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The Effect of Physicochemical Properties and Elemental Composition on Nutritional Value and Safety of Tomato Fruits

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ABSTRACT

Fruits and vegetables are key to a healthy diet, with tomatoes being among the most widely consumed. However, their nutritional quality and safety are not always regulated. This research focused on two aspects: the relationship between the visual appearance and texture of tomatoes and their nutritional value, and the health and safety concerns based on their elemental content. Eight samples, both local and imported, were collected in Erbil, Iraq. Physicochemical variables, including dry matter content, total soluble solids (TSS), total phenolic content (TPC), antioxidant activity, ascorbic acid, and lycopene levels, were measured. Additionally, elemental analysis using ICP-OES was conducted to assess beneficial and toxic elements. The study found positive correlations between taste index, lycopene, and TSS. Antioxidant activity was mainly influenced by ascorbic acid. High-quality tomatoes had a firm texture, deep red color, and small size. However, local samples contained higher levels of essential elements, but also higher cadmium (Cd) and lead (Pb) levels, posing potential health risks. One imported sample contained arsenic (As), and two local samples showed carcinogenic risks from Cd. Therefore, stricter monitoring of tomato safety is necessary

1.Introduction

Tomato plants (*Solanum lycopersicum* L.) belong to the Solanaceae family and is an important widely cultivated food crop. It is used both as fresh fruit and processed products included in variety of dishes where they are valued for their taste, nutritional value and health benefits. Tomatoes contain 93% to 97% water, with the remaining 5% to 7% consisting of organic acids, sugars, lipids, carotenoids and inorganic compounds (Preedy, 2008). Tomatoes contain considerable amounts of phenolic compounds, ascorbic acid and lycopene, all of which contribute to their antioxidant and free radical scavenging properties in addition to giving the fruit the desired taste and color (Chandra & Ramalingam, 2011).

Lycopene is the main antioxidant carotene in tomatoes comprising about 80% of its total carotenes (Rao et al., 1998). Several beneficial effects have been associated with this compound including its role in counteracting oxidative damage in cells and protection from cancer, cardiovascular diseases and osteoporosis (Rao A. V et al., 2006). Other compounds in tomato fruits that possess antioxidant activity include polyphenols and phenolic acids (Luthria et al., 2006; Schindler et al., 2005). Additional quality parameters of tomato include dry matter content, pH, total acidity and sugars often represented by total soluble solids (TSS). Total acidity and sugar content are factors that determine the sweetness, sourness and overall taste of tomatoes (Hernández Suárez et al., 2008a).

Tomato fruits are also good sources for essential trace elements. Examples are chromium (Cr), cobalt (Co), iron (Fe), nickel (Ni) and zinc (Zn) amongst others. These elements are essential for a number of enzymes' proper functioning, proper immune response, antioxidant and cancer preventing potential in the body (Attar, 2020; Lewicka et al., 2017; Stefanidou et al., 2006).

An important aspect of tomato inclusion in diet is its safety to consumers, which can be determined by investigating the presence of toxic heavy metals through elemental analysis (McLaughlin et al., 1999). Tomatoes are prone to elemental uptake from the surrounding environment. They are even considered appropriate species for phytoremediation due to their ability to accumulate high levels of heavy metals (An et al., 2011). Due to this characteristic, tomato fruits can be indicators for the presence of heavy metals in their surrounding environment (Osma et al., 2012). Consuming plants that contain high levels of heavy metals can be threatening to overall consumer's health. The Consensus Report on dietary reference intakes (Food and Nutrition Board, 2002) sets a limit for daily intake of cadmium (Cd), lead (Pb) and aluminum (Al) at 0.062, 0.18 and 70 mg Kg^{-1} respectively for a 70 Kg adult. This necessitates monitoring the levels of these elements in daily food items with special focus on common fruits and vegetables.

For average consumer, the judgement often made on any fruit is based largely on physical appearance (Normann et al., 2019; Oltman et al., 2014; Tarancón et al., 2021). There is therefore a need to determine the extent to which the physical appearance and characteristics can reflect the actual nutritional value.

This research hence aims to analyze physicochemical properties of tomato fruits to establish a correlation between fruits physical properties and nutritionally important chemical constituents. Additionally, it seeks to monitor their elemental content through ICP-OES elemental analysis to determine the nutritional value and safety for consumption. Based on the results, it could be determined whether a quality control and elemental analysis is necessary for local and imported tomato fruits on a regular basis.

2. Materials and methods

2.1 Chemicals and reagents

Ethanol (absolute), hydrochloric acid (37%, extra pure), nitric acid (65%, reagent grade) and hydrogen peroxide (30%, extra pure) were from Sharlau, Spain. Sodium hydroxide (>97%) was from Merck. Hexane (99%) analytical grade was from BIOCHEM, France. Gallic acid was from BDH, England. Folin-Ciocalteu's reagent was sourced from Oxford Lab FINECHEM LLP. The 2,2-Diphenyl-1-picrylhydrazyl (DPPH) reagent was from Alfa Aeser.

2.2 Tomato sample collection

Tomato samples were collected by surveying the markets of Erbil city - Iraq for various cultivars available to consumers. A total of eight samples were found for the year 2021 including five local cultivars and three samples imported from two neighboring countries (will be name coded as counties A and B). Scientific names were not adopted since some varieties such as plum, grape and cherry tomatoes have the same scientific name (*Solanum lycopersicum* var. *cerasiforme*) and cannot be distinguished by this way. Therefore, samples were referred to using variety names alone. The locally sourced samples were plum and round tomatoes from Haji Omaran, pink beefsteak and Kurdish tomatoes from Sidakan and Beefsteak tomatoes from Erbil. The imported samples were grape and big beef tomatoes from country (A) and plum tomatoes from country (B). The fruits were selected to be free from injuries, infections and at good appearance and texture. They were washed with distilled water to remove dust and dirt. Average fruit weights were recorded and the samples were juiced using a multipurpose mincer blender. Part of the juice was used immediately for the analysis of percentage dry matter, pH and acidity, TSS and ascorbic acid content. The remaining part of the juiced sample was kept in a freezer at -20^{o}C to be used later for analysis of TPC, antioxidant activity and lycopene content.

2.3 Physicochemical parameters

The weights of 4 – 6 fruits from each sample were measured and their average value was recorded as the fruit's weight.

For measurements of dry matter content, aliquots of juiced tomatoes were dried in an oven at (50-80^{o}C) for 2 days or until reaching constant weight (Campbell & Plank, 1998).

pH and titratable acidity were measured using a solution of approximately 5 g fresh tomatoes in 75 mL deionized water. Total acidity was determined employing a magnetic stirrer and a (pHS-550) pH meter. The solution pH is noted at the start, then 0.1 N NaOH (previously standardized against 0.1 N oxalic acid) is added until the target pH value of 8.1 is reached. Total acidity value was expressed as % citric acid.100 g^{-1} of fresh tomato following eq. (1) (Duma et al., 2017).

$$\% \; Citric \; acid = \frac{N_{NaoH} \times V_{NaoH} \times Eq \; Wt_{Citric \; acid}}{Wt_{Sample}} \times 100 \ldots \ldots (1)$$

A digital refractometer was used to measure TSS and values reported as ^{o}Brix at 20^{o}C. Taste and maturity indices were calculated using the values for total soluble solids and titratable acidity and applying eq. (2) and (3) reported by Hernández Suárez et al., (2008b).

$$Taste \; index = \frac{Brix \; degrees}{20 \times acidity} + acidity \ldots \ldots \quad (2)$$

$$Maturity \; index = \frac{Brix \; degrees}{acidity} \ldots \ldots \ldots \quad (3)$$

For TPC measurement, one gram of fresh tomato tissues was extracted with 10 mL of ethanol for 24h and Folin-Ciocalteu reagent was used according to the method reported by Riahi et al., (2009). Total phenolic content was measured as gallic acid equivalent (GAE) (mg)/ 100 g of the fresh samples weight.

Radical scavenging effect was measured using 2,2-Diphenyl-1-picrylhydrazyl (DPPH) and following the method by Chandra & Ramalingam, (2011) and the results were reported as % DPPH scavenging activity.

Ascorbic acid measurement was conducted using the method described by (Dioha et al., 2012).

Content of lycopene was determined following a reduced-volume lycopene measurement protocol reported by Fish et al., (2002).

2.4 Elemental analysis

Aliquots of 1 g dried tomato tissues were digested using (9:1) mixture of HNO_3 (69%):H_2O_2 (30%). Samples were digested using a Multiwave GO Plus microwave digestion system from Anton Paar. The temperature program involved heating the samples to 200^{o}C over 20 minutes, then holding at this temperature for 20 minutes. The digested mixture was filtered and the filtrate was made up to 50 mL with deionized water prior to analysis. A Thermo-Fisher iCAP 7600 Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) instrument was used employing a high performance solid-state CID86 chip detector. Elements analyzed included: chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), vanadium (V), zinc (Zn), antimony (Sb), titanium (Ti), strontium (Sr), barium (Ba), aluminum (Al), arsenic (As), cadmium (Cd), lead (Pb) and thallium (Tl). Instrumental parameters were: exposure time for UV (15 milliseconds) and for Visible (5 milliseconds). RF power: UV (1150 W) and Vis (1150 W). nebulizer gas flow rate: UV (0.5 L. min^{-1}), cool gas flow (12 L. min^{-1}), auxiliary gas flow rate (0.5 L. min^{-1}). The emission lines for the elements and their measuring modes were selected based on exhibiting highest signal to noise ratios and lowest interference.

2.5 Human risk assessment (HRA)

The United States Environmental Protection Agency (USEPA) guidelines were used to quantitatively explain the non-carcinogenic risk from all the elements detected in the samples except for Ti and carcinogenic risk from As, Cd and Pb (USEPA, 2023c). For HRA, daily intake rates (DIR) for the elements were first calculated by applying the following formula (eq. 4):

$$DIR = \frac{C_M \times CF \times D_{intake}}{BM} \dots\dots\dots\dots (4)$$

Where,
C_M is concentration of the element; CF, a conversion factor to account for the difference between daily intake in fresh weight and the elemental concentrations calculated on dry weight basis. D_{intake}, estimated daily consumption rate of tomatoes (55.89 g/day) (Atamaleki et al., 2019). BM: body mass 70 kg (Ahmed et al., 2023; Sadee, 2022).

2.5.1 Non-carcinogenic risk

The non-carcinogenic risk is related to teratogenic and genetic effects attributes to an individual's chronic exposure. It is expressed as the hazard quotient (HQ) value which is calculated as follows:

$$HQ = \frac{DIR}{RfD} \dots\dots\dots.. (5)$$

Where RfD is the reference dose for oral exposure to the metals.
As no RfD value is present for titanium, it was excluded from further human risk calculations.
A value of HQ less than or equal to 1, means that there is no significant health risk from exposure to that metal.

2.5.2 Carcinogenic risk (CR)

Carcinogenic risk assesses the probability of developing cancer due to long-term exposure of an individual to either a specific pollutant or a mixture of different pollutants. CR is calculated applying the following formula:

$$CR = DIR \times SFo \dots\dots\dots\dots. (6)$$

Where, SFo is the oral slope factor for the carcinogenic metals.
Elements identified as possessing cancer risk are those placed by the IARC classification (IARC, 2023) in groups A and B. These include: Cr, Co, Ni, Se, As, Cd, Pb, Ti. The carcinogenic effect of Cr (VI) has been established and this element is therefore classified as Group A (A known human carcinogen through inhalation route). However, carcinogenicity of Cr by the oral route of exposure has not been determined and chromium is thus classified within Group D (compounds not classifiable as human carcinogens) (US EPA, 2023). Based on unavailability of data to suggests Cr(VI)'s carcinogenicity by the oral route, and since exposure to this element from tomatoes is predominantly oral, Cr is therefore disregarded from calculations of CR. No oral slope factor was found for Co, Ni, Se and Ti. Therefore, their cancer risk was not calculated.

2.6 Statistical analysis

The Statistical Package for the Social Sciences (SPSS) version 25 for Windows was used for the statistical analysis of data. The data were tested for normality ($P < 0.05$) using Shapiro-Wilk's test, and when data distribution was not normal, inverse transformation was applied to covert the variables to normal distribution. Comparison between mean values for the variables for the different samples was performed using one way ANOVA. The Tukey's honestly significant difference (Tukey HSD) multiple comparison test was used to compare between variables and a value of ($P < 0.01$) was regarded as statistically significant. Pearson linear correlation analysis was used to indicate the strength and significance of relationship between variable pairs. Data are expressed as mean of at least two measurements ± standard error of mean (S.E.). Graphs were constructed using Microsoft Excel 2019 for Windows.

3. Results and Discussion

3.1 Physicochemical properties

Tomato samples showed varying properties. Table 1 lists the lowest, highest and mean values for chemical quality parameters. The samples showed significant differences with regards to all of the factors as shown in Figure 1.
The average content of dry matter and Mean value of TSS were the highest for grape tomatoes compared to the other samples at 9.43 ± 0.07% and 9.00 ± 0.00 respectively. It also scored the highest pH value at 4.58. The local beefsteak – Erbil scored highest in total acidity and lower in pH at 0.44 ± 0.01 and 3.90 ± 0.00 respectively. The average values are in agreement with previous reports by (Pieper & Barrett, 2009; Riahi et al., 2009).
As TSS is calculated as ^{o}Brix (where 1 degree Brix is defined as 1 g of sucrose in 100 g solution), and sugars are found to make up the majority of this quantity, therefore, this measure is often considered as indication for the content of soluble carbohydrate in the fruit (Riahi et al., 2009).
pH and total acidity are often perceived as being

Table 1: Chemical parameters of tomato samples from of Erbil city. Values are mean ± S.E. of n ≥ 2.

Chemical Parameters	Minimum – Maximum Values	Mean ± S.E.
% Dry matter	4.91 – 9.43	6.33 ± 0.30
pH	3.90 – 4.58	4.18 ± 0.05
Total acidity ($g.100g^{-1}$)	0.30 – 0.44	0.37 ± 0.01
TSS ^{o}Brix	3.80 – 9.00	5.27 ± 0.32
Total phenolic content (GAE $mg.100g^{-1}$)	26.80 – 71.70	38.16 ± 2.86
DPPH scavenging effect or % Inhibition	13.93 – 45.03	30.18 ± 4.06
Ascorbic acid ($mg.100g^{-1}$)	11.60 – 24.62	26.20 ± 30.36
Lycopene ($mg.kg^{-1}$)	60.89 – 142.19	90.03 ± 9.96
Taste index	0.88 – 1.57	1.08 ± 0.04
Maturity index	10.06 – 23.73	14.18 ± 0.83

correlated to how acidic a tomato may taste. On the other hand, TSS refers to how sweet the fruit is. However, a more accurate representation of the fruit taste is a combination of both acidity and sweetness represented by taste index. Taste index values ranged from 1.57 ± 1.17 for grape tomatoes to 0.88 ± 2.97 for round – Haji Omaran tomatoes. Although the average taste index value is in agreement with previous reports of 0.95 – 1.26 (Duma et al., 2019), the value for grape tomato is considerably higher which reflects its desirable flavor. The grape tomatoes also scored high on the maturity scale with a value of 23.73 ± 0.34 in comparison to the mean value 14.18 ± 4.06 for the other samples and what has been reported in the literature (Hernández Suárez et al., 2008b).

Lycopene content was found to be significantly different between majority of the samples. The mean value for lycopene content measured in milligrams per kilogram of fresh tissue weight was 90.0 ± 1.0 with the highest value being 142.2 ± 0.3 for grape tomatoes followed by plum tomatoes of Haji Omaran at 120.2 ± 5. The lowest values were recorded for beefsteak tomatoes from Erbil at 60.9 ± 4.0 followed by big beef - (A) tomatoes. Pink beefsteak tomatoes from Haji Omaran were found to contain higher amount of lycopene in comparison with the red beefsteak tomatoes from Erbil. Except for grape - (A) tomatoes and Plum Haji Omaran, most of the fruits scored lower than average for lycopene content in comparison to previous reports (Hallmann, 2012).

A significant difference in ascorbic acid content was found between some of the samples. Plum Haji Omaran, beefsteak - Erbil and grape tomatoes - (A) showed significantly higher values in comparison to big beef - (A) tomatoes. Mean content of ascorbic acid (vitamin C) was found to be 18.3 ± 1.8 $mg.100\ g^{-1}$. This value is in agreement with the previously published report (Duma et al., 2019).

The highest TPC was found in grape tomatoes followed by a large difference by Beefsteak – Erbil tomatoes. Results were in agreement with those of Anza et al., (2006) who reported values between 70 – 95 $mg.100g^{-1}$ for organic and conventionally farmed cultivars. TPC is widely known to be linked and correlated to radical scavenging activity especially when reporting health benefits of plants (Ghorbani et al., 2012; Ozgen et al., 2012). However, the trend of TPC values in the samples was not completely mirrored by radical scavenging effect of DPPH as can be seen in the subgraphs in Figure 1. Although a positive correlation was found between DPPH inhibition and TPC (r = 0.57, P < 0.01) in Table 2, this correlation was not as strong as the one with ascorbic acid (r = 0.87, P < 0.01) which indicates the higher contribution of the latter to antioxidant potential in tomatoes. Moreover, a strong negative correlation (r = - 0.72, P < 0.01) was found with fruit weight which explains in part the lower DPPH inhibition activities of the three larger sized pink – Sidakan, Kurdish – Sidekan and Big beef – (A) tomatoes.

The imported grape tomato variety scored high on most variables, but scored lower in DPPH radical scavenging activity. Dry matter, TSS, TPC and ascorbic acid amounts were found to correlate positively with lycopene content, while fruit weight showed negative significant correlations. A combination of the above traits resulted in that grape tomatoes scoring second in DPPH radical scavenging activity. A likely reason may refer to that it contains less ascorbic acid than the Beefsteak - Erbil sample. The rest of the factors (TPC, dry matter and lycopene) do have an effect on antioxidant activity of the sample, but at significantly less power.

Dry matter, TSS, TPC also showed a similar positive correlation with taste index. However, fruit weight showed negative correlations with these variables.

This means that a consumer can make a good selection of tomato in most cases as long as they choose solid, firm (high in dry matter and TSS) and brightly colored (higher in lycopene) fruits, while at the same time avoiding tomato varieties of larger fruit size. Maturity is similarly correlated to most of these factors. As the fruit ripens, the levels of dry matter, TSS, TPC and lycopene reach their maximum. This is the result of a significant increase in sweetness along

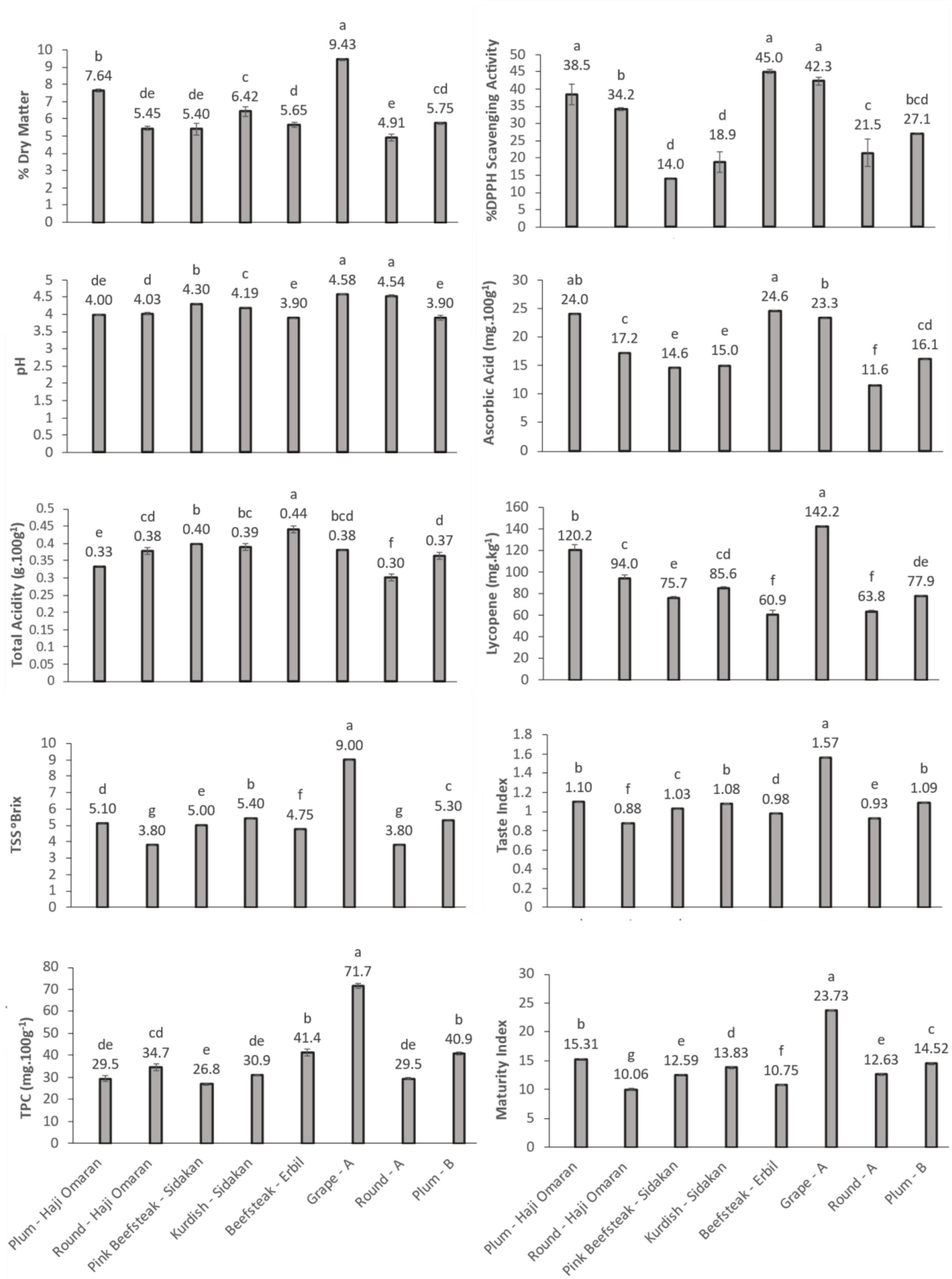

Figure 1: Chemical parameters of tomato samples from local markets of Erbil. Error bars are S.E. of at least two measurements. Data labels with different letters indicate significant differences at ($P < 0.01$).

Table 2: Correlation matrix for physical-chemical parameters. Significant correlations are shown as (*) $P < 0.05$ and (**) $P < 0.01$.

	%Dry matter	pH	Total acidity	TSS	TPC	DPPH	Ascorbic acid	Lycopene	Taste index	Maturity index
Fruit weight	- 0.519**	0.117	- 0.135	- 0.498*	- 0.659**	- 0.718**	- 0.709**	- 0.506*	- 0.504*	- 0.473*
%Dry matter		0.298	0.001	0.887**	0.735**	0.507*	0.636**	0.920**	0.909**	0.901**
pH			- 0.380	0.425*	0.329	- 0.258	- 0.308	0.279	0.464*	0.537**
Total acidity				0.183	0.228	0.232	0.396	- 0.158	0.058	- 0.143
TSS					0.866**	0.338	0.465*	0.744**	0.991**	0.946**
TPC						0.572**	0.511*	0.606**	0.850**	0.797**
DPPH							0.874**	0.437*	0.336	0.286
Ascorbic acid								0.524**	0.447*	0.364
Lycopene									0.780**	0.805**
Taste index										0.980**

with a decrease in acidity, and the fruit looks great and tastes even better. Based on the previous comparisons, it could be concluded that grape tomatoes are the fruits with optimum characteristics.
Maturity indices of the samples ranged from 10.06 – 23.73 in which the minimum was above those previously reported by Marcos Hernández Suárez et al. (2008) and Kapoulas et al. (2013). This indicates that all the study samples ranged between acceptable to high levels of maturity. However, maturity index is one of the significant aspects. Local samples showed low maturity index values in comparison with those of imported samples. This is likely due to the lack or insufficiency of marketing strategies by the farmers in the region. In other words, fruit harvesting is not well timed with their arrival to the market. This results in not allowing prematurely harvested fruits to ripen enough by the time of their display to consumers. An exception to this is plum tomatoes from Haji Omaran, which is high in dry matter content, ascorbic acid and lycopene. This aspect highlights the importance of adequate harvest marketing strategies on consumers obtainment of good quality produce.

3.2 Elemental analysis

The presence of essential elements in fruits and vegetables contribute to their nutritious value. Table 3 shows elemental content of the samples. Cr, Co, Cu, Fe, Mn, Mo, Ni, Se, V and Zn are considered essential trace elements that can contribute positively to the body's metabolic functions through binding to proteins or being enzyme co-factors (Kabata-Pendias & Mukherjee, 2007). The positive effects of essential elements is dependent on the dosage within the recommended dietary allowance (RDA) and negative impact or toxicity is observed when above upper tolerable daily intake levels (UL) (Kabata-Pendias & Mukherjee, 2007).
Beefsteak – Erbil tomatoes found to contain a remarkably higher amounts of Cr, Co, Mn, Se, V and Zn. Big Beef - (A) tomatoes were significantly high in their Ni content, while the local plum – Haji Omaran scored significantly higher in essential elements content in comparison to the imported Plum - (B) sample. Regarding the local samples, the four globe tomatoes ranked significantly higher in their Fe and Cu contents. Grape - (A) tomatoes were significantly high in Mo. The presence of Mo is affected by soil pH and its richness in granite rocks and the presence of certain elements such as sulphur (Aras & Ataman, 2006). However, this high concentration is still below the level reported as toxic to cattle at 1.5 $mg.kg^{-1}$ in grasses and 5.2 $mg.kg^{-1}$ in legumes (Kabata-Pendias & Mukherjee, 2007).
Tomato fruit's accumulation of elements is found to be element-dependent. For instance, high concentrations of Al and Ti are accumulated in the fruits, while smaller amounts of Pb and Cd were found to be accumulated in the fruits in comparison to the other plant parts (Trebolazabala et al., 2017). This suggests that tomatoes grown on a wider range of soil can still be consumed with relatively low risk. However, it also means that the concentration of these elements is still higher in that particular soil which may pose toxicity hazards to other crops planted in the same field (Wang et al., 2000).
Non-essential elements including Sb, Ti, Sr and Ba were also detected in the samples at concentrations which is consistent with the reported normal ranges

Table 3: Elemental composition of tomato samples from Erbil markets. Values are averages of n=3 measurements in ppm. Different letters in the same raw indicate significant differences at (*P* < 0.01).

		Plum - Haji Omaran	Round - Haji Omaran	Pink Beefsteak - Sidakan	Kurdish - Sidakan	Beefsteak - Erbil	Grape - (A)	Big Beef - (A)	Plum - (B)	UL mg/day	RDA mg/day
Essential Trace Elements	Cr	2.44 ± 0.0^{e}	2.89 ± 0.0^{b}	2.59 ± 0.0^{cd}	2.52 ± 0.0^{de}	3.99 ± 0.0^{a}	2.61 ± 0.0^{cd}	2.52 ± 0.0^{de}	2.66 ± 0.0^{c}	ND	0.025 - 0.035,
	Co	0.066 ± 0.0^{d}	0.068 ± 0.0^{d}	0.103 ± 0.0^{c}	0.035 ± 0.0^{f}	0.202 ± 0.0^{a}	0.007 ± 0.0^{g}	0.112 ± 0.0^{b}	0.054 ± 0.0^{e}	ND	
	Cu	3.25 ± 0.1^{g}	6.87 ± 0.1^{b}	7.71 ± 0.1^{a}	4.77 ± 0.0^{d}	5.32 ± 0.1^{c}	3.74 ± 0.1^{e}	3.34 ± 0.0^{f}	3.96 ± 0.0^{e}	10	0.9
	Fe	21.7 ± 0.2^{e}	40.0 ± 0.2^{a}	40.6 ± 0.2^{a}	40.8 ± 0.2^{a}	34.0 ± 0.1^{c}	35.9 ± 0.4^{b}	27.3 ± 0.2^{d}	18.1 ± 0.1^{f}	45	8 -27
	Mn	11.53 ± 0.1^{e}	17.97 ± 0.1^{c}	15.16 ± 0.1^{d}	15.21 ± 0.1^{d}	23.36 ± 0.0^{a}	15.26 ± 0.2^{d}	19.14 ± 0.1^{b}	10.92 ± 0.1^{e}	11	1.8 – 2.3
	Mo	0.287 ± 0.0^{b}	0.274 ± 0.0^{c}	0.297 ± 0.0^{b}	0.156 ± 0.0^{e}	0.143 ± 0.0^{f}	0.535 ± 0.0^{a}	0.149 ± 0.0^{ef}	0.227 ± 0.0^{d}	2	0.045
	Ni	0.67 ± 0.0^{g}	0.80 ± 0.0^{f}	1.81 ± 0.0^{c}	1.99 ± 0.0^{b}	1.10 ± 0.0^{d}	0.34 ± 0.0^{h}	2.49 ± 0.0^{a}	0.98 ± 0.0^{e}	1	
	Se	0.411 ± 0.1^{e}	0.674 ± 0.0^{a}	0.523 ± 0.1^{c}	0.460 ± 0.0^{d}	0.574 ± 0.2^{b}	0.519 ± 0.1^{c}	0.537 ± 0.1^{c}	0.407 ± 0.1^{e}	0.4	0.07
	V	2.35 ± 0.0^{e}	2.91 ± 0.0^{c}	2.63 ± 0.0^{d}	2.58 ± 0.0^{d}	3.62 ± 0.0^{a}	2.05 ± 0.0^{f}	3.09 ± 0.0^{b}	2.54 ± 0.0^{d}	1.8	
	Zn	15.49 ± 0.1^{c}	17.29 ± 0.0^{b}	17.71 ± 0.1^{b}	17.72 ± 0.1^{b}	20.30 ± 0.0^{a}	15.38 ± 0.0^{c}	12.21 ± 0.0^{d}	9.71 ± 0.0^{e}	40	8 - 11
Non-essential Elements	Sb	0.046 ± 0.0^{a}	-	-	-	0.037 ± 0.0^{c}	-	0.042 ± 0.0^{b}	0.043 ± 0.1^{b}	0.006	
	Ti	0.162 ± 0.0^{e}	0.265 ± 0.0^{a}	0.120 ± 0.0^{f}	0.206 ± 0.0^{c}	0.254 ± 0.0^{b}	0.170 ± 0.0^{e}	0.208 ± 0.0^{c}	0.182 ± 0.0^{d}	ND	
	Sr	5.69 ± 0.1^{d}	6.84 ± 0.0^{b}	2.25 ± 0.0^{h}	2.76 ± 0.0^{g}	6.00 ± 0.0^{c}	4.3 ± 0.0^{f}	4.65 ± 0.0^{e}	7.63 ± 0.1^{a}	0.13	
	Ba	1.06 ± 0.0^{e}	1.15 ± 0.0^{d}	0.55 ± 0.0^{f}	1.9 ± 0.0^{a}	1.35 ± 0.0^{c}	1.95 ± 0.0^{a}	1.61 ± 0.0^{b}	0.47 ± 0.0^{g}	0.21	
Toxic Elements	Al	58.8 ± 0.2^{b}	50.9 ± 0.4^{c}	53.0 ± 0.3^{c}	46.3 ± 0.2^{d}	58.7 ± 0.5^{b}	63.9 ± 0.3^{a}	47.8 ± 0.4^{d}	52.4 ± 0.3^{c}	70	
	As	-	-	-	-	-	-	0.232 ± 0.1	-	ND	0.012 -0.025
	Cd	0.110 ± 0.0^{e}	0.190 ± 0.0^{c}	0.255 ± 0.0^{b}	0.378 ± 0.0^{a}	0.187 ± 0.0^{c}	0.062 ± 0.0^{g}	0.140 ± 0.0^{d}	0.100 ± 0.0^{f}	0.062	
	Pb	0.198 ± 0.0^{a}	0.172 ± 0.0^{c}	0.162 ± 0.1^{d}	0.180 ± 0.1^{b}	0.121 ± 0.1^{f}	0.166 ± 0.1^{cd}	0.129 ± 0.0^{e}	0.059 ± 0.0^{g}	0.18	
	Tl	-	-	-	-	-	-	-	-	0.01	

UL and RDA values are based on: for antimony (WHO, 2011), aluminum (SCHHER, 2017), cadmium (Satarug et al., 2017), Sb, Sr, Ba, Tl (Oria et al., 2019) and for the rest of the elements (Food and Nutrition Board, 2002). RDA are minimum and maximum values recommended for adult female and males and are based on (Food and Nutrition Board, 2002; Oria et al., 2019). ND: not determined, when the element's UL is not clearly set due to unavailability of sufficient data and/or toxicity-related testing limitations.

(Kabata-Pendias & Mukherjee, 2007). These elements can be introduced through using carbonatite rocks as soil fertilizers (Jones et al., 2020), municipal wastewater and anthropogenic activities such as mining (Sasmaz et al., 2020). Unless present in high concentrations, Sr has not been found to cause toxicity. On the other hand, Ba compounds in their soluble form can be highly toxic to plants and animals (Bañuelos & Ajwa, 2008; Myrvang et al., 2016).

Toxic elements pose toxicity risk to the plant itself too. However, plants can use a number of safety mechanisms to tolerate trace amounts of toxic metals (Clemens and Feng Ma, 2016; Kabata-Pendias, 2004). Plants can sometimes tolerate elements such as Cd and Pb without showing toxicity signs up to levels exceeding what is considered safe for humans (Bañuelos and Ajwa, 2008). This leads to the deceptive situation of a visually healthy-looking plant actually containing high quantities of toxic metals. Therefore, it is necessary to take safety measures even when the plant appears healthy with no signs of impairment.

Toxic elements including Al, As, Cd and Pb were detected at varying levels in the samples. The sample of grape tomatoes contained the highest content of Al. Although not an essential element, aluminum still has beneficial role in plants growth. However, excess Al is toxic to most plants (Zhao and Shen, 2018).

Arsenic was not detected in the samples except Big Beef - (A) imported tomatoes which contained 0.232 ± 0.1 $mg.Kg^{-1}$. Arsenic has no tolerable upper level and exposure to such diet poses substantial toxicity risk.

Four of the local tomato samples scored significantly high concentrations of Pb and Cd, while grape tomatoes were on the lower end in this regard. The presence of these elements can possibly be traced back to the nature of rocks (igneous, sedimentary and metamorphic) where significant content of Cd has been reported (Abdulhaq et al., 2020). Another likely source is intensive agriculture and indiscriminate use of pesticides and fertilizers. In all cases, monitoring of the local tomato crop production is necessary to ensure better and safer crops.

Comparing the elemental content of the samples in this study with those from previous studies revealed both similarities and differences. The samples in this study showed similar levels of most elements, but contained higher concentrations of V and lower concentrations of Co and Ti when compared with samples from Spain (Rodriguez-Iruretagoiena et al., 2015; Trebolazabala et al., 2017). In contrast, a comparison with tomato fruits from Austria indicated a greater variation, with Cr, Ni, V, Ti, Ba, Al, Cd and Pb detected at lower concentrations than in this study (Sager, 2017). The primary cause for this variation in elemental content is geographical location (Mahne Opatić et al., 2018). However, other factors such as environmental pollutants (Atamaleki et al., 2019; Khan et al., 2015), differences in the growth medium of the plants (Gundersen et al., 2001) and atmospheric carbon dioxide content (Khan et al., 2013) can also have a significant impact.

3.3 Human risk assessment (HRA)

Human risk assessment is a process of evaluating the potential adverse health effects of exposure to trace elements in tomato fruits. The exposure pathway to trace elements is first identified, which is through ingestion in the case of tomato fruits. Then the exposure dose of each trace element is estimated for the selected population group based on their consumption patterns and body weight. The exposure dose is then compared with the reference dose (RfD) of each trace element, which are the estimated amounts of daily exposure that are unlikely to cause adverse health effects over a lifetime. The value of hazard quotient (HQ) of each trace element is thus calculated. The HQ indicates the potential for non-carcinogenic effects, such as organ damage, developmental impairment, or neurological disorders. A value of HQ less than 1 means that the exposure is unlikely to cause non-carcinogenic effects (Bleam, 2012). Most essential elements concentrations were found to be below the UL reported in Table 3. Also, upon calculation of daily intake rates and HQ, it could be seen that there is no risk of adverse non-carcinogenic risk (Table 4). Additionally, under normal daily tomato consumption levels, it is highly unlikely to experience any negative effects, and the presence of essential elements would positively contribute towards the body's daily requirement rather than being a toxicity hazard.

Cancer risk (CR) of each trace element, which is the probability of developing cancer over a lifetime due to exposure to a carcinogenic agent, is also calculated. This measurement is based on the slope factor (SF) of each trace element, which is the estimate of the increased cancer risk per unit of exposure. A CR greater than 10^{-4} means that the exposure is unacceptable (Demissie et al., 2024; Liu et al., 2013; USEPA, 2024). Samples that scored above the accepted level were: Pink Beefsteak – Sidakan and Kurdish - Sidakan as they contained high amounts of cadmium that poses appreciable carcinogenic risk (Table 5).

Table 4: Hazard quotient (non-carcinogenic risk) for the elements

	RfD (mg/kg).day^{-1}	Plum - Haji Omaran	Round - Haji Omaran	Pink Beefsteak - Sidakan	Kurdish - Sidakan	Beefsteak - Erbil	Grape - (A)	Big Beef - (A)	Plum - (B)
Cr	1.5	9.9E-05	8.4E-05	7.5E-04	8.6E-05	1.2E-04	1.3E-04	6.6E-05	8.1E-05
Co	0.0003	1.3E-02	9.9E-03	1.5E-01	6.0E-03	3.0E-02	1.8E-03	1.5E-02	8.3E-03
Cu	0.04	5.0E-03	7.5E-03	8.3E-02	6.1E-03	6.0E-03	7.0E-03	3.3E-03	4.5E-03
Fe	0.7	1.9E-03	2.5E-03	2.5E-02	3.0E-03	2.2E-03	3.9E-03	1.5E-03	1.2E-03
Mn	0.14	5.0E-03	5.6E-03	4.7E-02	5.6E-03	7.5E-03	8.2E-03	5.4E-03	3.6E-03
Mo	0.005	3.5E-03	2.4E-03	2.6E-02	1.6E-03	1.3E-03	8.1E-03	1.2E-03	2.1E-03
Ni	0.02	2.0E-03	1.8E-03	3.9E-02	5.1E-03	2.5E-03	1.3E-03	4.9E-03	2.3E-03
Se	0.005	5.0E-03	5.9E-03	4.5E-02	4.7E-03	5.2E-03	7.8E-03	4.2E-03	3.7E-03
V	0.005	2.9E-02	2.5E-02	2.3E-01	2.6E-02	3.3E-02	3.1E-02	2.4E-02	2.3E-02
Zn	0.3	3.2E-03	2.5E-03	2.5E-02	3.0E-03	3.1E-03	3.9E-03	1.6E-03	1.5E-03
Sb	0.0004	7.0E-03	0.0E+00	0.0E+00	0.0E+00	4.2E-03	3.9E-03	4.1E-03	4.9E-03
Sr	0.6	5.8E-04	5.0E-04	1.6E-03	2.4E-04	4.5E-04	5.4E-04	3.0E-04	5.8E-04
Ba	0.6	1.1E-04	8.3E-05	4.0E-04	1.6E-04	1.0E-04	2.5E-04	1.1E-04	3.6E-05
Al	1	3.6E-03	2.2E-03	2.3E-02	2.4E-03	2.6E-03	4.8E-03	1.9E-03	2.4E-03
As	0.0003							3.0E-02	
Cd	0.001	6.8E-03	8.3E-03	1.1E-01	1.9E-02	8.4E-03	4.7E-03	5.5E-03	4.6E-03
Pb	0.001	1.2E-02	7.5E-03	7.0E-02	9.2E-03	5.5E-03	1.3E-02	5.1E-03	2.7E-03

RfD values of Cr, Cu, Fe, Mn, Mo, Ni, Se, Zn, Sb, Sr, Ba, As, Cd from ((USEPA, 2023b)); Co, V and Al from (USEPA, 2015, 2023a); Pb has no set RfD value as per IRIS, EPA or OEHHA, but the value of 0.001 is used based on WHO's guidelines for drinking water (WHO, 2017).

Table 5: Carcinogenic risk assessment of the samples. Values higher than 10E-04 are shaded

	SFo	Plum - Haji Omaran	Round - Haji Omaran	Pink Beefsteak - Sidakan	Kurdish - Sidakan	Beefsteak - Erbil	Grape - (A)	Big Beef - (A)	Plum - (B)
As	1.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-05	0.0E+00
Cd	6.1	4.2E-05	5.0E-05	6.7E-04	1.2E-04	5.1E-05	2.8E-05	3.3E-05	2.8E-05
Pb	0.0085	1.0E-07	6.4E-08	5.9E-07	7.8E-08	4.6E-08	1.1E-07	4.3E-08	2.3E-08

4. Conclusion

This study indicated a strong correlation between physical attributes of tomatoes and beneficial chemical contents. These quality parameters include: smaller fruit size, brighter red colour and firmness. A fruit that fulfils these characteristics is likely to be high in lycopene and TSS, higher in taste and maturity index as well. Grape tomato sample exhibited the optimum chemical and physical characteristics compared to the other fruits. Local tomato samples showed in general higher acidity in comparison to the imported samples. Most of the parameters were within average values reported in the literature. However, lycopene content was below the average value for the majority of the samples except for grape – A and plum Haji Omaran. Elemental analysis revealed that the local samples contained Cd at higher levels (0.110 ± 0.0, 0.190 ± 0.0, 0.255 ± 0.0, 0.378 ± 0.0 and 0.187 ± 0.0 ppm) and Pb at (0.198 ± 0.0, 0.172 ± 0.0, 162 ± 0.0, 180 ± 0.0, 0.121 ± 0.0) for Plum - Haji Omaran, Round - Haji Omaran, Pink Beefsteak – Sidakan, Kurdish – Sidakan and Beefsteak – Erbil which were in most cases higher than the imported samples. Content of essential elements in all the samples is more likely to contribute beneficial effect towards daily requirement of these elements and does not pose toxicity risk under normal consumption rates. The content of Cd posed a carcinogenic risk for Pink Beefsteak – Sidakan and Kurdish – Sidakan samples. One of the imported samples contained arsenic at much higher concentration than the permitted UL which is a matter of high concern. The results of this study highlight the need for constant monitoring for tomato fruits (both imported and local samples) to ensure high quality and safe fruits reaching consumers.

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