Transport Factor Comparative Study of Some Heavy Metals Transfer from Soils to Fruits in Turabah Farms

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Keywords: *comparative study, soils, fruits, heavy metals, transfer factor, microwave, ICP-OES.*

The study aimed to determine transfer factor (TF) of heavy metals (HM) from soils to fruits in Wadi Turabah agricultural farms. This is in order to obtain information on retention mechanisms of metals in soils and their ability to transfer from soils to fruits. Obtained results (HM contents) were compared to those reported by FAO/WHO acceptable limits. Also TF values were compared to those stated in recent related studies. Fruit samples include cantaloupe melon, grape, pomegranate, mandarin and lemon. While, soil samples include surface soil (SS) and depth soil (DS) collected from same study area. Samples were digested by microwave-assisted oven and HM (Mn, Pb Cr, As and Cd) were determined using inductively coupled plasma-optical emission spectroscopy (ICP-OES). As and Pb were detected in almost all soil and fruit samples, while Cr and Mn were detected in all soil samples and not detected in other fruit samples except grape. Elevated levels of As and Mn were measured in fruit and soil samples respectively. However, general concentrations of studied HM in fruits from Turabah farms were lower than maximum permissible concentrations in fruits given by FAO/WHO. Results confirm that fruits in the study areas were safe and can be used for human consumptions. Statistical test revealed that concentration of HM were statistically significant differences ($P < 0.05$) in examined samples. Results indicate that Pb (TF = 0.774) transfer more than As (TF = 0.539), Cr (TF = 0.003), Mn and Cd (TF < 0.002). This indicates that general ability of HM to transfer from soils to fruits were low (TF < 1). Statistical tests ($P < 0.05$) indicate that obtained TF values were not differ significantly between different plant species grown in same location.

Introduction

Heavy meals (HM) refer to any metallic chemical element that has a relatively high density and is toxic at low concentrations such as Cr and Pb. Some HM like Mn and Cr are essential elements, with important functions that are indispensable for various biological processes. Other HM such as Pb and Cd exert toxic effects even at relatively low concentrations [1]. Fruits are basic and natural staple foods for all human beings. It contains large amounts of essential nutrients in excellent proportions [2]. Eating them on a regular basis is

crucial in providing health-promoting nutrients to human body.

Now a day contamination of soils with HM is a growing concern due to food safety issues and potential health risks. Moreover, fruits can potentially be contaminated with HM from irrigation waters and/or soils or through polluted air [3].

There are differences in concentration levels of HM between and within fruits species depending on characteristics of agriculture soils, composition of irrigation water, climate, growing condition, etc. Accumulation of HM in fruits occurs from different sources but soils are considered main one. Moreover, accumulations of HM in soils were associated with industrialization and other human activities such as mining, smelting, etc [4, 5]. In addition, pollution by fuel powers stations, various agricultural activities, use of fertilizers and pesticides, etc [6, 7].

Furthermore, solubility of HM in soils depends on several factors such as type of HM in soil, soil pH, soil temperature, redox potential, nutrient balance, etc. Uptake of HM from soil can also be through ion exchange, oxidation-reduction reactions, precipitation reactions, etc [8]. In addition, bioavailability of HM in soils are a complex dynamic processes that depends on multiple combinations of physical, chemical, biological, environmental and other factors [9].

Plants can absorb HM from soils by roots as well as from atmosphere through various plant organs such as leaves and fruits [10]. Similarly, different plants grown in same soisl may contain different levels of same HM [11, 12]. Furthermore, it was found that distribution of HM in plants is completely heterogeneous and is controlled by several barometers, most important of which are genetic and/or environmental. The dynamics of HM in fruit tissue–soil interactions mainly depend on soil contamination levels and plant species [13].

Since MH are readily accumulate in fruits, soil-fruit-human pathway has been considered as a major source for human exposure to HM. Previous studies have explained differences in accumulation of HM in different fruit samples [14-17]. Accumulation and transfer of HM from soils to fruits were studied using an indicator called transfer factor (TF) [16-18].

Various publications have indicated that TF can be considered as a useful indicator of potential HM-transport capabilities in soil-fruit-human pathway. Also, TF have been widely used in evolution of potential health risks of human exposure to HM from soil [16-18].

TF values were calculated as ratio of concentration of a particular element in fruits to concentration of same element in soils (both were represented in same units) [18]. Higher TF values (≥ 1) indicates greater uptake of HM from soils

by fruits and a higher suitability of fruits for phyto-extraction and phyto-remediation. On contrary, low values (< 1) indicate poor response of fruits towards HM uptake and therefore fruits can be used for human consumption [16, 18].

Traditionally, HM quantification involves well-established techniques, such as spectroscopy techniques and electrochemical methods [4]. Furthermore, various ion selective electrodes were also frequently used to identify HM [6, 7, 19-24].

Several literatures have emerged referring to HM contents of fruit in an effort to assess potential nutritional benefits as well as risks arising from fruit consumption. For this reason, a large number of researches have been conducted to identify potential risk factors from HM in various foods matrices.

Srinivasan *et al*. [25], have monitoring and evaluation of potential health risks associated with contents of HM in selected fruits grown in Arba Minch region, Ethiopia. Moreover, Ezra *et al*. [26], investigated of HM content in spices available in market of Asmara, Eritrea.

Also, Ibrahim *et al*. [27], determined concentration of HM content in date palm fruit growing in different locations in Riyadh, Saudi Arabia. Furthermore, Mohamed and Khairia [28], studied content of HM in fruits from markets of Saudi Arabian.

Moreover, Kalagbor *et al*. [29], studied levels of HM content in four fruits samples from Nigeria. Also, Amin and Nasim [30], have reported a survey on HM content in cydonia fruits collected from market sites in Hamadan (Iran). Furthermore, David [4], studied selected nutrients and HM content in fruits from Ethiopia. Also, Elbagermi *et al*. [2], reported content of HM in fruits and vegetables in Libya. Moreover, Saeed *et al*. [31], determined content of HM in mangoes grown in different regions of Pakistan.

Moreover, Rangnekar *et al.* [16], studied accumulation and translocation of nickel and cobalt in nutritionally important Indian vegetables grown in artificially contaminated soil of Mumbai, India. Also, Yeasmin *et al.* [17], determined transfer of metals from soil to vegetables and possible health risk assessment from Bangladesh. Also, Nataša *et al.* [18], reported transfer factor as indicator of heavy metals content in plants, from Kosovo. In addition, Jolly *et al*. [32], studied transfer of metals from soil to vegetables and possible health risk assessment in Bangladesh. Furthermore, Yu-Jing *et al.* [33], determined transfer of metals from soil to vegetables in an area nears a smelter in Nanning, China. They concluded that HM concentrations in plant tissues and soil were in association with each other. Thus at higher metal concentration in soil, metal concentration may exceed permissible levels causing toxicity in

plants as well as its successive components of food chain. Also, observed that physicochemical properties such as moisture, pH, electrical conductivity, texture and temperature, affects HM transfer from soils to plants. In addition, soil types, bulk density, organic carbon, nitrogen content, and nutrient levels of soils and climatic conditions were also determined in some studies [16, 17, 32, 33].

In this study, a systemic survey of soils and fruits quality in many agricultural farms in Wadi Turabah was conducted. The study were aimed to know levels of HM content in fruits and compare them with that in agricultural soils in which fruits were grown. This is, to assess ability of HM to transfer from soils and to accumulate in fruits that were collected from several agricultural farms in Wadi Turabah, Saudi Arabia. Obtained results (HM contents and TF values) were compared to those reported by FAO/WHO permissible limits for HM contents and that stated in recent related studies for TF values.

Experimental part

Materials and methods

Equipment's

Quadruple Elan DRC II (PerkinElmer Life and Analytical Sciences, Shelton, CT, USA) ICP-OES (Perkin Elmer Model Optima 2100 DV, USA) with CCD detector was used to analyze standards and samples. In this study some operating conditions for ICP have been carefully selected and well optimized. This is in order to maximize sensitivity of required elements and obtain best accuracy and precision. Furthermore, some MARS-5 and ICP-operating conditions were set according to manufacturer's instructions without modification.

Reagents

65% HNO_3, 40% HF, 36% HCl and 30% H_2O_2 (Merck, Germany) were used to digest samples as received from manufacturer. Also, high-purity grade V (Atomic Spectroscopy Standard Solution) consist of Pb (2 mg L^{-1}), Cd (5 mg L^{-1}), Cr and As (10 mg L^{-1}) and Mn (15 mg L^{-1}), was purchased from Perkin- Elmer, USA. This solution was used to prepare standard solutions for calibration curves and to spike some samples for recovery tests. Moreover, purity of Ar and N_2 gases used in this study were >99.99 % (v/v). All glassware used in this study were soaked in 10% HNO_3 for 24 hrs, then rinsed several times with distilled water and dried in an oven.

Study area

Turabah farms (Fig. 1) are located at Wadi Turabah in western part of KSA (Makkah region). The geographical coordinates of Turabah farms lie at longitude and latitude of 41° 37'59" E and 21°12'51" N respectively and at an elevation of 1164 m (3819 Ft) above sea level. It extends over a length of 400 km with a hot

deserts climate. This area is considered one of most fertile valleys in western region of KSA [34]. Soils of this area are sandy to fertile clay and seasonal plants such as watermelon and tomatoes grow in it, in addition to perennial plants such as palm dates. The sampling sites (read areas) are shown in **Figure 1**.

Fruits sampling and treatments

Twenty-four fruits samples were collected from different agricultural farms located in Wadi Turabah. Samples include cantaloupe melon, grape, pomegranate, mandarin and lemon. Samples were collected in clean polyethylene containers according to their types. After collection outer surface of fruits was first washed with distilled water, then air dried and kept in refrigerator before processing with drying and digestion process. For drying process, samples of each type were firstly cut separately with a clean stainless-steel knife into small pieces (2-3 mm size). Then mixed thoroughly and placed in an oven at 102°C until a constant weight was reached [35]. Three dried samples of each type were mixed, ground to a fine powder and homogenized using a clean commercial kitchen grinder. Specimens that were ground were properly graded and stored in polyethylene containers at -20°C until needed for analysis.

For digestion 0.5 g of each sample was accurately weighed into a PTFE digestion vessel and introduced into a Teflon digestion vessel of microwave assisted oven. 2.0 mL H_2O_2 and 4.0 mL HNO_3 were added to each sample. The contents were carefully shaken, then digestion vessels were well closed and optimum heating programs were followed. After digestions were completed, contents of vessels were quantitatively transferred to a 50 mL volumetric flask and diluted to mark with distilled water. This procedure was almost similar to that mentioned in our previous work with some modifications [36]. Also, many analytical blanks were prepared in same way as samples were prepared for characterization of instrumental drift.

Soils sampling and treatments

Eighteen soil samples were collected from six sampling points in same area where fruits were grown. Soils were taken from a surface (SS) and depth (DS) of 25.0 cm long using a hand-held polyethylene spoon after autumn season. Three samples from each point (about 500 gm) were reduced to one representative sample by cone and quarter. Samples were then dried at 102ºC, then ground to pass through a 63 μm nylon sieve and transferred to polyethylene bottles, stored at room temperature (27°C) until needed for analysis.

For digestion 0.25 g of each sample was accurately weighed into a PTFE digestion vessel and introduced directly into a Teflon digestion

vessel of microwave assisted oven. 1.0 mL H_2O_2, 2.0 mL HCl, 3.0 mL HF and 9.0 mL HNO_3 were added to each sample. Then same methods for fruit digestions were followed until end. This procedure was almost same as one mentioned in our previous work with some modifications [34]. Also, several analytical blanks were prepared in same way as samples so as to characterize instrumental drift.

Figure 1. Map of Saudi Arabia showing location of sampling sites (rose region), Turabah farms [34]

TF determination

The transfer ability of HM from soils to fruits was studied using an indicator called TF. It reflected ability of fruits to take up HM from soils. It's calculated as ratio of a specific metal concentration in fruit to concentration of same metal in soils where fruits were grown (both represented in same concentration units) [16]. This means that TF = C_{fruit} / C_{soil}, whereas, C_{fruit} and C_{soil} represents concentration (on dry weight basis) of certain metal in extracts of fruits and soils (mg kg^{-1}) respectively [16-18, 25, 32].

If TF >1, indicates high uptake of metal by fruits, while TF = 1 indicate that fruits are not affected by elements and TF <1 indicates that fruits exclude elements from absorption. If plants have higher TF values, it may be good if they are used for element-extraction and phytoremediation [16, 18, 33]. On contrary, lower values indicate a poor response of plants to metal uptake and plants can be used for human consumption [16].

Calibrations

About seven standard solutions were prepared by diluting a multi-element standard

solution containing analytes. Blanks were prepared in same way as standard solutions and calibration curves were plotted for each analyte.

Statistical analysis

The results were statistically evaluated by ANOVA and Student t-test, ($P < 0.05$), in addition to Microsoft Excel and Origin programs. In this study all statistical analysis were based on triplicate measurements [37].

ICP-method validation

To evaluate analytical methods used to analyze HM in fruits and soils by ICP-technique, some analytical figures of merit were estimated. These include spectral emission lines (wavelengths), linearity, accuracy, precision, LOD and LOQ. The analytical wavelengths (nm) for each analyte were set at primary (atomic) and secondary (ionic) lines. For linearity square correlation coefficient (R^2) was determined for each analyte by preparing calibration curve using non-weighted least-squares linear regression line.

Moreover, in order to know accuracy of analytical methods recovery (%) were measured by spiking some fruit and soil samples with standard solution and passing them through same digestion procedure. While, precisions of analytical methods were estimated by calculating relative standard deviation (RSD). LOD and LOQ were calculated for each analyte as follows: $LOD=3\sigma/m$, while $LOQ=10\sigma/m$. whereas, σ is standard deviation of seven blanks intensities and m is slope of calibration curve for each analyte [37].

Determination of HM in fruits and soils

All standards and sample solutions were analyzed three times on a Varian 710 ES axial ICP with a CCD detector. The Cetac automatic sampler with 15 mL sample tubes was connected to peristaltic pump. A Burgener Teflon Mira Mist (SCP Science) nebulizer and a glass cyclonic spray chamber were used to introduce standard and sample solutions. The concentrations of Mn, Pb, Cr, As and Cd were determined in digested fruit and soil samples by ICP using optimum instrumental parameters.

Results and discussion

Spectral lines selection

All analytes were measured in two different spectral emission lines (atomic and ionic line). The criteria for choosing between them were based on sensitivity, spectral interferences and concentration range of each analyte. In all cases, sensitivities were calculated on spectral lines with lower interferences and high sensitivity. The specific selected line (nm) for each analyte was indicated in **Table 1**.

Table 1. Selection of spectral lines

HM	Wavelengths (nm)
Mn	257.610
Pb	220.353
Cr	267.716
As	188.979
Cd	226.502

Microwave parameters optimization

The efficacy of sample digestion depends on sample matrix, so it is important to optimize microwave oven conditions. The temperature of microwave oven and acid/oxidant mixture further effects sample digestion, while, pressure, ramp, holding and ventilation time have relatively small effects. The microwave oven temperature was set between 210-260ºC, a clear solution was observed at 220 and 250ºC for fruits and soils, respectively. Therefore, oven temperature at 220 and 250ºC were used in this study.

Moreover, acid/oxidant mixture (H_2O_2/HNO_3) has been studied in a ratio of 1:1, 1:2, 1:2, 1:3 and 1:4, a clear solution was observed in a ratio of 1:2. Therefore, a ratio 1:2 was used to digest fruit samples throughout this study. While an acid/oxidizing mixture (H_2O_2/HCl/HF/HNO_3) in a ratio of 1:1:2:2, 1:2:4:8, 1:2:3:9, 1:3:5:7 and 1:4:6:9 was studied. A clear solution was observed in ratio of 1:2:3:9, therefore, ratio of 1:2:3:9 was used to digest soil samples during this study. The optimal values of microwave oven parameters were shown in **Table 2**.

ICP parameters optimization

Since signal intensity for each analyte depends on sample matrix, it is important to optimize ICP parameters. The emission intensity is mostly affected by radio frequency (RF) incident, Ar gas nebulizer flow rate and sample uptake flow rate that have a greater influence on measurement sensitivity. Whereas frequency, plasma and auxiliary Ar-gas flow rate have relatively small effects on sensitivity and were adjusted to accommodate memory effects due to a particular sample type such as organic materials and/or TDs [38]. The radio frequency (RF) incident power was studied in range between 1400-1800 W. The results indicate that sensitivity and linearity were better at 1600 W for nearly all analytes and improve plasma stability.

Table 2. MARS-5 heating program for digestion of fruits and soils

Condition	Used values
Temperature[a]	220 and 250°C for fruit and soil samples respectively
Pressure	800 (pis)
Ventilation	10 (min)
Holding time	10 (min)
Ramp time	25 (min)

[a]Optimized value

In addition, effect of nebulizer Ar-gas flow rate was studied between 0.40-0.80 L min^{-1}. A maximum intensity of 0.60 L min^{-1} was observed for all analytes, thus a flow rate of 0.60 L min^{-1} for nebulizer Ar-gas was adopted throughout this study, providing good precision and high sensitivity. Furthermore, sample uptake flow rate was investigated at three levels: 1.0, 2.0 and 3.0 mL min^{-1}. It was found that emission intensities for As, Cd, and Pb were higher at 1.0

mL min^{-1}, while for Cr, Al, and Mn were slightly higher at 2.0 mL min^{-1}. Therefore, sample uptake flow rate of 2.0 mL min^{-1} was chosen for this study, which provides sufficient sensitivity and low sample consumption (**Table 3**).

Table 3. ICP-instrumental conditions

Parameters	Selected values
RF-incident power[a]	1600 W
Frequency	40.68 MHz
Nebulizer Ar-gas flow rate[a]	0.60 L*min^{-1} (Ar-gas)
Plasma Ar-gas flow rate	15.0 L*min^{-1} (Ar-gas)
Auxiliary Ar-gas flow rate	0.2 L*min^{-1} (Ar-gas)
Sample uptake flow rate[a]	2.0 mL*min^{-1}

[a]Optimized value

Analytical figures of merits

The selected spectral lines that give high sensitivities and maximum emission intensities under optimal ICP operating conditions were described in **Table 4**. Furthermore, linearity of method was tested using selected analytical line were determined at five concentrations in range between 0.04-100 mg L^{-1}. That was satisfactory for all analytes with R^2 higher than 0.9990 in linear regression lines. This confirms linearity of analytical method used according to standards set by AOAC [39].

Furthermore, accuracy of analytical method was calculated as recovery (%), and it was found to be within acceptable range for all analytes [100±7] (**Table 4**). This indicates that there are no significant losses and/or gains for analytes using developed technique. In addition, precision of ICP-method was calculated as RSDs of five independent replicates for each sample and found to be less than 3.2% (**Table 4**).

Moreover, LOD of analytes were ranged between 0.0005-0.0062 mg kg^{-1}, while LOQ were ranged between 0.006-0.085 mg kg^{-1} (**Table 4**). The obtained values (LOD and LOQ) clearly demonstrated high sensitivity and linear range of ICP-method.

Table 4. Analytical figure of merits

HM	R^2	RSD (%)[a]	Recovery (%)	LOD (mg kg^{-1})	LOQ (mg kg^{-1})
Mn	0.9994	2.23	107±6	0.0005	0.006
Pb	0.9998	2.98	98±4	0.0062	0.085
Cr	0.9995	2.12	100±5	0.0012	0.043
As	0.9998	1.02	102±5	0.0054	0.017
Cd	0.9990	2.84	104±4	0.0007	0.019

[a]RSDs (%) are expressed as mean ± standard deviation

HM contents in fruit and soil samples

The ICP-method was used to identify HM in five varieties of most commonly consumed fruits in Turabah governorate and other regions in Saudi Arabia. In addition, soils of farmers' land where fruits were grown were also evaluated. The concentrations (mean, dry weight) of HM were shown in **Table 5** (fruits) and **Table 6** (soils). Moreover, concentrations of HM detected in fruit samples were then compared to WHO/FAO acceptable or permissible limits, which are listed in **Table 5**. The obtained results were below WHO/FAO acceptable limits that were reported by Ahamed [40] and WHO/FAO [41].

Table 5. Heavy metals contents in fruit samples

Fruits (English name/Scientific name)	**Part investigated**	**Concentration (mg Kg^{-1})[a]**					**Average concentration (mg Kg^{-1})[a]**
		Mn	**Pb**	**Cr**	**As**	**Cd**	
Cantaloupe melon (Cucumis melo var. Cantalupensis)	Edible tissues	ND	ND	ND	0.084	0.030	0.023
Grape (Vitis vinifera)	Whole	0.012	0.022	0.003	ND	0.032	0.014
Pomegranate (Punica granatum)	Edible tissues	ND	ND	ND	0.092	0.030	0.024
Mandarin (Citrus reticulate)	Edible tissues	ND	0.098	ND	0.064	0.033	0.039
Lemon (Citrus lemon)	Whole	ND	0.031	ND	ND	0.030	0.012
Average value (mg Kg^{-1})[a]	**-**	**0.002**	**0.030**	**0.001**	**0.048**	**0.031**	**0.022**
Acceptable limits by WHO/FAO [40, 41]	**-**	**500.0**	**0.30**	**0.05**	**0.2**	**0.05**	**-**

ND: not detected (below LOD of ICP-method), [a]analysis based on dry weight

The analyzed HM content in fruits (**Table 5**) showed different concentrations in most samples and were ND in few samples (below LOD of ICP-method). Such as, Cr and Mn were detected in grape (0.003 and 0.012 mg kg^{-1} respectively), but ND in other fruits (below LOD of ICP-method). Moreover, unexpected Pb, Cd and As were found in almost all studied fruit samples but at low concentrations (0.030, 0.031 and 0.048 mg kg^{-1}, respectively).

Also, most abundant element that found in fruits was As with average concentration of 0.048 mg kg^{-1}. While, lowest one was Cr with average concentration of 0.001 mg kg^{-1}. Furthermore, high average concentrations of HM were recorded in mandarin (0.039 mg kg^{-1}), while lowest one was recorded in lemon (0.012 mg kg^{-1}).

Moreover, results (**Table 5** and **Figure 2**) showed significant differences ($P < 0.05$) were

observed regarding HM concentrations in studied fruit samples. The concentrations of HM in studied fruits were in order: As > Cd > Pb > Mn > Cr. While, accumulation of HM were in order: mandarin > pomegranate > cantaloupe melon > grape > lemon.

Furthermore, results (**Table 5** and **Figure 2**) showed significant differences ($P < 0.05$) were observed regarding HM concentrations in studied fruit samples. However, general concentrations of studied HM in fruits from Turabah farms were lower than maximum permissible concentrations of fruits given by FAO and WHO [40, 41].

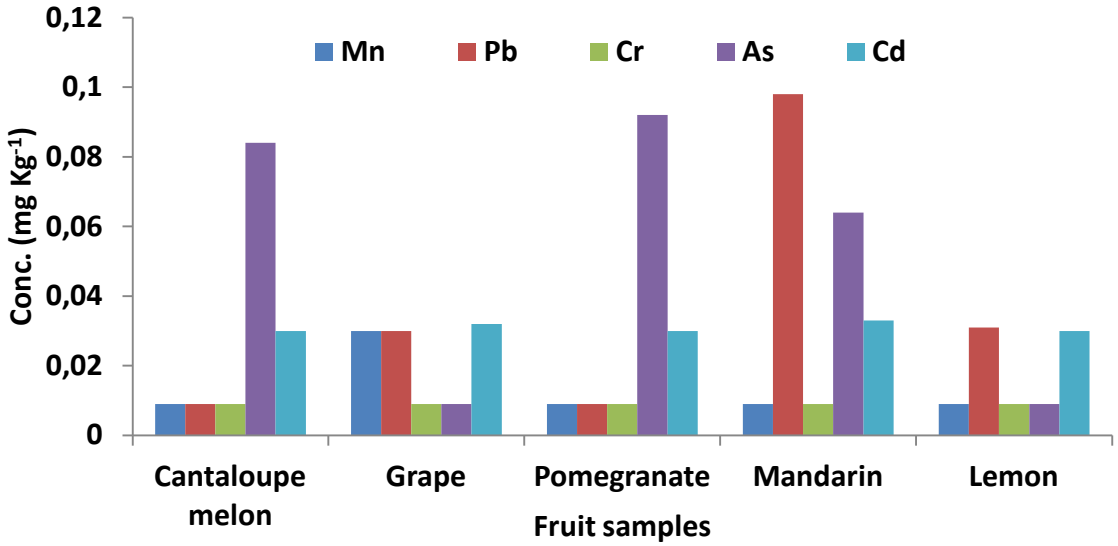

Figure 2. Heavy metals concentrations in fruit samples

Table 6. Heavy metals contents in soil samples

Samples	Concentration (mg Kg^{-1}, based on dry weight)					Average concentration (mg Kg^{-1})
	Mn	Pb	Cr	As	Cd	
SSi	3.554	0.043	0.296	0.132	ND	0.805
SSii	3.604	0.034	0.264	0.119	ND	0.804
SSiii	2.627	0.079	0.253	0.028	ND	0.597
DSi	3.539	0.037	0.270	0.084	ND	0.786
DSii	2.802	0.022	0.245	0.067	ND	0.627
DSiii	2.187	0.018	0.234	0.105	ND	0.509
Average value (mg Kg^{-1})	**3.052**	**0.039**	**0.260**	**0.089**	**NC**	**0.826**

ND: not detected (below LOD of ICP), NC: not calculated (below LOD of ICP)

The analyzed HM content in soils (**Table 6**) showed different concentrations in almost all samples. The contents HM in analyzed soil samples showed high concentrations of Mn in all samples (2.187-3.604 mg kg^{-1}), while, Cd was ND in all samples (below LOD of ICP-method). Moreover, unexpected Pb and As were found in all samples but at very low concentrations (0.039 and 0.089 mg kg^{-1}, respectively). Furthermore, moderate concentrations of Cr were recorded in almost all analyzed samples (0.260 mg kg^{-1}). However, high concentrations of HM were recorded in SSi (0.805 mg kg^{-1}), while lowest one was recorded in DSiii (0.509 mg kg^{-1}).

The concentrations of HM in studied soils were in order: Mn > Cr > As > Pb > Cd, while, accumulation of HM were in order: SSi > SSii > DSi > DSii > SSiii > DSiii. Moreover, results (**Table 6** and **Figure 3**) indicated significant differences ($P < 0.05$) were observed regarding concentrations of HM in different studied soils.

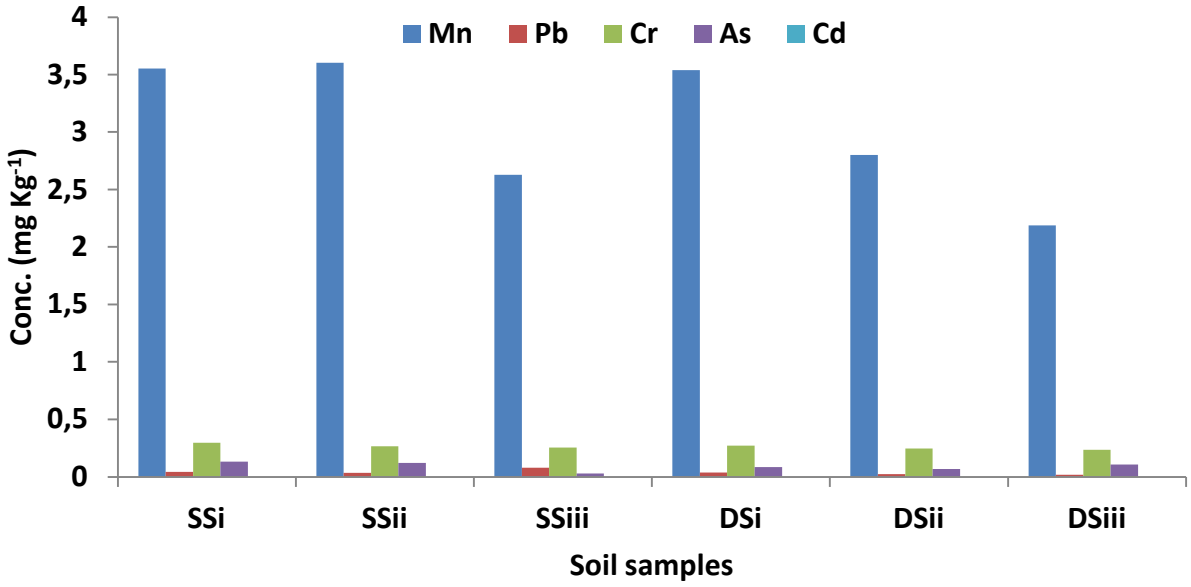

Figure 3. Heavy metals concentrations in soil samples

Figure 4 indicated that concentration of HM is relatively high in soils (0.826 mg kg^{-1}) compared to fruits (0.022 mg kg^{-1}). Dilek and Ahmet [42] and Govind *et al.*, [43], reported that level of HM in fruits were generally lower than in soils. For example, Mn and Cr were high in soils (3.052 and 0.260 mg kg^{-1} respectively) and low in fruits (0.002 and 0.001 mg kg^{-1} respectively). The absorption and bioaccumulation of HM from soils to fruits is a combined result of uptake processes from soils to fruits pathway chains.

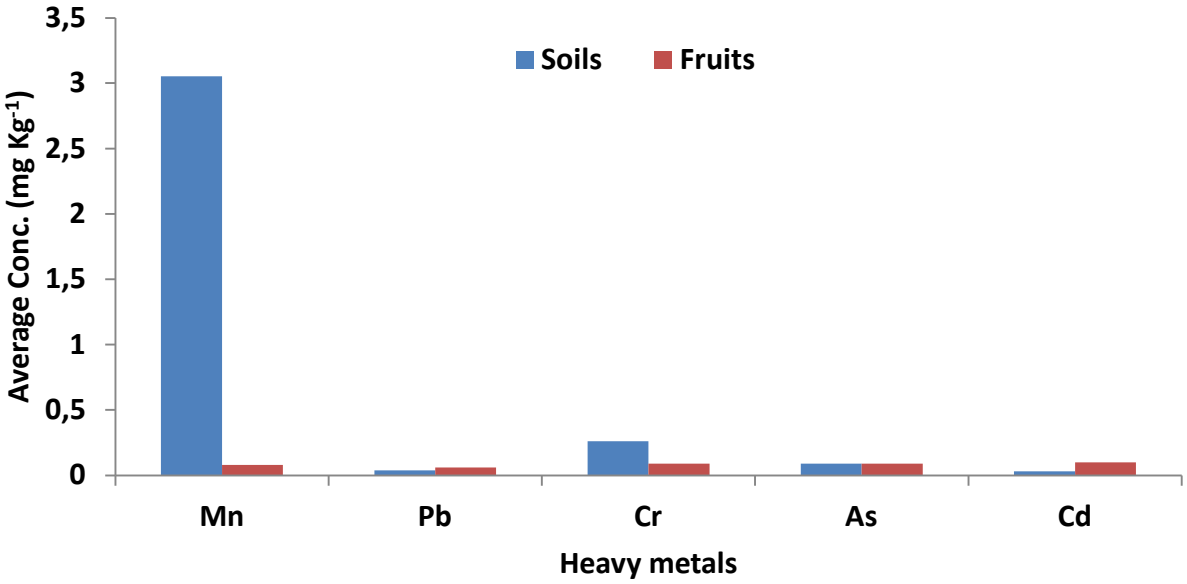

Figure 4. Average concentration of heavy metals in fruit and soil samples

TF of HM from soils to fruits

The ability of a particular metal to transfer from soils to fruits is referred to as TF for that metal. They are calculated to find out level of certain metal absorption from soils by fruits. Their values (**Table 7**, **Figures 5** and **6**) reflect actual ability of fruits to take a metal from soils [16-18, 25, 42]. Their values (TF) depend upon many factors such as pH, electrical conductivity, texture, moisture, temperature, soil organic matter, and available nitrogen. High values indicate that fruits have ability to absorb and accumulate metal and this might pose a potential health risk to consumers. While low values indicate that fruits have low affinity to absorb and accumulate metal in their organs [16-18, 25, 32, 33, 43, 45].

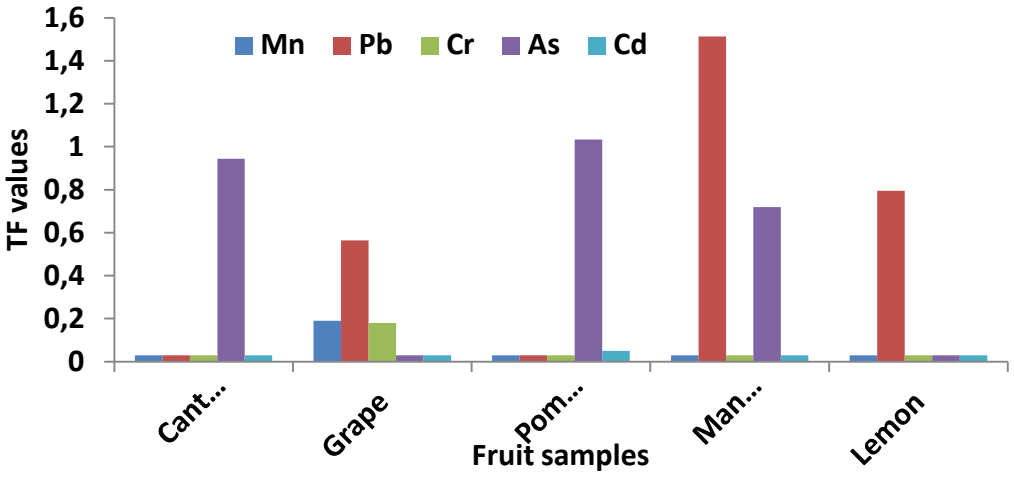

Figure 5. Transfer factor of heavy meals from soils-to-fruits

Table 7. Transfer factor from soils to fruits

HM	TF values (Present study)						TF values (reported in literature)
	Cantaloupe melon	Grape	Pomegranate	Mandarin	Lemon	Average value	
Mn	NC	0.004	NC	NC	NC	0.001 (<1)	0.001-0.038 [32] 0.01-0.1 [18];
Pb	NC	0.564	NC	1.513	0.795	0.774 (<1)	0.01-0.065 [32]; 0.0001-3.4333 [45]
Cr	NC	0.012	NC	NC	NC	0.003 (<1)	0.008-0.028 [32]; 0.1651-1.3382 [45]
As	0.944	NC	1.034	0.719	NC	0.539 (<1)	0.002-0.003 [32] 1.0-10 [18];
Cd	NC	NC	NC	NC	NC	NC	0.001-1.161 [32]; 0.4674-2.3571 [45]

NC: not calculated (below LOD of ICP), calculated values were reported in dry-by-dry basis

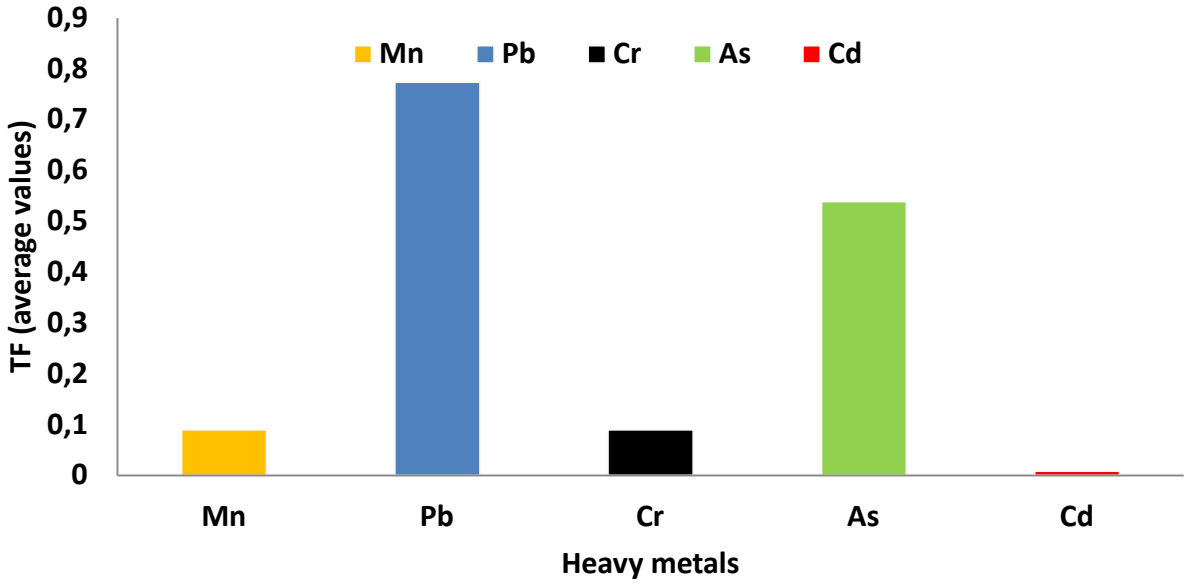

Figure 6. Average transfer factor values of heavy meals from soils-to-fruits

Table 7 indicates TF values of HM for soils to fruits. From results Pb had high TF (TF = 0.774), while Cd and Mn have low TF (TF ≈ 0.001). This indicates that Pb had ability to transfer from soils to fruits more than other HM, while, Cd and Mn have low ability. Higher TF values for Pb might be due to natural occurrence of Pb in soils and this will increase metal mobility.

Results (**Table 7**) revels that mandarin had high ability to absorb and accumulate HM more than other fruits. In contrast, grape had low ability to absorb and accumulate HM less than other fruits. Moreover, TF values of HM from soils to fruits show following trend: Cd > Cr > Mn > As > Pb (Fig. 6).

Conclusions

Soil contaminations with HM are receiving increasing attention worldwide. There are basically two main pathways of human exposure to soil pollutions: food chain pathway (soil-fruit-human) and accidental soil ingestion pathway (soil-human). Current study focused on transfer ability of some HM from soils to fruits grown on same soils in Turabah farms. The results indicate that general concentrations of studied HM in fruits from studied areas were lower than maximum permissible concentrations in fruits given by FAO/WHO. Also, our findings indicat that Pb and As have ability to transfer and accumulate more than others HM. It was observed that general ability of HM to transfer from soils to plants were very low (TF < 1). In this study statistical tests ($P < 0.05$) indicate that obtained TF values were not differ significantly

between different plant species grown in same location.

Acknowledgements

The author would like to acknowledge Deanship of Graduate Studies and Scientific Research, Taif University for funding this work.

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