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RESEARCH ARTICLE

Effects of some industrial and organic wastes application on growth and heavy metal uptake by tomato (*Lycopersicum esculentum*) grown in a greenhouse condition

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Abstract

In this study, pot experiments were conducted to determine the effects of industrial solid wastes (ISWs) (ceramic, stone, and sugar factory wastes) and organic wastes (rice husk and wheat straw) on growth and heavy metals uptake by tomato (*Lycopersicum esculentum*) plants. The soil was treated with 10% of ISWs and 5% of organic wastes. The fractionation of heavy metals also has been studied in all treated soils. It was observed that the addition of ISWs in soil increased heavy metal contents in all fractions. The addition of organic wastes to control and treated soils decreased exchangeable fraction and increased organic matter and residual fractions. Following the ceramic factory and stone cutting waste addition, tomato yield significantly decreased as compared to control soil. The application of ISWs caused an increase in heavy metal contents of tomato plants. In control and ISWs-treated soils, dry matter yield of tomato grown in the presence of wheat straw was significantly restricted, while the application of rice husk increased tomato shoot and root dry weight. Results of experiments indicated that the application of both organic wastes significantly decreased heavy metal uptake by tomato plants. The investigation of health risk index (HRI) values indicated that in these industrial areas, potential health risk by intake of heavy metals from tomato for both adults and children generally assumed to be safe. The values of HRI were lesser when rice husk was applied to the soil. In general, these results highlighted that the application of rice husk in soils contaminated with ISWs increased the growth and yield of tomato and reduced the heavy metal toxicity for tomato consumption in contaminated soils.

Keywords Ceramic factory waste · Fractionation · Health risk index · Rice husk · Stone cutting waste · Wheat straw

Introduction

Soil and water pollution is an area of increasing interest to environmental scientists. The addition of industrial solid wastes (ISWs) to agricultural soils may have significant effects on the properties of soils and agricultural products. Industrial wastes contain high amounts of macro- and micronutrients with the fertilizer replacement value. Despite the presence of nutrients, ISWs also contain some heavy metals, and the addition of these wastes in the soils may lead to environmental changes and soil contamination. Soils contaminated with heavy metals pose a risk of increased plant uptake, leaching and groundwater contamination, microbial or chemical degradation, and adverse effects on human health. The behavior of heavy metals in soil is affected by environmental factors, soil properties such as pH, redox potential, soil components, speciation, and bioavailability of heavy metals (Jalali and Khanlari 2008; Tangahu et al. 2011). These heavy metals transferred and concentrated into plant tissues from the soil by absorption in the root system. Therefore, for the effective management of the addition of these wastes to soils requires the knowledge of heavy metals bioavailability, fractions, and their uptake by plants in soil contaminated with ISWs. On the other hand, it is necessary to find the best methods to reduce the uptake of heavy metals by plants in contaminated sites.

Application of biological materials to contaminated sites for heavy metals immobilizing is an environment-friendly and relatively low-cost management practice. Among the biological materials, plant wastes such as rice husk (RCH)

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(Ajmal et al. 2003; Teixeira Tarley et al. 2004), wheat straw (WTS) (Doan et al. 2008; Dang et al. 2009; Osman et al. 2010), corncobs (Vaughan et al. 2001; Khan and Wahab 2006), and fruit or vegetable wastes (Gupta and Ali 2004; Junior et al. 2006) usually play an important role due to being widely and easily produced for detoxification of heavy metals. Crystian et al. (2009) demonstrated that the RCH is an attractive adsorbent for copper (Cu), zinc (Zn), and cadmium (Cd) removal from aqueous solutions. These organic amendments decrease heavy metal bioavailability through adsorption, precipitation, and surface complexation (Shaheen et al. 2015) and improve soil fertility and soil structure by essential nutrient supply (Shahbaz et al. 2014). Dourado et al. (2013) reported that the organic waste application in soil increases metal immobilization by the formation of organic-metal complex and restrict heavy metal translocation in different parts of the plant.

Different researchers have investigated the high contents of heavy metals in ISWs and their problems to the environment (Kamon et al. 2000; Ract et al. 2003, Taghipour and Jalali 2015, Taghipour and Jalali 2018). On the other hand, it is found that heavy metal availability in soils is controlled by their interaction with soil matrix and amendments. Therefore, at first, it is necessary to study the heavy metal fractionation when assessing the availability of heavy metals in the soil treated with ISWs and organic wastes. The use of sequential extraction techniques provides some information to understand the availability and uptake of heavy metals by plants.

Some studies have investigated heavy metal fractionation in soil treated with organic wastes (Abbaspour et al. 2007; Jalali and Rostaii 2011) and the effect of organic wastes on plant growth (Njoku and Mbah 2012; Tampio et al. 2016; Tekwa et al. 2017). But, the various chemical forms of heavy metals in soil treated with ISWs and organic wastes and their bioavailability for the plant have not been studied. Wheat is the main crop in the world, and large amounts of (WTS) are produced every year. Rice husk is an important agricultural waste generated during the dehusking process at rice mills. To produce every ton of rice, about 0.23 tons of RCH is formed (Kumar and Bandyopadhyay 2006). Thus, the use of these organic wastes as a no costly sorbent can reduce environmental pollution. Therefore, the objectives of the present study were (1) to investigate the fractionation of Cd, chromium (Cr), Cu, Nickel (Ni), lead (Pb), and Zn in soil treated with ISWs (ceramic factory (CFW), stone cutting (SCW), and sugar factory (SFW) wastes) in the presence and absence of organic wastes (RCH and WTS); and (2) to study the potential of these organic wastes using as a sorbent material to remove heavy metals from soils treated with ISWs and prevent the uptake of heavy metals by tomato under greenhouse condition.

Materials and methods

Soil, industrial solid, and organic wastes

The soil and ISW samples were collected from an agricultural area, and three factories in Hamadan Province, Iran, respectively. The soil was a sandy loam of the Azandarian Series (*Typic Calcixerolic Xerochrept*). The factories of ceramic, sugar, and stone cutting are the most important industries in Hamadan and have a significant impact on the province economy. These factories discharge a considerable amount of wastes without any management. Soil and waste samples were dried and passed through a 2-mm sieve, and then stored for future analysis.

Rice husk was purchased at a local market. Wheat straw was harvested from an agricultural farm in Hamadan Province, Iran. Organic wastes were washed carefully first with tap water several times and then deionized water to remove any dust or other foreign particles from their surface. After that, they were dried in an oven at 60 °C for a period of 48 h. The dried materials were crushed and milled, and then passed through 2-mm sieve. Two grams of the ISWs and organic wastes samples were digested by 12.5 mL 4 M HNO_3 at 80 °C overnight (Sposito et al. 1982), and the heavy metal contents of digestions were measured by atomic absorption spectroscopy, AAS (Varian, spectra 220) (Banat et al. 2005; Ben Achiba et al. 2009). In order to evaluate the accuracy of the analytical procedure, a recovery test was performed by spiking soil sample with varying amounts of the standard solutions of the heavy metals. The recovery percentages of the studied heavy metals were 97.1, 95.7, 101.3, 111.7, 104.7, 89.0, 94.6, and 106.2 for Cd, Cr, Cu, Fe, Ni, Mn, Pb, and Zn, respectively. The precision of analysis methods also was evaluated from the standard deviation for three replicate analyses of the sample, and it ranged from 0.0 to 21.5 for all heavy metals in control and treated soils. The AAS was calibrated with high purity chemical solutions. Blank samples were used to remove the contamination sources. The P content in digestions was measured by molybdenum blue method (Murphy and Riley 1962) and the Ca content by titration and K content by flame photometry (Rowell 1994). The pH of all wastes was measured in 0.002 M $CaCl_2$, 1:5 (*w*/*v*) ratios (Jalali and Rostaii 2011). Some properties of the ISWs and organic wastes used are given in Table 1.

Incubation

The incubation experiment was carried out using 13 treatments: 10% of three ISWs plus soil (Soil-CFW, Soil-SCW, and Soil-SFW), soil plus 5% of two organic wastes (Soil-WTS and Soil-RCH), and soil plus 10% of ISWs and 5% of two organic wastes (Soil-CFW-RCH, Soil-CFW-WTS, Soil-SCW-RCH, Soil-SCW-WTS, Soil-SFW-RCH, and Soil-SFW-WTS). Soil sample without any treatment was prepared

Table 1 pH, total heavy metals, K, Ca, and P in studied industrial solid and organic wastes

Wastes	pH	Cd	Cr	Cu	Fe	Ni	Mn	Pb	Zn	K	Ca	P
		mg kg^{-1}										
CFW	9.0 ± 0.4	5.2 ± 0.1*	96.9 ± 1.6*	105.0 ± 6.1*	11,452.0 ± 14.6	224.3 ± 10.9*	775.0 ± 11.3	1037.9 ± 5.5*	582.8 ± 16.9*	2388.0 ± 13.7	10.3 ± 0.4	1254.0 ± 25.8
SCW	7.7 ± 0.1	12.4 ± 0.6*	318.3 ± 2.9	716.5 ± 5.7*	9612.0 ± 10.9	612.5 ± 18.5*	1162.5 ± 3.9	343.4 ± 11.4*	215.8 ± 2.6*	7799.8 ± 29.5	41.6 ± 1.6	976.5 ± 4.0
SFW	10.1 ± 0.9	4.9 ± 0.4*	294.2 ± 1.3*	201.9 ± 2.8*	8941.0 ± 18.5	319.1 ± 20.0*	912.7 ± 4.5	25.7 ± 0.9*	187.9 ± 13.4*	6869.7 ± 17.8	83.9 ± 2.7	1476.0 ± 9.1
WTS	5.4 ± 0.0	ND	ND	6.3 ± 1.0	209.0 ± 21.5	7.9 ± 0.7	28.5 ± 1.4	ND	8.9 ± 0.7	23,000.0 ± 6.1	957.8 ± 2.1	1557.0 ± 20.0
RCH	5.1 ± 0.2	0.6 ± 0.0	0.4 ± 0.0	2.0 ± 0.2	93.0 ± 7.8	6.1 ± 0.3	30.4 ± 1.9	0.4 ± 0.0	32.0 ± 1.1	4152.0 ± 10.6	1500.0 ± 12.9	1400.0 ± 24.7

Data are means ± SD of three replications

CFW ceramic factory waste, *SCW* stone cutting waste, *SFW* sugar factory waste, *WTS* wheat straw, *RCH* rice husk

*Taghipour and Jalali (2018)

as a control. The appropriate weights of wastes were mixed with 3 kg of soil and incubated for 2 months at 25 °C.

Heavy metals fractionation

After incubation, 2 g of each sample was weighed into a 50-mL centrifuge tube and fractionation of heavy metals in all treated soils was conducted by using the sequential extraction procedure proposed by Sposito et al. (1982). The four fractions were exchangeable metals (EXC; soil extracted with 25 mL 0.5 M KNO_3), metals bound to organic matter (OM; residue from EXC extracted with 25 mL 0.5 M NaOH), inorganic precipitates of metals (CAR; residue from OM extracted with 25 ml 0.05 M EDTA), and metals in the residue (RES; residue from CAR extracted with 25 ml 4 M HNO_3). After every step, the supernatant was collected by centrifuging at 10,000 rpm for 10 min and filtered to remove fine particles. Concentrations of heavy metals in the extracts were determined using AAS.

The bioavailability of heavy metals in soil treated with ISWs and organic wastes depends not only on the total content but also on their existing forms. Exchangeable contents of heavy metals represent direct toxicity and bioavailability, and heavy metal contents in OM and CAR fractions relate to potential toxicity and bioavailability, while heavy metals in RES fraction possess no toxicity and bioavailability (Li et al. 2012). The risk assessment code (RAC) was carried out based on the proportion of EXC fraction to the total content of each metal, which can be classified as no risk (< 1%), low risk (1–10%), medium risk (11–30%), high risk (31–50%), and very high risk (> 50%) (Shi et al. 2013; Xiong et al. 2018).

Greenhouse experiments

After incubation , 2.5 kg of all treated soils were air-dried, sieved, and weighed into plastic pots (23-cm diameter top and 21.5-cm depth). Each treatment had three replicates and, as a consequence, a total of 36 pots were utilized. One young plant of tomato (*Lycopersicum esculentum*) with three leaves was planted in each of the pots. Tomato was selected because the wide range of human diets is made from tomato and it constitutes one of the major materials in different foods. The plants were grown in greenhouse conditions and watered using distilled water to approximately field capacity (Jones 2007). No fertilization was applied during the experiment. Harvesting was done after 2 months of plant growth and the roots, shoots, and fruits were separated. The plants were washed using distilled water and oven-dried at 60 °C (for 48 h) to constant weight for dry matter yield determination, and then shelved and ground for chemical analysis. Heavy metal contents in various plant issues were determined by AAS following HNO_3-H_2O_2 digestion (Cao et al. 2010). Dried samples (0.3 g) were digested with 5 mL HNO_3, and then 2 mL H_2O_2 was added and placed in the room temperature. The detection limits of AAS were 0.02, 0.03, 0.06, 0.10, 0.10, and 0.01 mg L^{-1} for Cd, Cu, Cr, Ni, Pb, and Zn, respectively. A diagram of the experimental design is shown in Fig. 1.

The plant concentration factor (PCF) was calculated based on the ratio of heavy metal contents in plants (root + shoot + fruit) to the soil (Khan et al. 2008):

$$\mathrm{PCF} = \frac{\text{heavy metal content in plant } (\text{root} + \text{shoot} + \text{fruit})}{\text{heavy metal content in soil}}$$

In order to evaluate the risk from tomato ingestion in the presence of ISWs and organic wastes, estimated daily intake (EDI) (mg kg^{-1} day^{-1}) and health risk index (HRI) of heavy metals in each treatment were calculated by the following equations (Munoz et al. 2017; Jalali and Hemati Matin 2019):

$$\mathrm{EDI} = \frac{\mathrm{C} \times \mathrm{F_{IR}}}{\mathrm{W_{AB}}}$$

$$\mathrm{HRI} = \frac{\mathrm{EDI}}{\mathrm{ORD}}$$

where EDI represents the estimated daily intake of heavy metals (mg kg^{-1} day^{-1}) and C is the heavy metal content in tomato fruits in each treatment (mg kg^{-1}). The daily vegetable consumption (F_{IR}) was considered to be 109.0 g $person^{-1}$ day^{-1} (Institute of standard and Industrial Research of Iran, ISIRI 2010). W_{AB} is the average body weight (kg). In this study, people were divided into two groups, children and adults, and the average body weight was 70.7 for adults and 32.9 kg for the child (Rout et al. 2013). ORD is the reference dose of a specific metal. The ORD values (mg kg^{-1} day^{-1}) for Cd (0.001), Cr (1.5), Cu (0.04), Ni (0.02), and Zn (0.3) were selected from the US-EPA integrated risk information system (IRIS) 2006. The fresh weight of tomato fruits was converted to a dry weight based on the measured water content of the tomato fruit samples (90%). Thus the conversion factor for fresh tomato fruits to dry weight was 0.1.

Statistical analysis

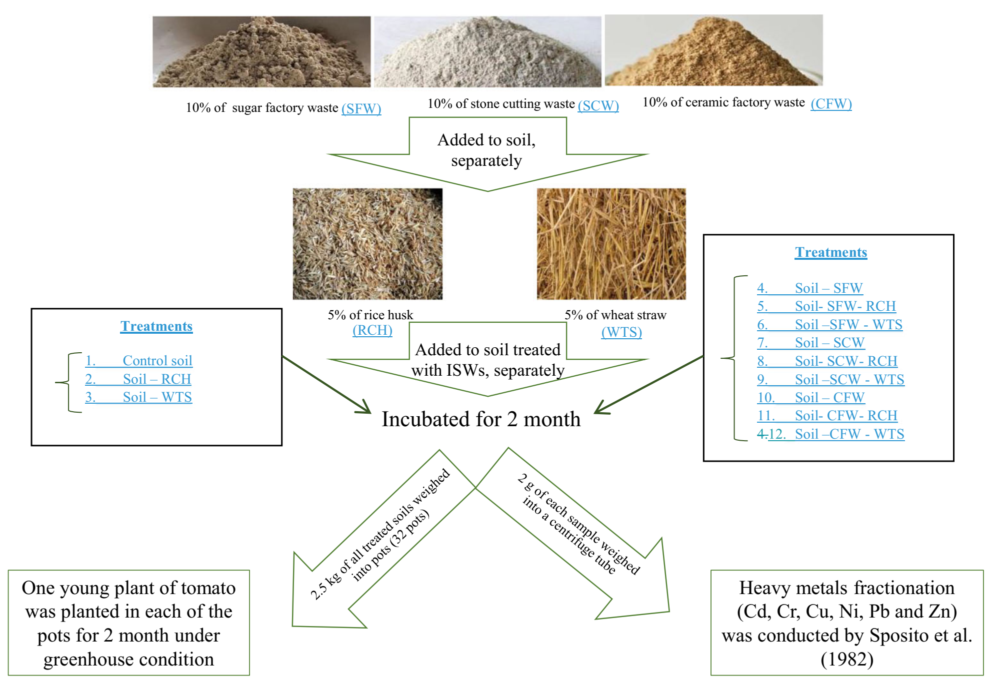
All analyses were performed in triplicates. Data were analyzed by one-way ANOVA (SAS Institute 1982), and Duncan's test at a significance level of $p < 0.05$ was used to distinguish significant differences among treatment means. Correlations between the different forms of heavy metals in the soil and their contents in plants were determined using Pearson's correlation analysis.

Results and discussion

The effect of ISWs and organic wastes on heavy metal fractionation

Figure 2 presents the percent fraction of heavy metals in the treated and control soils. In all treated soils, heavy metal

Fig. 1 A diagram of the experimental design



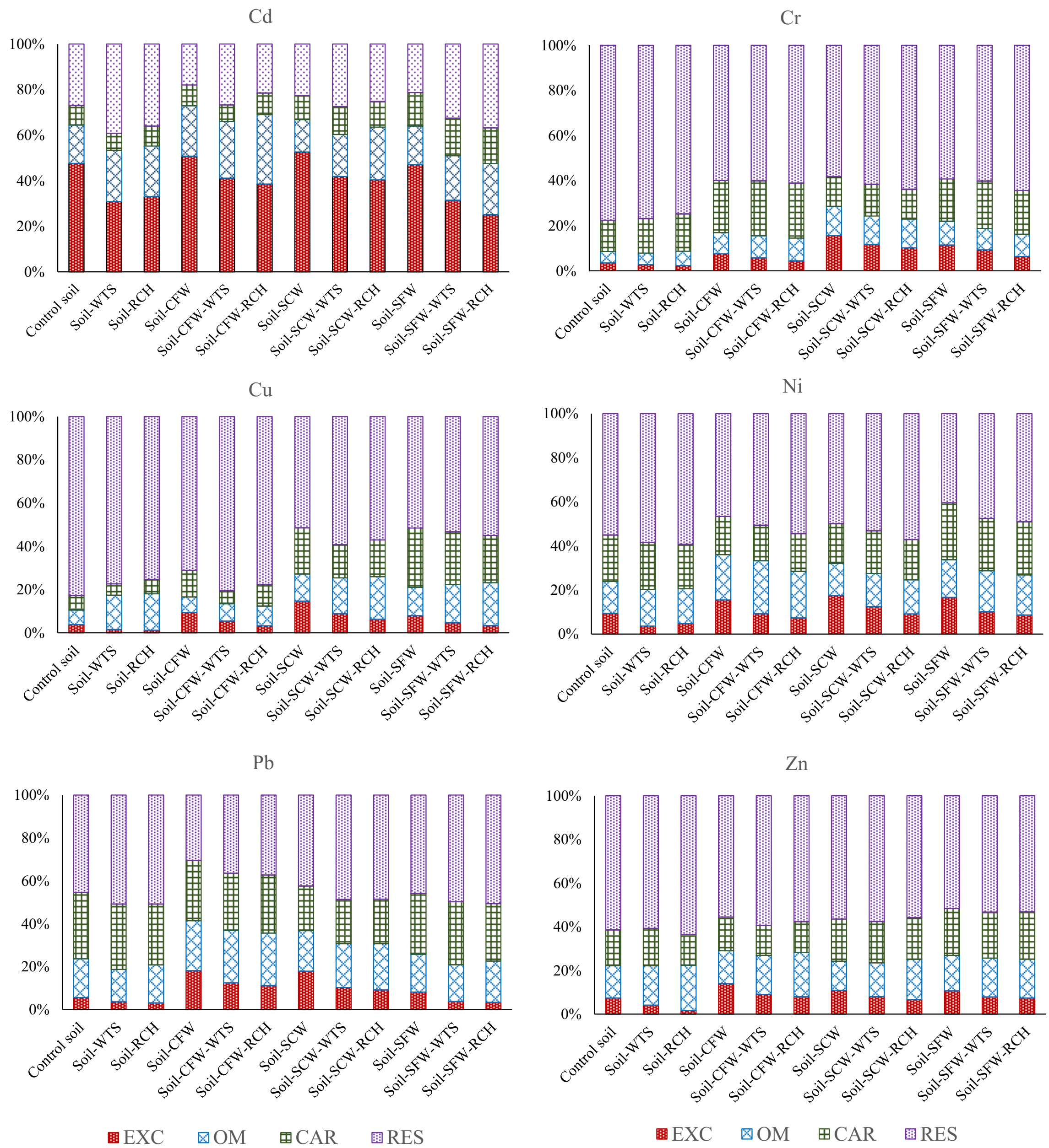


Fig. 2 Heavy metal fractionation in soil treated with industrial solid and organic wastes ($n = 3$). WTS wheat straw, RCH rice husk, CFW ceramic factory waste, SCW stone cutting waste, SFW sugar factory waste

recovery from the sequential extraction analysis was within ± 13% of the heavy metal total contents, which digested by the HNO_3-$HClO_4$ digestion method (Burau 1982). It indicated that errors from the fractionation procedure were negligible. The geochemical baseline contents of Cd, Cr, Cu, Ni, Pb, and Zn in soils of Hamadan were 1.36, 36.69, 29.99, 53.59, 39.60, and 103.80 mg kg^{-1}, respectively (Beygi and Jalali 2018). The total contents of Cd, Ni, and Pb in control and all treated soils, Cr and Cu contents in all ISWs-treated soils and Zn content in CFW-treated soils (Taghipour and Jalali, 2019) were higher than the metal background level. Therefore, the addition of ISWs to soil leads to an increase in the contents of all studied heavy metals than the geochemical baseline contents.

In treated soils, the highest percentage of Cr, Cu, Ni, Pb, and Zn were associated with RES fraction and the order of fractions was the same as in control soils. In most treatments, the majority of Cd was in the EXC fraction indicating potential mobility of Cd in these treatments. The high content of Cd in EXC fraction also has been reported in other studies (Jalali and Khanlari 2008). In soil treated with two organic wastes (Soil-RCH and Soil-WTS) and soil treated with SFW in the presence of two organic wastes (Soil-SFW-RCH and Soil-SFW-WTS), Cd was found mainly in RES fraction. The behavior of heavy metals in organic amended soils is controlled by biological (mineralization-immobilization) and chemical (absorption-desorption, dissolution-precipitation) processes (Jalali and Rostaii 2011).

It was observed that the addition of ISWs in soil increased heavy metal contents in all fractions. Compared to control soil, all fractions of Cd, Cr, Cu, and Ni increased in the SCW-treated soil higher than the other ISWs (Fig. 2), which can be attributed to the high heavy metal contents in these wastes. Mosaferi et al. (2014) studied heavy metal concentrations in stone cutting sludge samples and observed the considerable amounts of Pb, Cu, Cr, and Cd in this sample. Compared to other wastes, the addition of CFW to soil increased all fractions of Pb and Zn (Fig. 2). Glazes are applied in the production of ceramic and pottery ware to protect the pottery from wear and water. Lead is a heavy metal commonly used in ceramic glazes. Other heavy metals also are used in the ceramic and pottery ware for coloring. The application of SFW had less effect on heavy metal contents than the other wastes.

Figure 2 also illustrates the effect of organic waste treatments on the fractionation of heavy metals in soil. In general, the contents of all heavy metals were decreased in EXC fraction, while they increased in OM and RES fractions after the addition of both organic wastes. The organic wastes had little influence on the CAR fraction in all treatments. Hamid et al. (2018) found that the organic amendment converted the soluble forms of metals (EXC fraction) to organically bound fraction and thus decreased their availability to plants. It has been reported that the organic amendments played an important role in decreasing the bioavailability of metals (Abbaspour et al. 2007; Khan et al. 2014). Jalali and Rostaii (2011) studied Cd distribution in plant residues amended calcareous soils and found an increase of Cd content in OM and RES fractions and a decrease of Cd content in CAR fraction in compared to unamended soil.

Table 1 shows the variation of RAC in the soil after ISWs and organic waste treatments. Based on the percentage of each metal in the EXC fraction (Table 2 and Fig. 2), the proportions of each metal that existed in the EXC fraction are low (between 1 and 10%, except for Cd 47.6%) in control soil. According to the RAC values, Cd was most available with RAC > 30, showing high ecological risk. These results concur with the findings of Sundaray et al. (2011), Li et al. (2016), and Wang et al. (2018), while other heavy metals exhibited medium and low availability.

The values of RAC were increased after ISWs addition, indicating their negative effect on increasing the toxicity and bioavailability of these heavy metals. Organic waste treatments exhibited the most effect on reducing all heavy metal toxicity due to the lowest EXC fraction obtained in these treatments. From the above results, it can be inferred that heavy metals in all treatments could be transformed from weakly bounded fractions to a more stable state by the addition of organic wastes, implying that some stable organic-metal complex might form between heavy metals and organic wastes (Tan and Xiao 2009; Shaheen et al. 2015).

Effect of industrial solid and organic wastes on tomato growth

Data in Table 3 presented the effect of ISWs and organic waste addition on the root, shoot, and fruit dry weight in tomato. There were significant ($p < 0.05$) differences in the dry weight of the plant between all treatments with the control soil. An increase in the root, shoot, and fruit dry weight was significantly higher in the presence of SFW, by 71.4%, 47.1%, and 177.0%, respectively, as compared to control soil. The addition of CFW and SCW to soil significantly decreased tomato yield. It has been pointed that if the content of heavy metals in available fractions (i.e., EXC fraction) in the soil increases, plants show physiological damage in response to the heavy metals. Decreasing of plant biomass may be attributed to heavy metal toxicity for plants and deficiency of macronutrients, which results from an inhibition of their uptake under heavy metal exposure. Similarly, Akinci et al. (2010) found that dry biomass of roots, shoots, and leaves in tomato were negatively affected by increasing Pb concentration. Therefore, in this study, the decrease of tomato biomass in the soil treated with CFW and SCW perhaps was due to the high available contents of heavy metals (such as Cd, Cu, Pb, and Ni) in these wastes (Fig. 2).

As compared to control soil, the application of RCH produced 1.5% and 32.2% more tomato shoot and fruit dry weight, respectively. This agrees with the report of Anikwe (2000) and Njoku and Mbah (2012), which indicated that the RCH provides essential nutrients for effective growth parameters. Tekwa et al. (2017) recommended that the application of RCH in the soil can improve the efficient growth and yield of tomato. The results of Tekwa et al. (2010) study showed that RCH could improve soil aggregate stability and even supplement essential nutrients for crop production. Mbah (2006), and Mbah and Onweremadu (2009) observed an increase in dry matter yield of plants with application of organic wastes. In general, the application of SFW alone and in combination with RCH significantly increased tomato yield by providing nutrients and decreasing heavy metal contents.

In control and ISWs-treated soils, dry matter yield of tomato grown in the presence of WTS was significantly restricted. For example, a decrease of root and shoot dry weight by 28.6% and 71.4%, respectively, was achieved in WTS-treated soil (Soil-WTS) as compared to control soil. In plants grown in WTS-treated soils, only four to five leaves formed during the growth period, and chlorosis and necrosis were observed in this treatment. There is evidence that the decomposition of plant residue in the soil can lead to the formation of favorable or unfavorable compounds

Table 2 The risk assessment code (RAC) values of heavy metals in soil treated with industrial and organic waste

Treatment	Cd	Cr	Cu	Ni	Pb	Zn
Control soil	47.62 H	3.54 L	3.75 L	9.34 L	5.53 L	7.36 L
Soil-WTS	30.83 M	2.76 L	1.55 L	3.70 L	3.55 L	4.09 L
Soil-RCH	33.05 H	2.32 L	1.19 L	4.75 L	3.11 L	1.55 L
Soil-CFW	50.70 H	7.53 L	9.42 L	15.49 M	18.09 M	13.94 M
Soil-CFW-WTS	41.10 H	5.79 L	5.37 L	9.24 L	12.48 M	9.04 L
Soil-CFW-RCH	38.61 H	4.42 L	3.26 L	7.31 L	11.17 M	7.93 L
Soil-SCW	52.63 VH	15.80 M	14.60 M	17.53 M	17.83 M	10.87 L
Soil-SCW-WTS	41.90 H	11.65 M	8.84 L	12.42 M	10.29 L	8.01 L
Soil-SCW-RCH	40.40 H	10.16 L	6.28 L	9.15 L	9.12 L	6.62 L
Soil-SFW	47.14 H	11.47 M	7.95 L	16.63 M	8.14 L	10.64 L
Soil-SFW-WTS	31.42 H	9.37 L	4.64 L	10.07 L	3.77 L	7.79 L
Soil-SFW-RCH	25.08 M	6.38 L	3.30 L	8.69 L	3.31 L	7.33 L

Risk assessment code (RAC): low risk (L), medium risk (M), high risk (H) and very high risk (VH)

WTS wheat straw, *RCH* rice husk, *CFW* ceramic factory waste, *SCW* stone cutting waste, *SFW* sugar factory waste

for plants. It has been shown that WTS inhibits the growth of several crops through the allelochemical present in WTS and microbial toxins produced during decomposition (Wu et al. 2000; Li et al. 2005; Nakano et al. 2006; Khaliq et al. 2011). Khanh et al. (2005) found that plant growth decreased with the addition of WTS in the soil, which may be due to the increased concentration of allelochemicals and their compound. The presence of phytotoxic compounds such as phenolics, alkaloids, and fatty acids was reported in WTS (Wu et al. 2001; Ma 2005; Khaliq et al. 2011; Lam et al. 2012). Saffari et al. (2010) reported that the WTS had significant negative allelopathic effects on corn varieties; therefore, cultivating corn after wheat caused less growth and yield. Xu et al. (2016) also found that the return of straw to agricultural lands reduced the yield and root dry weight of plants.

Heavy metal contents in tomato as effected by industrial solid and organic wastes

The contents of heavy metals (Cd, Cr, Cu, Pb, Ni, and Zn) in various tissues of tomato are presented in Figs. 3 and 4 and Table 4. The results showed that in all treatments, the shoot of tomato plants had the highest contents of Cr and Cu, while the highest contents of Cd, Ni, Pb, and Zn were accumulated in the root. Fruits contained the lowest heavy metals in all treatments, and Pb contents in the fruits of tomato were not

Table 3 Roots, shoots, and fruits dry weight (g pot^{-1}) of tomato as affected by industrial solid and organic wastes

Treatment	Root dry weight	% of control	Shoot dry weight	% of control	Fruit dry weight	% of control
Control soil	1.40 ± 0.08 c	100.00	12.73 ± 0.43 b	100.00	0.95 ± 0.07 d	100.00
Soil-WTS	1.00 ± 0.08 d	71.43	3.64 ± 0.31 e	28.59	–	–
Soil-RCH	1.36 ± 0.08 c	97.14	12.92 ± 0.40 b	101.49	1.26 ± 0.06 c	132.21
Soil-CFW	0.95 ± 0.15 d	67.86	6.80 ± 0.10 d	53.42	0.35 ± 0.10 e	36.62
Soil-CFW-WTS	0.60 ± 0.11 e	42.86	1.63 ± 0.06 f	12.80	–	–
Soil-CFW-RCH	1.85 ± 0.03 b	132.14	10.38 ± 0.72 c	81.54	1.06 ± 0.04 cd	111.54
Soil-SCW	1.54 ± 0.06 bc	110.00	7.47 ± 0.13 d	58.68	0.82 ± 0.08 d	86.21
Soil-SCW-WTS	0.98 ± 0.13 d	70.00	1.47 ± 0.15 f	11.55	–	–
Soil-SCW-RCH	1.75 ± 0.09 b	125.00	9.78 ± 0.32 c	76.83	0.93 ± 0.04 d	97.59
Soil-SFW	2.40 ± 0.12 a	171.43	18.72 ± 0.11 a	147.05	2.64 ± 0.06 a	277.02
Soil-SFW-WST	1.25 ± 0.05 cd	89.29	4.52 ± 0.41 e	35.51	–	–
Soil-SFW-RCH	2.68 ± 0.12 a	191.43	20.10 ± 0.20 a	157.89	2.30 ± 0.14 b	241.76

Data are means of three replications. Columns marked with the same letter are not significantly different (Duncan's multiple range test) at the $p < 0.05$ level

WTS wheat straw, *RCH* rice husk, *CFW* ceramic factory waste, *SCW* stone cutting waste, *SFW* sugar factory waste

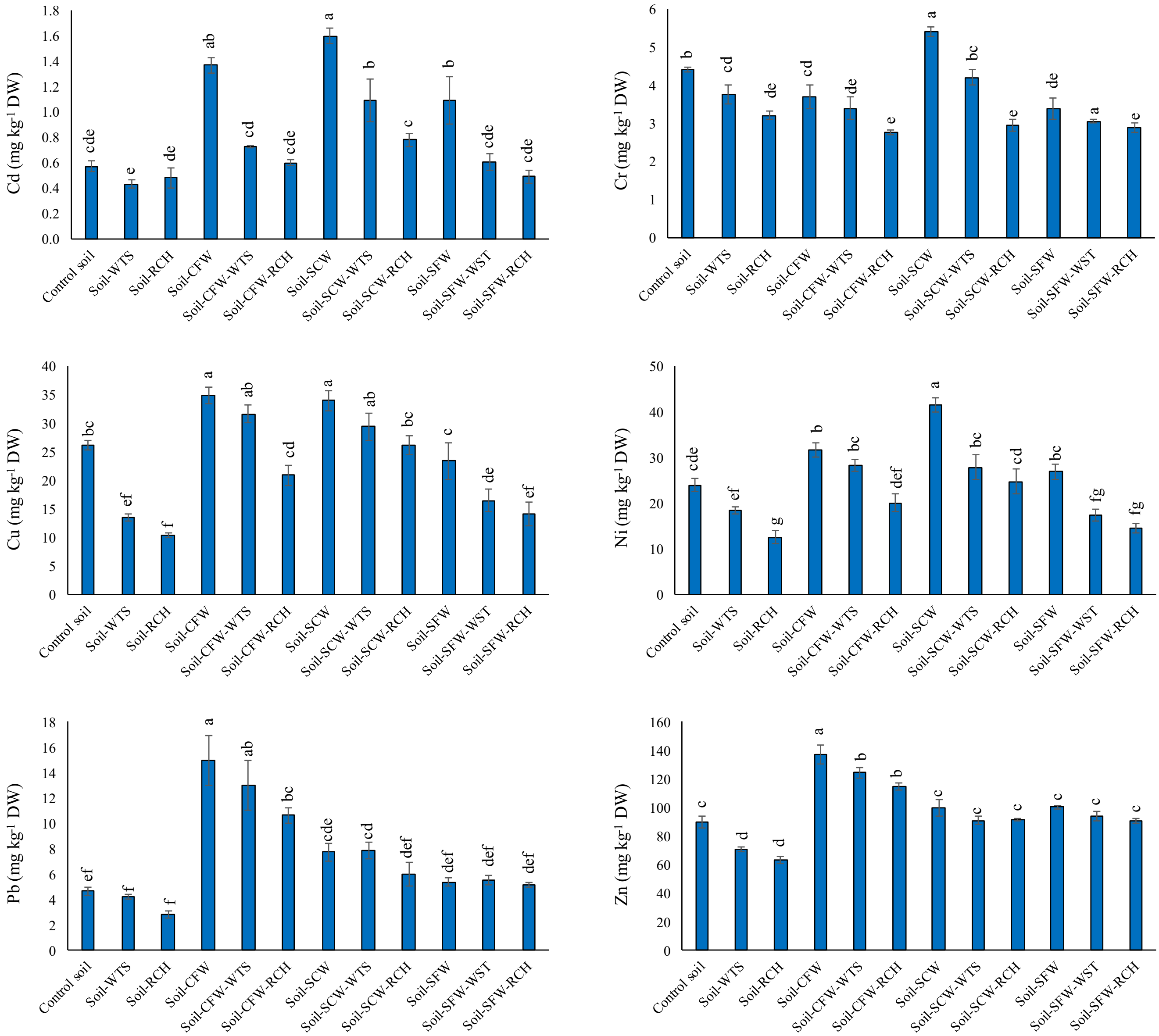


Fig. 3 Heavy metal content in root of tomato as affected by industrial solid and organic wastes. WTS wheat straw, RCH rice husk, CFW ceramic factory waste, SCW stone cutting waste, SFW sugar factory waste. Data are means ± SD of three replications. Columns marked with the same letter are not significantly different (Duncan's multiple range test) at the $p < 0.05$ level

detected. The fruit was not formed in WTS treatments (soil-WTS and soil-ISWs-WTS).

Industrial solid wastes appeared to have different impacts on the uptake of heavy metals by tomato plants. The greatest uptake of Cd, Cr, Cu, and Ni by the addition of ISWs was found in the soil treated with SCW, i.e., compared to control soil, Cd, Cr, Cu, and Ni contents in tomato roots were respectively 2.8, 1.2, 1.3, and 1.7 times higher for soil treated with SCW (Soil-SCW). The application of CFW caused a significant increase in Pb and Zn contents of tomato roots, shoots, and fruits. For example, the contents of Pb and Zn measured in roots from CFW-treated soils (Soil-CFW) were respectively increased by 69.1% and 34.6% as compared to control soil (Fig. 3). According to the results of Table 5, the correlation coefficient between EXC fractions and total contents of heavy metals in control and treated soils and their amount in tomato plants were ranged between 0.39 and 0.96, and −0.04 and 0.86, respectively. Therefore, the EXC fractions of heavy metals had a stronger influence on the uptake than their total contents in soils.

In most treatments, the application of organic wastes in control soil and ISWs-treated soils significantly reduced heavy metal contents in all parts of tomato plants. The effect of organic wastes on bioavailability and plant accumulation of heavy metals has been investigated by Xu et al. (2016). Their results showed that the shoot Cd accumulation of maize was

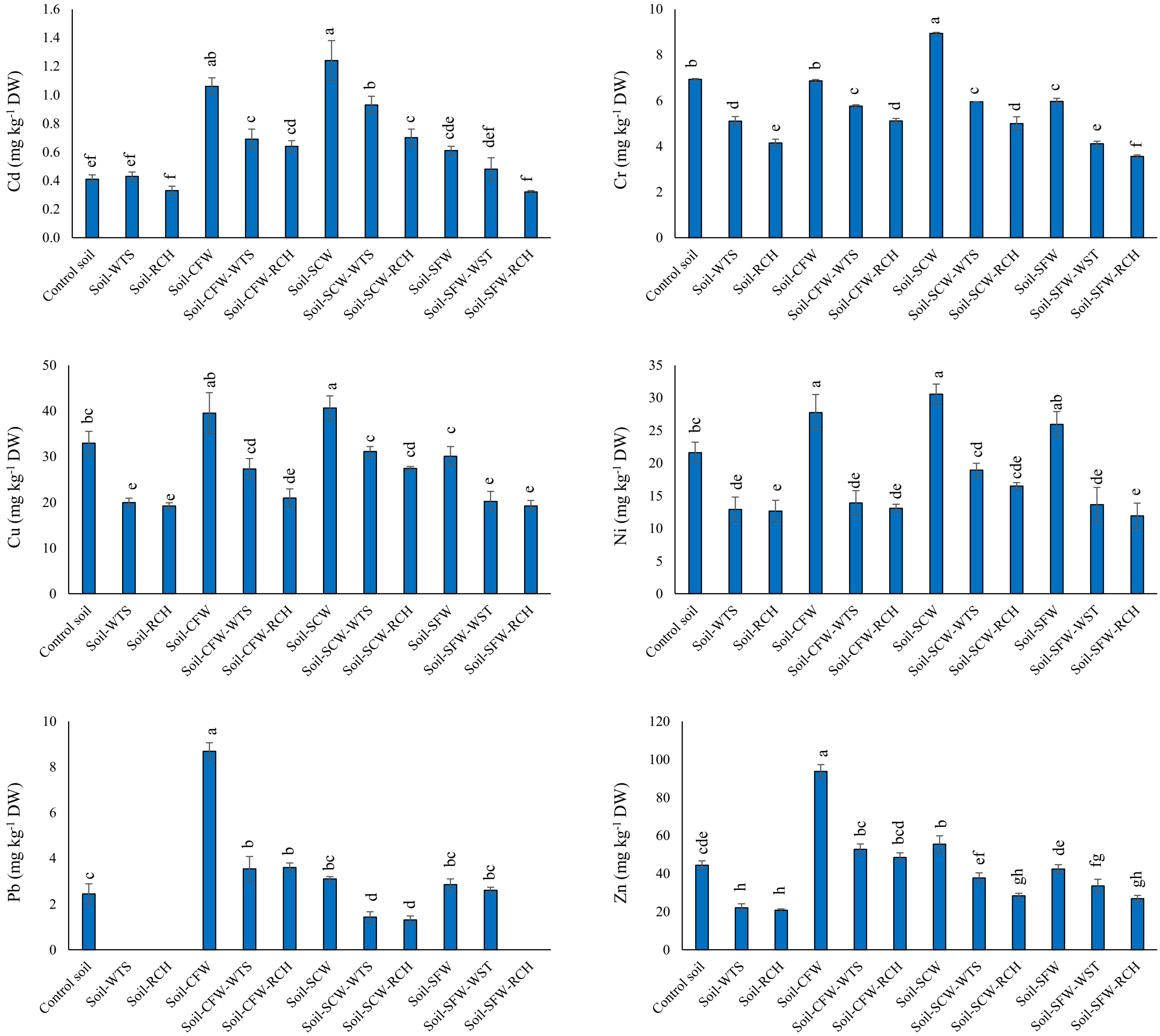


Fig. 4 Heavy metal content in shoot of tomato as affected by industrial solid and organic wastes. WTS wheat straw, RCH rice husk, CFW ceramic factory waste, SCW stone cutting waste, SFW sugar factory waste. Data are means ± SD of three replications. Columns marked with the same letter are not significantly different (Duncan's multiple range test) at the $p < 0.05$ level

obviously reduced by 69.5% and 66.9% in the presence of RCH and WTS, respectively. The findings are in line with the results of above section (The effect of ISWs and organic wastes on heavy metal fractionation), which showed that the addition of organic waste in the soil leads to the conversion of the mobile fraction to the geochemically stable phase of heavy metals in soil. This transformation occurs via sorption, precipitation, and complexation of heavy metals in soils. Immobilization of heavy metals by organic wastes also could be due to different mechanisms such as biological processes, an increase in negative charge (soil effective cation exchange capacity) on the soil surface and the presence of some organic compounds such as cellulose, hemicellulose, and lignin in organic wastes. An increase in adsorption of heavy metals due to the negative charges using RCH was reported by Anda and Shamshuddin (2015). Doan et al. (2008) reported that WTS comprised of about 40% cellulose, which is a natural biopolymer with ion-exchange property. It is documented that RCH contained about 32% cellulose, 21% lignin, 21% hemicellulose, and 20% silica (Chuah et al. 2005). Therefore, the presence of these groups in organic wastes strongly affects heavy metal sorption in the treated soils and reduces their uptake by the plants. According to the results of Fig. 2, the EXC fraction of heavy metals redistributed to other forms following the application of two organic wastes. Farooq et al. (2010) found that the sorption mechanism of heavy metals by WTS comprises a number of mechanisms including adsorption, surface precipitation, ion-exchange and

Table 4 Heavy metal content (mg kg^{-1}DW) in tomato fruits as affected by industrial solid and organic wastes

Treatment	Cd	Cr	Cu	Ni	Zn
Control soil	0.19 ± 0.05 b	1.30 ± 0.1 ab	24.11 ± 2.2 ab	8.41 ± 0.3 a	13.90 ± 0.9 abc
Soil-RCH	ND	ND	9.10 ± 1.0 d	3.65 ± 0.6 c	12.36 ± 0.4 c
Soil-CFW	0.21 ± 0.12 b	1.62 ± 0.1 a	30.11 ± 3.1 a	8.22 ± 0.2 a	14.49 ± 0.5 ab
Soil-CFW-RCH	ND	ND	17.94 ± 2.8 bc	3.50 ± 0.9 c	13.84 ± 0.8 abc
Soil-SCW	0.35 ± 0.09 a	1.49 ± 0.1 ab	31.40 ± 3.0 a	9.15 ± 0.2 a	13.20 ± 0.2 abc
Soil-SCW-RCH	0.20 ± 0.02 b	ND	24.60 ± 2.6 ab	4.32 ± 0.3 bc	10.12 ± 0.1 d
Soil-SFW	0.18 ± 0.03 b	1.10 ± 0.2 b	22.93 ± 2.9 ab	8.54 ± 0.9 a	14.70 ± 0.7 a
Soil-SFW-RCH	ND	ND	10.96 ± 1.9 cd	5.70 ± 0.2 b	12.60 ± 0.6 bc

Data are means ± SD of three replications. Columns marked with the same letter are not significantly different (Duncan's multiple range test) at the $p < 0.05$ level

WTS wheat straw, *RCH* rice husk, *CFW* ceramic factory waste, *SCW* stone cutting waste, *SFW* sugar factory waste, *ND* not detected

complexation. Teixeira Tarley and Zezzi Arruda, (2004) reported that heavy metals sorption on RCH is attributed to adsorption process (ion-exchange or surface complex formation) on the particle surface. Dang et al., (2009) also found that the adsorption of heavy metals by WTS can be considered to be influenced by the chemisorption mechanism.

The results also indicated that the efficient heavy metal immobilization was obtained when RCH was applied in comparison to WTS. For example, the reduction of Cd, Cr, Cu, Ni, Pb, and Zn contents in roots of tomato as a results of RCH and CFW application (Soil-CFW-RCH) was 56.2%, 25.7%, 40.3%, 36.7%, 29.0%, and 16.3%, respectively, in comparison to the CFW-treated soil (Soil-CFW) (Fig. 3). Similarly, the application of WTS in CFW-treated soil (Soil-CFW-WTS) reduced Cd, Cr, Cu, Ni, Pb, and Zn contents by 46.7%, 8.2%, 9.6%, 10.6%, 13.1%, and 9.3% in tomato roots, respectively, as compared to CFW-treated soil (Soil-CFW). A similar trend was observed in other ISWs and heavy metals. Osman et al. (2010) reported that RCH showed higher efficiency in adsorption of heavy metals than WTS. They suggested that the higher adsorption capacity of RCH for removal of heavy metals was probably due to the higher surface area and the presence of silanol (≡Si–OH) groups in the structure of RCH.

In general, the application of RCH improved growth and reduced heavy metal contents in all tissues of tomato as compared to the untreated soil (Figs. 3 and 4 and Tables 3 and 4), which could be mainly due to the increasing soil organic matter, improvement of soil physical and chemical properties, the availability of different nutrients, and the sorption of heavy metals (Osman et al. 2010; Liu et al. 2015).

Plant concentration factor of heavy metals in tomato

Based on the ratios of heavy metal contents in soils and tomato plants, the PCF values of heavy metals were calculated and are shown in Table 6. The average PCF for Cd, Cr, Cu, Ni, Pb, and Zn were 0.52, 0.20, 1.68, 0.58, 0.09, and 1.63, respectively, suggesting that the Cr and Pb are relatively difficult to enter tomato plants from the soil. The transfer of heavy metals from soil to plant was significantly influenced by ISWs and organic waste application. Applications of ISWs resulted in a decrease in the PCF values of all heavy metals (except Cd). Although the addition of ISWs has increased the contents of heavy metals in the tomato plant, the high contents of these metals in ISWs-treated soils have led to a reduction in the PCF values as compared to control soil. Such inverse relationships between heavy

Table 5 Correlation coefficient between different forms of heavy metals in control and treated soils and the heavy metal contents in tomato plant

Heavy metal forms	Heavy metal content in plant					
	Cd	Cr	Cu	Ni	Pb	Zn
Exchangeable	0.938**	0.386	0.594*	0.821**	0.944**	0.960**
Bound to organic matter	− 0.066	0.088	0.129	0.220	0.844**	0.420
Inorganic precipitates	− 0.395	− 0.159	0.358	0.229	0.868**	0.649*
Residual	− 0.395	− 0.159	0.358	0.229	0.640*	0.649*
Total	0.622*	− 0.045	0.376	0.415	0.857**	0.721**

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

Table 6 Plant concentration factor of heavy metals in tomato plant as affected by industrial solid and organic wastes

Treatment	Cd	Cr	Cu	Ni	Pb	Zn
Control soil	0.506 ± 0.04 bcd	0.377 ± 0.01 a	3.995 ± 0.12 a	0.969 ± 0.04 a	0.126 ± 0.01 ab	2.311 ± 0.18 a
Soil-WTS	0.358 ± 0.10 efg	0.263 ± 0.03 b	1.438 ± 0.15 cde	0.552 ± 0.01 d	0.070 ± 0.00 de	1.303 ± 0.20 c
Soil-RCH	0.339 ± 0.05 fg	0.211 ± 0.05 bcd	1.579 ± 0.20 cd	0.495 ± 0.04 def	0.043 ± 0.00 e	1.335 ± 0.14 c
Soil-CFW	0.930 ± 0.01 a	0.275 ± 0.03 b	3.259 ± 0.24 b	0.849 ± 0.03 b	0.148 ± 0.01 a	1.996 ± 0.23 b
Soil-CFW-WTS	0.486 ± 0.02 cde	0.183 ± 0.01 de	1.639 ± 0.08 cd	0.533 ± 0.01 de	0.101 ± 0.02 bcd	1.401 ± 0.18 c
Soil-CFW-RCH	0.409 ± 0.02 defg	0.154 ± 0.06 def	1.710 ± 0.05 c	0.450 ± 0.07 def	0.084 ± 0.00 cd	1.350 ± 0.27 c
Soil-SCW	0.884 ± 0.13 a	0.251 ± 0.03 bc	1.143 ± 0.03 def	0.709 ± 0.08 c	0.111 ± 0.02 abc	1.963 ± 0.32 b
Soil-SCW-WTS	0.564 ± 0.05 bc	0.149 ± 0.01 def	0.650 ± 0.06 f	0.415 ± 0.01 ef	0.093 ± 0.00 bcd	1.427 ± 0.15 c
Soil-SCW-RCH	0.475 ± 0.07 cdef	0.114 ± 0.01 f	0.836 ± 0.11 f	0.397 ± 0.02 f	0.069 ± 0.00 de	1.433 ± 0.09 c
Soil-SFW	0.633 ± 0.01 b	0.190 ± 0.20 cd	1.958 ± 0.17 c	0.778 ± 0.08 bc	0.127 ± 0.00 ab	2.025 ± 0.46 b
Soil-SFW-WST	0.367 ± 0.02 defg	0.122 ± 0.01 ef	0.944 ± 0.14 ef	0.369 ± 0.02 f	0.119 ± 0.01 abc	1.545 ± 0.05 c
Soil-SFW-RCH	0.271 ± 0.03 g	0.104 ± 0.00 f	1.040 ± 0.06 ef	0.391 ± 0.01 f	0.070 ± 0.00 de	1.510 ± 0.12 c

Columns marked with the same letter are not significantly different (Duncan's multiple range test) at the $p < 0.05$ level

WTS wheat straw, *RCH* rice husk, *CFW* ceramic factory waste, *SCW* stone cutting waste, *SFW* sugar factory waste

metal contents in soils and PCF were also reported by Wang et al. (2006). Moreover, organic wastes exhibited a significant decrease in the values of PCF in tomato plants. For example, as compared to CFW-treated soils (Soil-CFW), the decreasing trend in PCF values for Cd, Cr, Cu, Ni, Pb, and Zn was 56%, 44%, 48%, 47%, 43%, and 32%, respectively, in CFW-RCH-treated soils. Hamid et al. (2018) reported that the organic amendments restrict the transfer of metals from soil to roots.

Estimated daily intake and health risk index of heavy metals

The results of EDI and HRI for both adults and children are shown in Table 7. The highest intakes and potential risk of heavy metals were from the consumption of tomato grown in ISW-treated soils for both adults and children (Cd, Cu, and Ni in Soil-SCW; Cr in Soil-CFW; and Zn in Soil-SFW treatments). On the other hand, the EDI and HRI values decreased with the application of organic wastes, suggesting that organic wastes could decrease health risk for populations through tomato consumption grown in areas contaminated by ISWs.

In general, the amount of ORD is a value of daily oral exposure to the human population that is probably to be without an appreciable risk of deleterious effects during a lifetime. In this study, the EDI level of heavy metals for both adults and children through the consumption of tomato in all treatments was lower than the ORD limit suggested by the US-EPA, IRIS (except the daily intake of Cu in Soil-CFW and Soil-SCW treatments). The HRI mean values of Cd, Cr, Cu, Ni, and Zn were 0.348, 0.001, 0.824, 0.496, and 0.068, respectively, for adults, while were 0.374, 0.0007, 0.886, 0.533, and 0.073, respectively, for children. Therefore, Cu, Ni, and Cd contamination in tomato plants had the greatest potential to pose a health risk to the consumers. The data indicated that in all treatments and heavy metals, the HRI values were < 1. It suggests that in these industrial areas, potential health risks by intake of heavy metals from tomato for both adults and children are generally assumed to be safe.

In general, the results of EDI and HRI suggest that the health risk of heavy metals in soil contaminated with CFW, SCW, and SFW is higher than untreated soil. It should be noted that, although contaminated soil with ISWs is free of risks, there are other sources of metal exposures such as dust, dermal contact, and the eating of metal contaminated soils by children, which were not studied in this study.

In general, the addition of ISWs to soil increased heavy metal availability and the application of organic wastes in contaminated soils with ISWs can be an appropriate management method for ameliorating these soils, heavy metals immobilization, and reducing the heavy metal contents in plants. Additionally, careful research needs to be conducted on the different technologies for reducing heavy metals, the effect of organic wastes/soil ratios on plant growth, the mechanisms of their uptake, and the long-term effects of wastes on plant growth at the field scale.

Conclusion

The results of this study showed that the addition of CFW and SCW to soil resulted in increase in all fractions of heavy metals, which can be attributed to the high heavy metal contents in these wastes. An increase in the root, shoot, and fruit dry weight was significantly higher in the presence of SFW, but the addition of CFW and SCW to soil significantly decreased tomato yield and increased heavy metal contents in different parts of the tomato. Decreasing of plant biomass may

Table 7 Estimated daily intake (EDI) (mg kg^{-1} day^{-1}) and health risk index (HRI) of heavy metals in response to different industrial and organic wastes

Treatment	Cd		Cr		Cu		Ni		Zn	
	EDI	HRI	EDI	HRI	EDI	HRI	EDI	HRI	EDI	HRI
Adult										
Control soil	0.00029	0.293	0.002	0.001	0.037	0.929	0.013	0.648	0.021	0.071
Soil-RCH	–	–	–	–	0.014	0.351	0.006	0.281	0.019	0.064
Soil-CFW	0.00032	0.324	0.002	0.002	0.046	1.161	0.013	0.634	0.022	0.074
Soil-CFW-RCH	–	–	–	–	0.028	0.691	0.005	0.270	0.021	0.071
Soil-SCW	0.00054	0.540	0.002	0.002	0.048	1.210	0.014	0.705	0.020	0.068
Soil-SCW-RCH	0.00031	0.308	–	–	0.038	0.948	0.007	0.333	0.016	0.052
Soil-SFW	0.00028	0.278	0.002	0.001	0.035	0.884	0.013	0.658	0.023	0.076
Soil-SFW-RCH	–	–	–	–	0.017	0.422	0.009	0.439	0.019	0.065
Children										
Control soil	0.00031	0.315	0.002	0.001	0.040	0.998	0.014	0.697	0.023	0.077
Soil-RCH	–	–	–	–	0.015	0.377	0.006	0.302	0.020	0.068
Soil-CFW	0.00035	0.348	0.003	0.002	0.050	1.247	0.014	0.681	0.024	0.080
Soil-CFW-RCH	–	–	–	–	0.030	0.743	0.006	0.290	0.023	0.076
Soil-SCW	0.00058	0.580	0.002	0.002	0.052	1.300	0.015	0.758	0.022	0.073
Soil-SCW-RCH	0.00033	0.331	–	–	0.041	1.019	0.007	0.358	0.017	0.056
Soil-SFW	0.00030	0.298	0.002	0.001	0.038	0.950	0.014	0.707	0.024	0.081
Soil-SFW-RCH	–	–	–	–	0.018	0.454	0.009	0.472	0.021	0.070

WTS wheat straw, *RCH* rice husk, *CFW* ceramic factory waste, *SCW* stone cutting waste, *SFW* sugar factory waste

be attributed to heavy metal toxicity for plants and deficiency of macronutrients, which results from an inhibition of their uptake under heavy metal exposure. Application of RCH resulted in an improvement for tomato growth, while the addition of WTS to soil significantly reduced the dry weight of tomato plants that may be explained by increased concentration of allelochemicals or their compound in the presence of WTS. On the other hand, the application of both organic wastes significantly reduced the mobile fraction of heavy metals in control and ISW-treated soils and consequently in different parts of tomato plants. The highest HRI values of heavy metals were from the consumption of tomato grown in ISW-treated soils. Additionally, PCF and HRI of heavy metals were lesser when organic wastes, especially RCH, were applied to the soil.

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