more vulnerable to infections and other diseases.(Borowska & Brzóska, 2015; Salama et al., 2019).

Vulnerable populations, such as children, pregnant women, and the elderly, are particularly at risk from heavy metal exposure. Children, due to their smaller body size and ongoing developmental processes, are more sensitive to the toxic effects of heavy metals. Pregnant women, on the other hand, face heightened risks because heavy metals can cross the placental barrier, exposing the developing fetus to these toxins and potentially leading to developmental delays, low birth weight, and other adverse outcomes (Salama et al., 2019).Moreover, emerging research suggests that heavy metal exposure is associated with an increased risk of cancer and cardiovascular diseases. The bioaccumulation of these metals can disrupt various metabolic and enzymatic processes within the body, leading to oxidative stress, DNA damage, and inflammation—all of which are implicated in the development of chronic diseases (سالمet al., 2023). For instance, cadmium exposure has been linked to an increased risk of lung cancer, while mercury has been associated with cardiovascular complications, including hypertension and heart disease.(سالمet al., 2023).

Given the serious health implications of heavy metal exposure, it is crucial for regulatory bodies to implement and enforce strict guidelines for the levels of these contaminants in food products. Monitoring programs must be comprehensive and ongoing to ensure that food sources are free from unacceptable levels of heavy metals. Additionally, efforts should be made to educate the public about the risks associated with heavy metal exposure and to promote practices that minimize contamination in the food supply chain. By taking these steps, public health authorities can help protect populations from the adverse effects of heavy metal toxicity and reduce the burden of related diseases.

4.1. Mechanisms of Metal Uptake in Plants

Plants employ various mechanisms for metal uptake, primarily through root absorption, which serves as the main entry point for metals (Dalvi & Bhalerao, 2013). Transport proteins play a crucial role in facilitating this process, with distinctions between the uptake of essential and non-essential metals. Soil pH and composition significantly influence metal uptake, affecting pathways like symplastic and apoplastic transport (Kochian, 1991). Mycorrhizal fungi enhance uptake, while genetic factors determine efficiency. Metal chelators impact metal mobility and availability, aiding in the translocation from roots to shoots and (Shahid et al., 2017; Shi et al., 2019). Understanding these mechanisms is vital for assessing heavy metal contamination in date palm fruits.

4.2. Factors Affecting Metal Accumulation in Date Palms

The uptake of heavy metals by date palms is significantly influenced by the composition and pH of the soil. Soils with varying mineral content and acidity levels can alter the availability of metals to plant roots (Kochian, 1991). The quality of irrigation water plays a critical role in metal accumulation(Aleid et al., 2016). Contaminated water sources can introduce additional metals, enhancing their presence in the plants. Different species and varieties of date palms exhibit varying rates of metal absorption, largely due to differences in root structure and function, which affect how metals are taken up (Chamon et al., 2024; Zwolak et al., 2019). External factors such as temperature and humidity can affect metal accumulation. Additionally, agricultural practices, including the use of fertilizers and pesticides, contribute to the presence of metals, The bioavailability of metals in the soil, influenced by microbial activity, also affects uptake, The age and growth stage of date palms are crucial, as younger plants may absorb metals differently compared to mature ones (Al-Dashti et al., 2021; Hamid, 2011; Tsado Mathew et al., 2014)**.**

5. Geographical Variations in Contamination Levels

The contamination of heavy metals in date palms varies significantly across different regions due to a multitude of factors. Geographical variations in metal levels are influenced by local agricultural practices, which can either mitigate or exacerbate these issues (Abdalla et al., 2018; Achakzai et al., 2022; Aldjain et al., 2011). Urban areas often show higher contamination levels compared to rural settings, largely due to industrial activities. Industrial activities contribute to environmental contamination, yet natural barriers and ecosystems can mitigate such effects (Aly & El-soad, 2009; Ramadan & Farag, 2022). Historical land use and organic farming practices play crucial roles in managing long-term soil contamination and reducing heavy metal presence in date palms. Additionally, the composition of the soil and local climate conditions play critical roles in these differences (Al-Busaidi et al., 2015; Hassan et al., 2017). Studies reveal regional contamination challenges, highlighting the variable effectiveness of regulatory measures. Understanding these trends is crucial for addressing public health concerns related to heavy metal exposure.

Table (1) The contamination of heavy metals in date palms across different regions in the world.

Reference	Location (City/Country)	Metals Studied	Measurement Method	Results
(Aldjain et al., 2011)	Riyadh/Saudi Arabia	Pb and Cd,	Anatomic absorption spectrometer	All metals were within permissible limits.
(Taha & Ghtani, 2015)	Kharj/ Saudi Arabia	Al, Mn, Fe, Ni, As, Rb, Ru, Cd, In, Ba, Tl and Bi.	flame photometry inductivity coupled plasma and atomic absorption	The concentrations of all elements in the dated fruit samples are lower than those reported in the literature.
(Al-Busaidi et al., 2015)	Oman	Cu, Cr, Cd, Pb, Mn, Fe and Zn	Inductively coupled plasma (ICP) spectroscopy	All metals were within permissible limits.
(Hassan et al., 2017)	Jeddah/ Saudi Arabia	Ag, Al, B, Ba, Cd, Cu, Cr, Fe, Ni, Pb, Se and Zn	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	The concentrations of these elements were higher in the urban site compared to the residential site and showed an increase over the harvest period.
(Abdalla et al., 2018)	Turaba District/ Saudi Arabia	Al, As, Cd and Pb	Inductively coupled plasma-optical emission spectrometry (ICP-OES).	(Cd, Al, As and Pb) were below limit of detection
(Salama et al., 2019)	Saudi Arabia	Al, As, Cr, Pb, Cd, and Sb	iCAP 6300 Duo Inductively Coupled Plasma – Optical Emission Spectrophotometer (ICP-OES, Thermo Fischer Scientific).	All metals were within permissible limits.
(Suleman, 2019)	Zilfi/Saudi Arabia	Ag, Al, As, Bi, Cd, Co and Cr	Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	The concentrations of all elements in the dated fruit samples are lower than those reported in the

				literature.
(Al-Shali et al., 2019)	Al-Rusail / Sultanate of Oman	Ni, Zn , Pb , Cd	coupled plasma optical emission spectrometer	Elevated levels of Pb and Cd in fruits from industrial regions.
(Badarusham et al., 2019)	Lahore/ Pakistan	Al, Ba, Cu, Fe, Mg, Ni, Pb, Zn and Se	Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES).	A comparison of elements in the samples revealed that the flesh samples had higher concentrations of aluminum, barium, and selenium.
(Faisal et al., 2020)	Basra/ IRAQ	Pb	/	Elevated levels of Pb and Cd in leaves from industrial regions.
(Khalilia, 2020)	Palestine.	Pb, Cd, Zn	Atomic Absorption Spectroscopy (AAS)	All metals were within permissible limits.
(Elsherif & Aljaroushi, 2021)	Libya	Fe, Zn, Cu, Cd, and Pb	Flame Atomic Absorption Spectrometry (FAAS)	Significant contamination of Pb and Cd in fruits
(Omar & Al, 2021)	Al Ain/ United Arab Emirates	Fe, Zn, Cu, Mn, Cd and Cr	Coupled Plasma Mass Spectroscopy (ICPMS).	Elevated levels of Cd in fruits from industrial areas.
(Mohamed Malik & Hamadnalla, 2021)	Sudan	Pb and Cd	Atomic Absorption Spectrophotometer, (Thermo Scientific Pvt. Ltd. India Model No. AA 350)	The concentrations of Cd in the dated fruit samples are lower than those reported in the literature.
(Abdel-Rahman et al., 2022)	Giza/ Egypt	Pb, Cd, Cr and Na	Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)	Significant contamination of Pb, Cd and Cd in fruits
(Achakzai et	Balochistan	Fe, Pb, Co,	Atomic Absorption	All metals were

al., 2022)	(Panjgoor and Turbat)/Pakistan	Mn, Cd, Cu	Spectroscopy (AAS)	within permissible limits.
(Chamon et al., 2023)	Dhaka/ Bangladesh	Cd, Cr, Pb, Ni, Cu, Zn, Fe, and Mn	Absorption Spectrophotometer (Varian 240).	High levels of Na and Cd in fruits
(Anteneh et al., 2024)	Jigjiga / Ethiopia	Fe, Zn, Cu, As, Pb, and Cr	Flame Atomic Absorption Spectroscopy (FAAS).	All metals were within permissible limits.
(Tamirat et al., 2024)	Ethiopia, Iraq, and Saudi Arabia	Na, Ca, Fe, Zn, Ni, Mn, Cu, Cd, and Pb	Flame Atomic Absorption Spectrometry	All metals were within permissible limits.

6. Mitigation and Management Strategies

6.1. Agricultural Practices to Reduce Contamination

To address heavy metal contamination in date palm fruits, several agricultural practices can be implemented. Crop rotation helps in preventing soil exhaustion, while organic fertilizers reduce the need for chemical inputs. Phytoremediation techniques, utilizing plants that absorb heavy metals, can be adopted to cleanse the soil (Ali et al., 2013; Ghosh & Singh, 2005; Tangahu et al., 2011; Thakur et al., 2016). Controlled irrigation prevents water contamination, and regular monitoring of soil and water quality allows for early detection of contaminants. Integrated pest management minimizes pesticide usage, and selecting date palm varieties resistant to heavy metal uptake is beneficial (Anli et al., 2020; Elnahal et al., 2022; Ghosh & Singh, 2005; Oguh et al., 2019; Rahman et al., 2022). Educating farmers on sustainable practices, using biochar to immobilize heavy metals, and incorporating green manure to enhance soil health are also vital strategies (Ahmad et al., 2018; Gong et al., 2022; Hou, Bolan, et al., 2020; Joseph et al., 2019; Ntsomboh-Ntsefong et al., 2024; Ray & Bharti, 2023; Sachdeva et al., 2023).

6.2. Role of Government and Policy in Contamination Control

Government regulations play a pivotal role in controlling heavy metal contamination by establishing permissible limits for these substances in agricultural products. Policies that incentivize sustainable farming practices are essential to mitigate contamination risks (Chen & Ding, 2023; Khanam et al., 2023; Nofriandi et al., 2024). The effectiveness of these policies is contingent upon robust monitoring and enforcement mechanisms to ensure compliance. Additionally, public awareness campaigns are vital for educating both farmers and consumers about the potential dangers of heavy metal exposure. International collaboration can align local standards with global best practices, while government funding for research fosters innovation in detection and mitigation technologies. Finally, subsidies and grants encourage the adoption of cleaner technologies, supported by adequate resources and training for regulatory agencies.

7. Future Research Directions and Innovations

In addressing heavy metal contamination in date palm cultivation, future research should focus on several innovative directions. The exploration of advanced bioremediation techniques is crucial for effective removal of contaminants from soils. Investigating genetic modifications could enhance date palms' resilience against heavy metal stress, while real-time monitoring systems would enable prompt detection of contamination. Moreover, assessing the long-term effects of exposure on productivity and quality is essential. Sustainable agricultural practices must be evaluated to minimize uptake, and interdisciplinary collaborations are vital for developing eco-friendly solutions. Additionally, understanding climate change impacts and exploring nanotechnology applications could offer new pathways for detoxification. The examination of heavy metal contamination in the fruit of date palms across various locations underscores the critical need for ongoing monitoring and management strategies. The insights gathered from this literature review highlight significant geographical variations in contamination levels, influenced by environmental factors and human activities. In addition, understanding these variations is essential for developing localized strategies to mitigate risks associated with heavy metal exposure.

8. Conclusion .

Heavy metals, originating from both natural and anthropogenic sources, pose a severe threat to food safety and public health. Date palms, being a vital agricultural commodity in many regions, require careful attention to ensure their safe consumption. The findings emphasize the importance of implementing effective mitigation techniques, such as soil remediation and the adoption of sustainable agricultural practices, to reduce heavy metal uptake by these plants. Moving forward, it is imperative to enhance research efforts focused on identifying specific sources of contamination and developing innovative solutions tailored to different environmental contexts. Collaborative efforts between scientists, policymakers, and local communities will be crucial in addressing this complex issue. By building on the knowledge gained from this review, stakeholders can work towards ensuring the safety and sustainability of date palm cultivation, safeguarding both the environment and human health.

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