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Detection of Heavy Metals in Greenhouse *Solanum lycopersicum*: A Food Safety Assessment

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ABSTRACT

This study investigates the presence of heavy metals in greenhouse-grown *Solanum lycopersicum* (tomatoes) collected from 17 farms in west of Tripoli during the planting season of 2024. Tomatoes are widely consumed and crucial to the agricultural economy. The risk of contamination from heavy metals due to agricultural practices and environmental exposure is a public health concern. Tomato samples were collected, both washed and unwashed, to assess external contamination, particularly from pesticide residues. The concentration of several heavy metals including arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), nickel (Ni), lead (Pb), zinc (Zn), and mercury (Hg) was measured. Results revealed detectable levels of certain heavy metals, particularly chromium, cadmium, and nickel, in unwashed samples, with some reduction observed after washing. Notably, elevated levels of Cr and Ni were found in specific locations such as Joudaim and Alzawiya, suggesting possible environmental or agricultural sources of contamination. The levels of other elements, like Pb, Zn, and Hg, were consistently below detection limits across all samples. The findings highlight the importance of routine monitoring of heavy metals in vegetables, especially in greenhouse farming, and underscore the role of washing in reducing surface contaminants. This study contributes valuable data toward food safety assurance and environmental health risk assessments in the region.

Keywords: Heavy metals, Greenhouse *Solanum lycopersicum* , Food safety, Environmental Risk Assessment, West Triopli.

الكشف عن المعادن الثقيلة في الطماطم *Solanum lycopersicum* المزروعة في البيوت البلاستيكية: تقييم سلامة الغذاء

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ملخص البحث

تهدف هذه الدراسة للكشف عن وجود المعادن الثقيلة في الطماطم *Solanum lycopersicum* المزروعة في البيوت البلاستيكية، والتي جُمعت من 17 مزرعة غرب طرابلس خلال موسم الزراعة 2024. تُستهلك الطماطم على نطاق

واسع، وهي ذات أهمية حيوية للاقتصاد الزراعي. ويُشكل خطر التلوث بالمعادن الثقيلة الناتج عن الممارسات الزراعية والتعرض البيئي مصدر قلق للصحة العامة. جُمعت عينات من الطماطم، مغسولة وغير مغسولة، لتقييم التلوث الخارجي، وخاصةً بقايا المبيدات. تم قياس تركيز المعادن الثقيلة التالية: الزرنيخ (As) والكادميوم (Cd)، الكوبالت (Co)، الكروم (Cr)، النيكل (Ni) العينات غير المغسولة، مع ملاحظة انخفاض في تركيز بعض المعادن الثقيلة بعد عملية غسل ثمار الطماطم، والجدير بالذكر أنه تم العثور على مستويات مرتفعة من الكروم والنيكل في مواقع محددة مثل جودايم والزاوية، مما يشير إلى مصادر تلوث بيئية أو زراعية محتملة. كانت مستويات العناصر الأخرى مثل الرصاص والزنك والزئبق، أقل باستمرار من حدود الكشف في جميع العينات. تسلط النتائج الضوء على أهمية المراقبة الدورية للمعادن الثقيلة في الخضروات، وخاصة المزروعة في البيوت البلاستيكية، وتؤكد على دور عملية الغسيل بالماء في الحد من وجود الملوثات السطحية. تساهم هذه الدراسة ببيانات قيّمة نحو ضمان سلامة الأغذية وتقييم مخاطر الصحة البيئية في المنطقة.

الكلمات المفتاحية: المعادن الثقيلة، الطماطم المزروعة في البيوت البلاستيكية، سلامة الغذاء، تقييم المخاطر البيئية، طرابلس الغرب.

1. Introduction

Tomato (Solanum lycopersicum), a member of the Solanaceae family, is one of the most widely cultivated vegetables globally, with an annual production of approximately 129.65 million tons. Turkey ranks as the third-largest producer, following China and the United States. Heavy metals, though naturally present in the Earth's crust, can become highly concentrated due to anthropogenic activities. These metals can enter plant, animal, and human systems through inhalation, ingestion, or dermal contact, potentially disrupting cellular functions. Among the top ten chemicals of major public health concern identified by the World Health Organization are cadmium (Cd), lead (Pb), mercury (Hg), and arsenic (As) (World Health Organization [1]. Primary sources of heavy metal contamination include atmospheric deposition, industrial discharge, waste disposal, fertilizer and pesticide application, and nuclear activities. Soil, a complex matrix composed of water, air, living organisms, organic matter, and mineral particles, acts as a major reservoir for these contaminants [2, 3]. Heavy metals typically defined as elements with a density greater than 5 g/cm³ are commonly monitored in environmental assessments due to their persistence and toxicity. While certain trace elements such as copper (Cu), zinc (Zn), and nickel (Ni) serve essential biological functions in plants and animals, they become toxic when accumulated in high concentrations. Conversely, non-essential elements like lead (Pb) and cadmium (Cd) have no known physiological role and are highly toxic, posing significant risks to ecosystem integrity and human health when concentrations exceed safety thresholds [4, 5]. The excessive use of fertilizers and pesticides is a significant contributor to heavy metal accumulation in agricultural soils. Since the human body lacks efficient mechanisms to eliminate these metals, the consumption of contaminated crops, including tomatoes, increases the risk of bioaccumulation and associated adverse health effects [6, 7]. The aim of this study is to detect and quantify the presence of heavy metals in greenhouse-grown tomatoes collected from various agricultural sites in west of Tripoli. The research seeks to assess potential contamination levels, evaluate the effectiveness of washing in reducing surface residues, and determine associated food safety risks for consumers.

2. Materials and Methods

2.1. Sample Collection

Tomato samples were systematically collected from greenhouses across 17 farms located in diverse regions in west of Tripoli. For reference, Table 1 provides the geographical coordinates (latitude and longitude) of each farm. To assess the potential presence of heavy metals both on the surface and within the fruit, samples were analyzed before and after washing, considering that pesticide residues on the outer skin may contain heavy metals. After collection, the samples were transported to the Petroleum Research Center in Tripoli for heavy metal analysis.

Table 1. The geographical location of farms

No.	Location	Geographical position	
		Latitude	Longitude
1	An-Najila (A)	32.742977	13.006822
2	Sayyad (A)	32.80043	12.58004
3	Alzahra	32.679	12.873
4	Zawiya (A)	32.7571	12.7276
5	Alkramiya	36.1167	13.080328
6	Qasr Bin Qhshir (A)	32.6878	13.1739
7	Alzahra of East	32.674319	12.878001
8	Alzawiya (B)	32.428194	12.491849
9	Joudaim	32.7778	12.7826
10	Mamora	32.7166461,	12.8629885
11	Tina	32.7597	12.8958
12	Glada	30.582959	12.514556
13	Qasr Bin Qhshir (B)	32.671783	13.204029
14	Najila (B)	32.738485	13.008434
15	Janzour	32.779258	12.893411
16	Alhashan	32.865130	13.238287
17	Sayyad (B)	32.801417	12.957175

2.2. Sample Digestion

Tomato samples were digested using a laboratory-grade microwave digestion system designed specifically for chemical analysis, rather than a conventional kitchen microwave. This method employs strong nitric acid under controlled temperature and pressure within a sealed, pressure-resistant polytetrafluoroethylene (PTFE/TFM) vessel to effectively break down the organic matrix of the tomato samples. Prior to digestion, each tomato sample was cut into small pieces to increase surface area and improve digestion efficiency. Approximately 0.5 grams of each sample was weighed accurately and placed into the TFM vessel. Then, 7 mL of 65% nitric acid (HNO_3) and 1 mL of 30% hydrogen peroxide (H_2O_2) were added to the vessel. The mixture was gently stirred to ensure thorough mixing. The vessel was securely sealed and placed in the rotating carousel of the microwave digestion system, fastened with a torque wrench to ensure pressure-tight closure. A temperature sensor was connected to monitor the process. The microwave digestion program was run according to the parameters listed in Table 2. After completion, the rotor was cooled by air and water until the solution reached room temperature.

Finally, the vessel was carefully opened, and the resulting clear digest solution was transferred to a volumetric flask for further analysis [8, 9, 10].

Table 2. Microwave Digestion Program Parameters

Step	Time	Temperature T1 (°C)	Temperature T2 (°C)	Pressure (bar)	Power
1	15 minutes	200	110	45	Maximum
2	15 minutes	200	110	45	Maximum

(Note: T1 and T2 refer to primary and secondary temperature sensors; pressure and power values are monitored for safety and digestion efficiency).

2.3. Instrumental Analysis

Heavy metal concentrations in the digested tomato samples were determined using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) at the Petroleum Research Center in Tripoli. The instrument was operated under the conditions summarized in Table 3. After sample digestion, the solutions were introduced into the ICP-OES system. The plasma was run for 20 minutes prior to analysis to ensure complete removal of residual elements and to stabilize the instrument. Calibration curves were established by analyzing a series of standard solutions at concentrations of 0.1, 1, 5, and 10 ppm for each target element. The blank and the tomato sample digests were then analyzed, and the concentrations of heavy metals were recorded in parts per million (ppm) as displayed on the instrument's output.

Table 3. ICP-OES operational parameters.

Parameter	Value
Power (kW)	1.20
Plasma Flow Rate (L/min)	15.0
Auxiliary Flow Rate (L/min)	1.50
Nebulizer Flow Rate (L/min)	0.75
Viewing Height (mm)	10
Replicate Read Time (s)	3.00
Instrument Stabilization Delay (s)	15

2.4. Determination of Heavy Metal Concentrations

Heavy metal concentrations in tomato samples were calculated after sample digestion and analysis. Blank readings were used to correct for background interference, and the final concentrations (ppm) were determined based on sample weight and dilution volume [11,12, 13]. The calculation was performed using the following equation (1):

$$\text{Metal concentration (ppm)} = \frac{\text{Sample reading} - \text{Blank reading}}{\text{Weight of Sample (g)}} \times \text{Dilution volume (mL)} \quad \ldots\ldots\ldots\ldots \mathbf{1}$$

2.5. Assessment of Washing Efficiency

The effectiveness of washing in reducing heavy metal concentrations was assessed by calculating the percentage decrease in metal content between unwashed and washed tomato samples. The following formula (2) was used to quantify the reduction:

$$\text{Percentage Decrease} = \frac{\text{Unwashed} - \text{Washed}}{\text{Unwasshed}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2}$$

This method is commonly employed in food safety and environmental studies to evaluate decontamination efficiency in agricultural produce [14, 15].

2.6. Statistical analysis:

Data were analyzed using SPSS version 20 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp). The data were presented as mean and standard deviation. T-tests were performed to compare the mean concentrations of heavy meatal in unwashed and washed tomato samples. All P values reported are two sided; a significance level of less than 0.05 was considered statistically significant. Finally, normality test was performed before analysis by using the Kolmogorov-Smirnov test.

3. Results and discussion

3.1. Sampling location

To provide spatial context for the study, the sampling locations of the 17 greenhouse farms were geo-referenced using GPS coordinates and are shown in Figure 1. These farms are distributed across various regions in west of Tripoli, representing a range of environmental and agricultural settings, including both peri-urban and rural zones. Mapping these sites helps visualize the potential influence of geographical factors on heavy metal presence in tomato samples. Such spatial representation is essential in environmental monitoring studies to assess contamination patterns and identify potential hotspots [16].

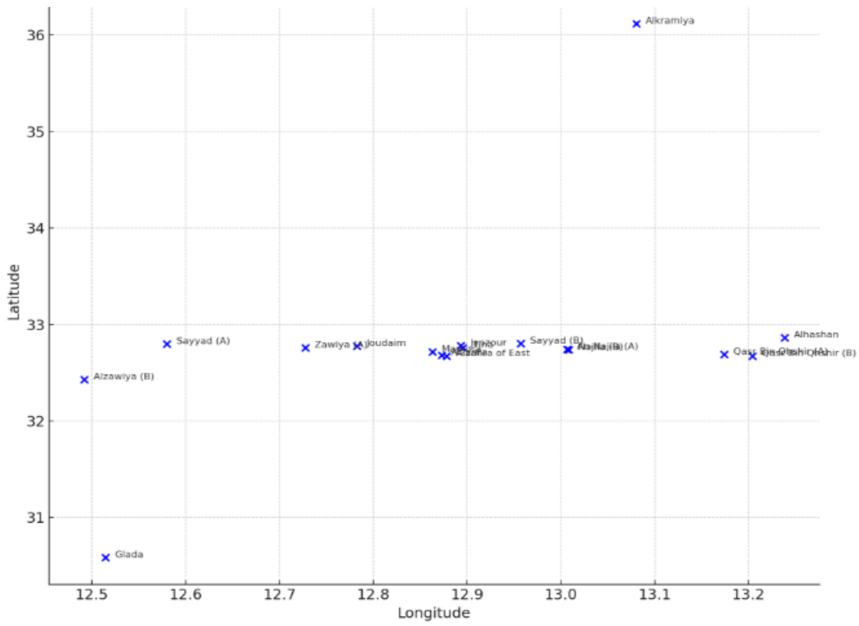

Figure 1: Map showing the locations of 17 greenhouse farms in the west of Tripoli region where tomato samples were collected for heavy metal analysis.

3.2. Evaluation of the heavy metals

The assessment of heavy metal concentrations in tomato samples collected from 17 different greenhouse locations reveals critical insights into both environmental contamination and post-harvest food safety. The analyzed elements arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), nickel (Ni), lead (Pb), zinc (Zn), and mercury (Hg) represent a mixture of essential micronutrients and toxic metals, each with varying degrees of health implications depending on exposure levels, bioavailability, and accumulation patterns. From the collected data in Tables 4A and 4B, a significant finding is the efficacy of surface washing in reducing detectable levels of some heavy metals, although this decrease did not reach statistical significance (P>0.05). For instance, in multiple sampling sites such as Najila (A), Joudaim, and Alzawiya (A**),** unwashed samples showed elevated concentrations of As**,** Cr, and Ni, which were either significantly reduced or undetectable after washing.

The decline in detectable levels post-washing suggests that the metals were likely deposited on the outer surface of the tomato fruits, probably due to atmospheric deposition, use of contaminated irrigation water, or the application of fertilizers and pesticides [14,17]. These findings reinforce previous studies that found leafy and smooth-skinned vegetables more vulnerable to surface contamination, which can be mitigated by appropriate washing or peeling [18]. However, not all contaminants were fully eliminated by washing, indicating that systemic uptake of heavy metals via roots is also occurring. In particular, washed samples from Alzahra and Alzawiya (B) still contained measurable concentrations of chromium (0.722 ppm and 0.347 ppm, respectively), well above WHO/FAO maximum permissible limits for vegetables (typically 0.1 ppm for Cr).

This observation points to the bioaccumulation capacity of *Solanum lycopersicum*, which has been documented to absorb and translocate certain metals especially those with high soil mobility through xylem transport from roots to fruits [19, 20]. Furthermore, cadmium, a known nephrotoxic and carcinogenic metal, was detected in several unwashed samples (e.g., 0.081 ppm in Joudaim), and in some cases remained detectable after washing, suggesting partial systemic absorption. Cadmium tends to accumulate in fruits when phosphate fertilizers are excessively applied or when grown in soil irrigated with industrial effluents**,** both of which increase bioavailable Cd fractions in soil [21]. Long-term dietary intake of cadmium can result in skeletal damage, kidney dysfunction, and cancer, especially in populations with high consumption of vegetables like tomatoes [22].

In contrast, lead (Pb), mercury (Hg), and zinc (Zn) were consistently found at very low levels, mostly below detectable limits in both washed and unwashed samples. Although this is a positive finding, it is crucial to note that instrumental detection limits and matrix interferences in ICP-OES can occasionally mask low-level contamination, especially for elements like mercury that require cold vapor techniques for more accurate quantification [23]. Zinc, while essential in trace amounts for enzymatic function and human metabolism, can also become toxic in excessive concentrations, but in this study, its levels remained far below risk thresholds.

Nickel (Ni) concentrations were notably elevated in unwashed samples from Alzawiya (A) (0.253 ppm) and Joudaim (0.370 ppm), and were reduced to below detectable levels after washing. Though the detected levels are lower than the FAO/WHO maximum permissible level for vegetables (typically 0.5 ppm), chronic exposure to nickel can cause dermatitis, respiratory symptoms, and reproductive toxicity [24]. The geographic variation in metal concentrations across sampling sites may reflect heterogeneity in soil contamination, irrigation water quality, proximity to industrial activities, and differences in greenhouse management practices**.** For example, elevated Cr and Ni in Alzahra and Joudaim suggest localized sources of contamination that may include vehicular emissions, untreated wastewater, or use of metal-based agrochemicals. This aligns with prior environmental assessments that highlight Libyan urban and peri-urban areas as hotspots for heavy metal contamination due to inadequate waste management and intensive agricultural inputs [25].

From a public health perspective, the detection of heavy metals especially arsenic, cadmium, and chromium in commonly consumed vegetables raises significant concern. These metals are classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC), and prolonged exposure through diet is associated with increased risks of cancer, organ toxicity, and developmental disorders [20, 26]. Moreover, bioaccumulation through the food chain may amplify exposure, particularly in vulnerable populations such as children and pregnant women. Table 4 presents the concentration of heavy metals in 17 greenhouse tomato samples, both before and after washing. The results are expressed in parts per million (ppm) for metals such as As, Cd, Co, Cr, Ni, Pb, Zn, and Hg. The symbol “>” indicates concentrations below the detection limit of the instrument.

Table 4. The mean Heavy Metal Concentration in Tomato Samples Before and After Washing in milligram per kilogram presented as the mean±standard.

N0	Location	As (ppm)		Cd (ppm)		Co (ppm)		Cr (ppm)		Ni (ppm)		Pb (ppm)		Zn (ppm)		Hg (ppm)	
.		unwashed	washed	unwashed	washed	unwashed	washed	unwashed	washed	unwashed	washed	unwashed	washed	unwashed	washed	unwashed	washed
1	**Najila (A)**	0.339	0.02	0.002	0.002	0.004	0.004	0.002	0.302	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
2	**Sayyad (B)**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
3	**Alzahra**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.722	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
4	**Alzawiya (A)**	0.02	0.02	0.002	0.002	0.004	0.004	1.269	0.002	0.253	0.01	0.03	0.03	0.001	0.001	0.03	0.03
5	**Alkramiya**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.271	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
6	**Qasr Bin Qhshir (A)**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
7	**Alzahra of East**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
8	**Alzawiya (B)**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.347	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
9	**Joudaim**	0.02	0.02	0.002	0.002	0.004	0.004	1.868	0.002	0.37	0.01	0.03	0.03	0.001	0.001	0.03	0.03
10	**Mamora**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
11	**Tina**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
12	**Glada**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
13	**Qasr Bin Qhshir (B)**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
14	**Najila (B)**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
15	**Janzour**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
16	**Alhashan**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03

17	**Sayyad (B)**	0.02	0.02	0.002	0.002	0.004	0.004	0.002	0.002	0.01	0.01	0.03	0.03	0.001	0.001	0.03	0.03
	mean	0.0387	0.02	0.002	0.002	0.004	0.004	0.186	0.098	0.045	0.01	0.03	0.03	0.001	0.001	0.03	0.03
	Standard deviation	0.0773	0.00	0.00	0.00	0.00	0.00	0.53	0.2004	0.102	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P- value	0.3321		1		1		0.552		0.171		1		1		1	

Therefore, while washing proves somewhat effective in reducing superficial contamination, it does not address endogenous accumulation from contaminated agricultural inputs. The findings from this study highlight the urgent need for:

A. Regular monitoring of heavy metals in greenhouse and open-field vegetables;
B. Implementation of safe agricultural practices, including pre-planting soil analysis and the use of clean irrigation sources;
C. Stricter regulations on the use of fertilizers and pesticides that may contribute to metal contamination;
D. Public education on post-harvest washing and food safety handling.

3.3. Washing Efficiency in Metal Removal

To evaluate the effectiveness of washing in reducing heavy metal contamination in tomato samples, the percentage decrease in metal concentrations was calculated for locations where quantifiable data were available. As shown in Table 5, substantial reductions in the levels of certain heavy metals were observed after washing, although not statistically significant, particularly for arsenic (As), chromium (Cr), and nickel (Ni). The most notable decreases were recorded for chromium in samples from Alzawiya (A) and Joudaim, where concentrations dropped by approximately 99.8% and 99.9%, respectively. Similarly, arsenic levels in Najila (A) were reduced by roughly 94.1% following washing. Nickel also showed significant reductions in Alzawiya (A) and Joudaim, with decreases exceeding 96%. These findings highlight the potential of simple washing practices to mitigate consumer exposure to certain heavy metals in fresh produce, especially when contamination is primarily surface-bound. Previous studies have reported similar outcomes, showing that rinsing vegetables with clean water can effectively remove surface-deposited metals such as Pb, Cd, and As. However, the efficiency of washing largely depends on the chemical properties of the metals, surface morphology of the produce, and environmental deposition pathways [14, 15,27].

Table 5. Percentage Decrease in Heavy Metal Concentration After Washing Tomato Samples

No.	Location	Metal	Unwashed (ppm)	Washed (ppm)	% Decrease
1	Najila (A)	Arsenic (As)	0.339	<0.02	~94.1%
2	Alzawiya (A)	Chromium (Cr)	1.269	<0.002	~99.8%
3	Joudaim	Chromium (Cr)	1.868	<0.002	~99.9%
4	Alzawiya (A)	Nickel (Ni)	0.253	<0.01	~96.0%
5	Joudaim	Nickel (Ni)	0.370	<0.01	~97.3%
6	Alzawiya (A)	Ni	0.253	<0.01	~96.0%
7	Joudaim	Ni	0.370	<0.01	~97.3%

3.4. Comparison of Heavy Metal Levels in Tomatoes Against International Standards

The findings from this study indicate varying levels of heavy metals in greenhouse-grown tomatoes, which can be compared to international standards set by organizations such as the FAO/WHO, Codex Alimentarius Commission, and the European Union. For nickel (Ni), concentrations in unwashed samples from locations such as Alzawiya (0.370 ppm) and Joudaim (0.253 ppm) approached the maximum permissible limit of 0.5 ppm for vegetables as established by the European Food Safety Authority [28]. Notably, all washed samples fell below this threshold, suggesting that washing is an effective measure for reducing surface contamination and enhancing consumer safety (Figure 2).

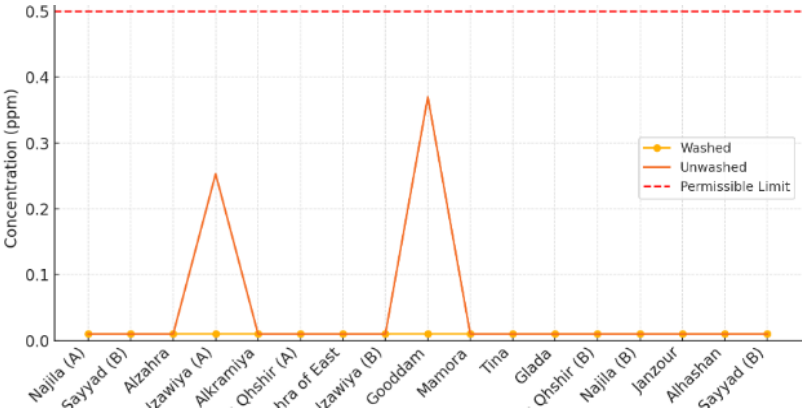

Figure 2: Comparison of Nickel concentration in local Tomato samples with international standards.

As shown in figure 2, 3. the levels of Nickel and Arsenic levels remained low in all samples, not exceeding 0.10 ppm, and thus were within the 0.1 ppm limit for arsenic in vegetables according to the Codex Alimentarius [29]. This implies a minimal risk of arsenic exposure through tomato consumption (Figure 3) [30]. Likewise, cadmium (Cd) levels did not exceed the 0.05 ppm threshold specified by Codex standards for fruits and vegetables, reflecting the effectiveness of agricultural practices in limiting cadmium uptake from soil (Figure 4) [31, 32].

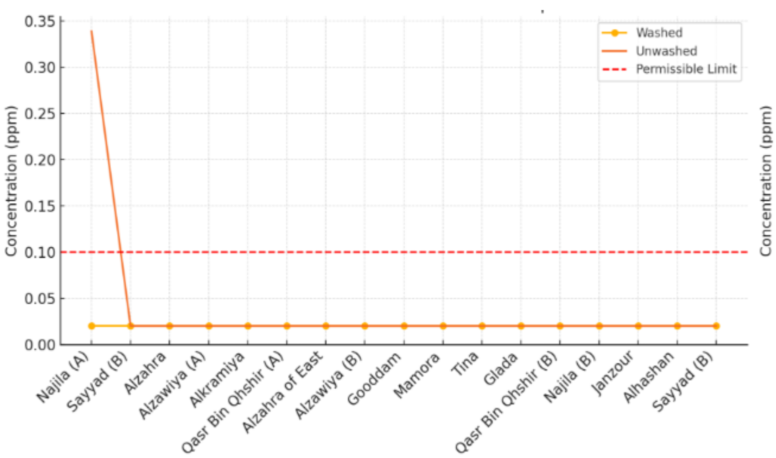

Figure 3: Comparison of Arsenic concentration in local Tomato samples with international standards.

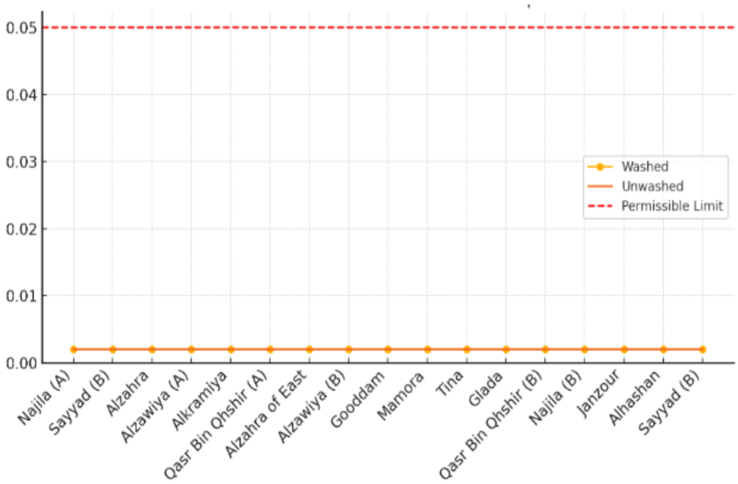

Figure 4: Comparison of Cadmium concentration in local Tomato samples with international standards.

The concentration of cobalt (Co) averaged around 0.004 ppm across all samples. Although no official maximum limit for cobalt in vegetables is universally established, EFSA and WHO guidelines suggest that levels below 0.05 ppm are considered safe for human consumption [33]. The lack of difference between washed and unwashed samples indicates that cobalt contamination is likely endogenous rather than surface-derived (Figure 5).

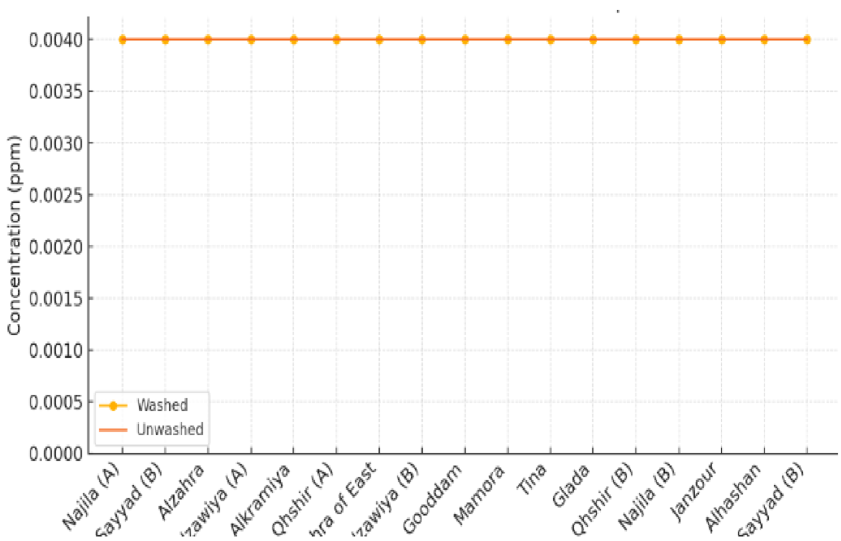

Figure 5: Comparison of cobalt (Co) concentration in local Tomato samples with international standards.

In contrast, chromium (Cr) concentrations showed greater variability, with some unwashed samples exceeding 0.2 ppm, though all washed samples remained below this value. The FAO/WHO safe limit for Cr in food is approximately 0.3 ppm [34]. These results highlight the importance of washing produce to reduce potential dietary exposure (Figure 6). Lead (Pb) concentrations were consistently low across all samples, remaining below the permissible limit of 0.05 ppm (Figure 7). This finding suggests that lead contamination in the region is not a significant concern, likely due to stringent regulations and monitoring practices in place [35].

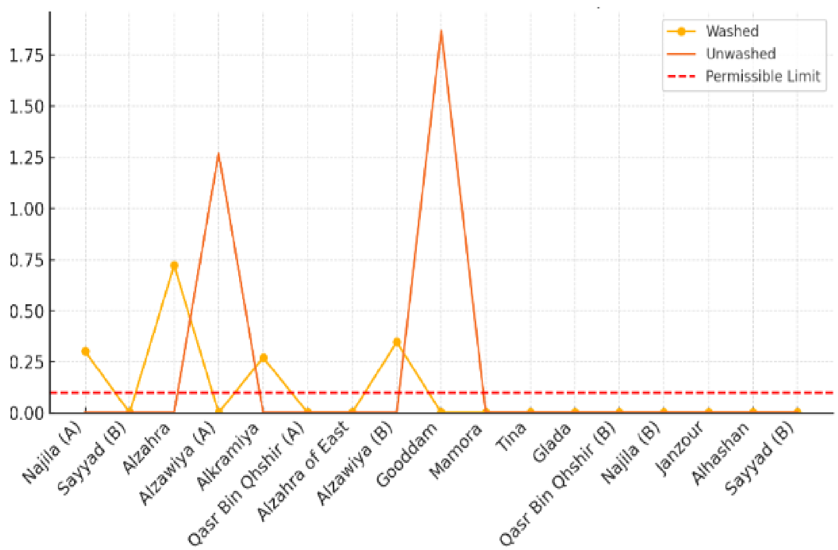

Figure 6: Comparison of cobalt (Cr) concentration in local Tomato samples with international standards.

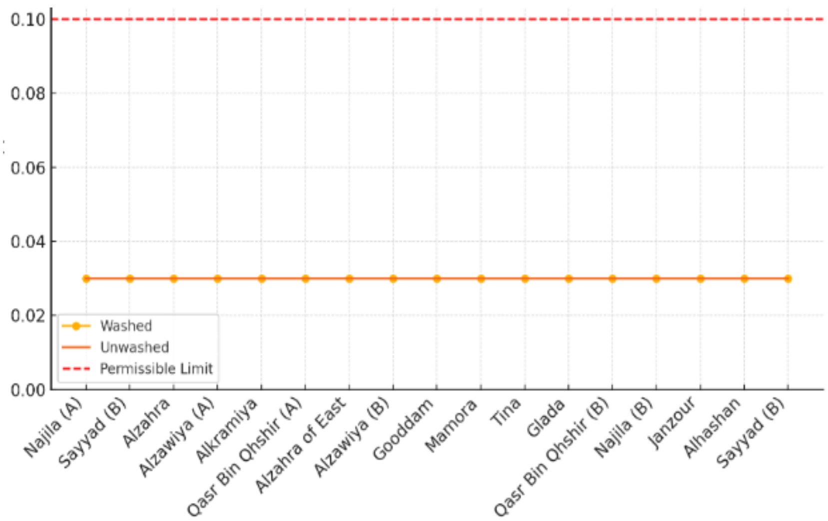

Figure 7: Comparison of lead (pb) concentration in local Tomato samples with international standards.

Zinc (Zn) concentrations were higher than those of other metals but remained well below the maximum tolerable level of 60 ppm, as recommended by WHO guidelines, and thus do not pose a health concern (Figure 8). Mercury (Hg) was detected in only trace amounts, staying far below the 0.01 ppm permissible limit established by international safety standards, confirming minimal risk from mercury exposure (Figure 9) [36].

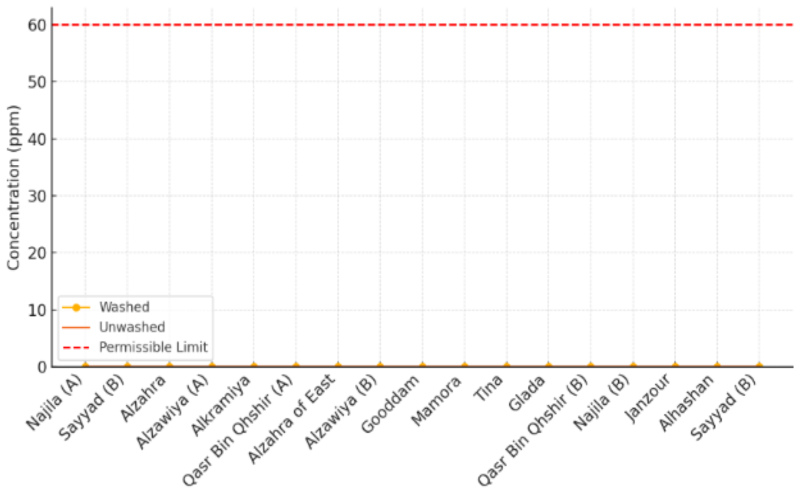

Figure 8: Comparison of zinc (Zn) concentration in local Tomato samples with international standers

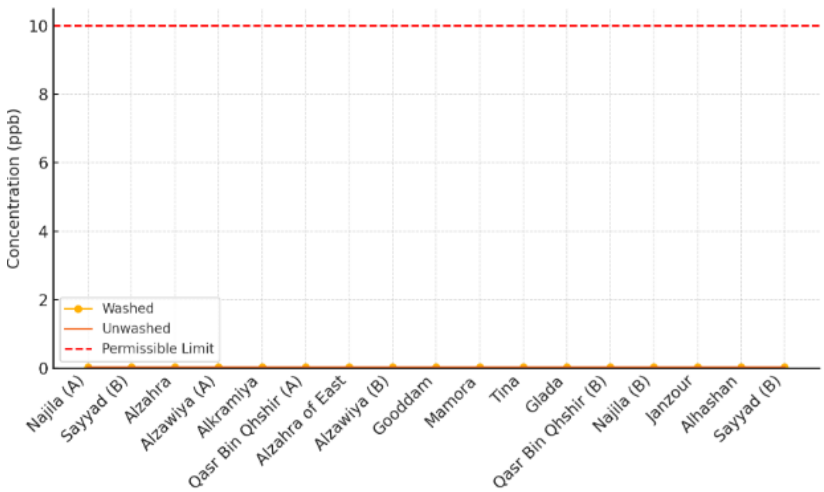

Figure 9: Comparison of mercury (Hg) concentration in local Tomato samples with international standards.

Overall, while some metals particularly nickel and chromium demonstrated the need for careful monitoring and risk assessment, the majority of heavy metals analyzed remained within safe limits. These findings underscore the effectiveness of current agricultural practices in the region, suggesting that with continued vigilance and adherence to safety protocols, the health risks associated with heavy metal contamination in greenhouse grown tomatoes can be effectively managed. Future research should aim to further investigate the sources of these contaminants and explore additional strategies for minimizing their impact on food safety.

4. Conclusions

This study investigates the presence of heavy metals in greenhouse-grown tomatoes (*Solanum lycopersicum*) collected from 17 farms in the western region of Tripoli. Given the significant role tomatoes play in the agricultural economy and human diet, the potential risk of contamination from heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), and nickel (Ni) is a pressing public health concern. Tomato samples were analyzed both washed and unwashed to evaluate external contamination, particularly from pesticide residues. Results indicated detectable levels of certain heavy metals, notably chromium, cadmium, and nickel, in unwashed samples, with washing leading to reductions in contamination levels. Elevated concentrations of Cr and Ni were found in specific locations, suggesting potential environmental or agricultural sources of contamination. The findings highlight the importance of routine monitoring of heavy metals in greenhouse vegetables and emphasize the role of washing in mitigating surface contaminants.

Additionally, the study underscores the need for safe agricultural practices and public education regarding food safety to minimize health risks associated with heavy metal exposure from contaminated produce. This research contributes valuable data for food safety assurance and environmental health risk assessments in the region.

To effectively manage the risks associated with heavy metal contamination in food crops, it is essential to establish a regular monitoring program for heavy metals in greenhouse and open-field vegetables to ensure food safety and protect public health. Implementing safe agricultural practices, including soil testing for heavy metals prior to planting and utilizing clean irrigation sources, will help mitigate contamination. Furthermore, promoting effective washing techniques among consumers is crucial, as rinsing with clean water can significantly reduce surface contaminants on fruits and vegetables. Increasing public awareness about the risks of heavy metal contamination, particularly for vulnerable populations such as children and pregnant women, is also vital. Stricter regulations on the use of fertilizers and pesticides that contribute to heavy metal accumulation in soils should be enacted. Lastly, supporting further research into the sources of contamination and their impacts on health will inform better policies and practices. By addressing these recommendations, stakeholders can enhance food safety and protect consumer health.

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