Int J Recycl Org Waste Agricult (2017) 6:367–373
https://doi.org/10.1007/s40093-017-0178-2

SHORT COMMUNICATIONS

Evaluation of nineteen food wastes for essential and toxic elements

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Received: 11 April 2017 / Accepted: 4 October 2017 / Published online: 9 October 2017

Abstract

Purpose The study evaluates and provides an overview of the nutritional importance of 19 selected food wastes as aids in human/livestock/soil/plant health.

Methods Nitric acid-digested extracts of food wastes belonging to four different classes (fruits, vegetables, oilseeds and beverages) were analysed for different elements in an inductively coupled plasma mass spectrometer.

Results Our study recommends spent coffee grounds, tea leaves, radish peel, watermelon rind and pineapple skin that contain substantially high concentrations of essential elements such as N, P, K, S and Fe for their use as: (a) substrates for composting, (b) biofertilizers, (c) soil amendments, and (d) bioadsorbents of toxins. Although these food wastes are rich in essential nutrients, we do not suggest them for the preparation of food supplements as they contain non-essential elements in concentrations beyond the human safety limits. However, food wastes like banana peel, plum pomace and pistachio shell that contain low and permissible concentrations of toxic elements can be recommended as dietary supplements for oral intake in spite of their lesser essential elemental composition than the other residues examined.

Conclusions Our study confirms that food wastes are rich sources of essential nutrients and there is need to harness their real industrial systems.

Keywords Food wastes · Nutrients · Essential elements · Waste management

Introduction

Global food production is estimated to be 6273 million tonnes per annum, of which one-third (2375 million tonnes) is contributed by cereals followed by fruits and vegetables (1600 million tonnes). Around 60% of the total food produced is lost or wasted so that the final household consumption accounts for only 2438 million tonnes per annum. This waste is an ample portion of the food that can feed the estimated 3 billion starving people in the world. Food losses are paramount in industrialized Asian and European countries in addition to South and Southeast Asia. Nearly 14% of the greenhouse gas emission is from the food waste (Gustavsson et al. 2011). As the accumulation of food wastes is detrimental to the environment, concerns are rising and there is a need to develop eco-friendly technologies for the minimization of food wastes. In addition, according to an UN estimate, by 2050 the mass of global food waste will increase even further as food production is expected to increase by 70% (FAO 2013). Hence, governments as well as international organizations are currently focusing more on waste management issues. In recent days, efforts have been made to transform food

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wastes into products of commercial utility as they are very rich in bioactive compounds such as vitamins, minerals, amino acids and polyphenols. Among these bioactive compounds, some essential mineral elements play an important role as cofactors in many enzymatic processes involved in humans, plants, animals and soil microbes (Kuppusamy et al. 2015).

Industries and households are the major sources of food wastes. Detailed studies of the food wastes originating from these two sources, especially from households, are meagre. With this in mind, the study reported here mainly focused on household food wastes along with some common industrial wastes such as pomace and pulp from agricultural by-products. Fruits, vegetables, oilseeds and beverages are the commodity groups that contribute to the major share of the food wastes. These four classes of food wastes were considered for evaluation in the present study as they contribute particularly large quantities of essential elements. Apart from essential elements, food wastes are expected to contain traces of toxic elements which may or may not be within human health or environmental permissible limits. Information on the detailed toxicological profile of the most common food wastes such as butternut peel, onion peel, watermelon rind, radish peel, pineapple skin, strawberry pomace, plum pomace and pistachio shell is so far not reported in the literature. The available literature shows only the utilization of food wastes, but not their full elemental composition. Since such information would facilitate their effective utilization, the primary objective of our study was to evaluate and provide an overview of the nutritional importance of 19 selected food wastes as aids in human/livestock/soil/plant health.

Materials and methods

Samples of food wastes

The food materials investigated were the wastes of 19 types of fruits, vegetables, oilseeds and beverages procured from local markets in South Australia. Five copies of each waste collected from same market have been analysed. Orange (*Citrus sinensis* (L.) Osbeck), watermelon (*Citrullus lanatus* (Thunb.) var. *lanatus*), honeydew (*Cucumis melo* L.), banana (*Musa paradisiaca* L.), butternut (*Cucurbita moschate* Duchesne ex Poir.), pineapple (*Ananas comosus* (L.) Merr.), potato (*Solanum tuberosum* L.), onion (*Allium cepa* L.), radish (*Raphanus sativus* subsp. *sativus* (L.) Domin), pistachio (*Pistacia vera* L.) and peanut (*Arachis hypogaea* L.) samples were cleaned, manually peeled, and the peels/rinds/skin/shell cut into small pieces and dried in a temperature-controlled room (37 °C) for 2 weeks. Subsequently, apple (*Malus domestica* Borkh.), strawberry (*Fragaria ananassa* Duchesne), plum (*Prunus domestica* L.), grape (*Vitis vinifera* L.), carrot (*Daucus carota* L.), and olive (*Olea europaea* L.) were grated, homogenised and filtered for separating the juice. The pomace or pulp left after juice extraction was dried in a forced air oven at 40 °C for 72 h. Similarly, spent coffee grounds (*Coffea arabica* L.) and tea (*Camellia sinensis* (L.) Kuntze) leaves were also dried. After complete drying, the samples were finely ground to a particle size of approximately 0.5 mm with a coffee grinder and were stocked in sealable polythene bags in a desiccator until further use.

Digestion and analysis for total metals

Elemental composition (except C and N) of the selected food wastes was analysed in digests after sample decomposition in nitric acid. About 0.5 g of the sample was digested with 5 mL of 70% conc. HNO_3 in a Teflon digestion vessel using a microwave accelerated reaction system (CEM-MARS X®) according to US EPA method 3015a. After digestion, the residue was diluted with 50 mL of the deionized water and filtered through 0.45 µm filter. A 10 mL diluted aliquot was analysed for different elements in an Agilent 7500c (Agilent Technologies, Tokyo, Japan) inductively coupled plasma mass spectrometer (ICP-MS) using a modified method described by Das et al. (2002). Another 0.5 g of the dry ground sample was used for total C and N analysis using a Trumac (Leco® Corporation, Michigan, USA) Carbon–Nitrogen–Sulphur analyser (CNS analyser). All samples were assayed in triplicate, and the data are expressed on dry weight of the samples.

Statistical analysis

All experimental data are presented as mean values of three observations with their corresponding standard deviations. Differences between means were tested for significance by one-way ANOVA with Tukey's test using SPSS (Statistical Program for Social Sciences, IBM® Corporation, USA) statistical software v.20. Differences at the $P < 0.05$ were considered to be significant.

Results and discussion

Figure 1 and Table 1 shows the results of chemical analyses of the macroelements present in the selected food wastes. Of the 19 food wastes considered, beverage wastes stood out clearly from the others for their high macroelemental content (554–556 mg g^{-1} dry wt.) followed by oilseeds (473–519 mg g^{-1}) and fruits (428–516 mg g^{-1}) (Fig. 1). Vegetable wastes had the lowest values ranging from 438 to 488 mg g^{-1} sample. Spent coffee grounds and

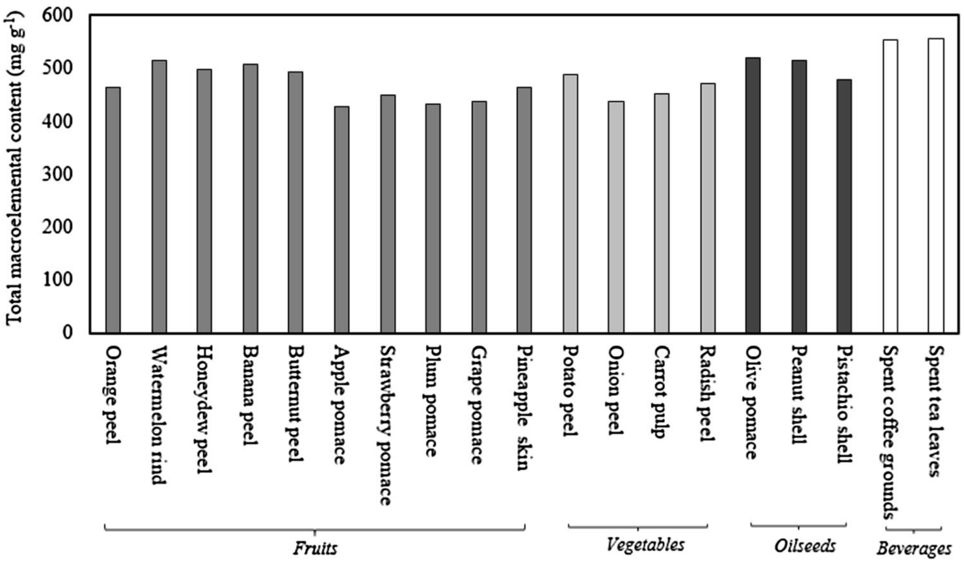

Fig. 1 Concentration of total macroelements (dry weight basis) in different food wastes

Table 1 Concentrations (mg g^{-1} dry weight) of macroelements in different food wastes

Food class and waste	Primary macroelements				Secondary macroelements			
	C	N	P	K	Ca	Mg	S	Na
a. Fruits								
Orange peel	433.7 ± 32	8.5 ± 1.2	1.1 ± 1.5	10.2 ± 3.8	8.5 ± 2.1	0.7 ± 2.2	0.5 ± 1.6	0.7 ± 4
Watermelon rind	373.4 ± 12	42.2 ± 2.6	10.7 ± 1.0	73.4 ± 1.5	6.3 ± 2.4	3.8 ± 2.7	4.5 ± 1.3	1.6 ± 2.8
Honeydew peel	430.5 ± 11	16.0 ± 1.5	4.8 ± 1.1	37.0 ± 1.6	1.8 ± 1.6	3.6 ± 0.1	1.8 ± 1.7	2.0 ± 3.8
Banana peel	426.1 ± 86	9.9 ± 1.8	1.9 ± 1.5	65.2 ± 4.2	2.6 ± 1.1	1.5 ± 0.1	0.4 ± 1.2	0.05 ± 3.2
Butternut peel	427.4 ± 21	27.7 ± 2.3	6.2 ± 1.2	24.7 ± 3.2	2.7 ± 1.1	3.1 ± 0.5	1.4 ± 1.6	0.01 ± 3.6
Apple pomace	414.4 ± 26	4.1 ± 1.5	0.8 ± 1.6	8.2 ± 4.1	0.2 ± 4.3	0.3 ± 2.4	0.2 ± 1.9	0.04 ± 5.8
Strawberry pomace	432.2 ± 52	2.9 ± 1.6	0.7 ± 1.6	7.5 ± 1.1	2.7 ± 1.9	1.2 ± 2.9	0.3 ± 1.6	0.8 ± 1.4
Plum pomace	413.7 ± 59	3.7 ± 1.1	1.2 ± 5.0	11.5 ± 1.4	0.2 ± 1.4	0.4 ± 2.9	0.1 ± 1.1	0.6 ± 2.6
Grape pomace	415.0 ± 29	5.9 ± 0.8	1.1 ± 2.8	13.3 ± 1.9	0.8 ± 1.3	0.5 ± 4.6	0.4 ± 1.5	0.02 ± 2.2
Pineapple skin	446.2 ± 31	12.8 ± 1.1	0.1 ± 1.4	0.5 ± 1.9	2.2 ± 1.9	0.7 ± 3.2	0.6 ± 1.1	0.9 ± 2.0
b. Vegetables								
Potato peel	420.2 ± 61	22.2 ± 1.3	3.2 ± 1.8	34.8 ± 1.2	1.2 ± 4.2	1.2 ± 1.9	1.6 ± 1.1	3.6 ± 1.2
Onion peel	410.2 ± 59	3.4 ± 1.1	0.2 ± 1.6	2.5 ± 1.8	12.9 ± 1.2	2.8 ± 2.3	0.9 ± 1.2	4.8 ± 5.2
Carrot pulp	402.3 ± 82	10.0 ± 2.3	3.3 ± 2.9	23.4 ± 1.1	2.8 ± 2.6	1.3 ± 2.2	0.8 ± 1.2	9.0 ± 1.1
Radish peel	367.4 ± 22	39.9 ± 1.5	6.9 ± 1.6	39.6 ± 1.2	5.5 ± 1.2	2.6 ± 1.5	6.9 ± 1.1	2.2 ± 3.2
c. Oilseeds								
Olive pomace	473.9 ± 18	11.2 ± 2.0	2.0 ± 1.3	28.6 ± 2.1	1.7 ± 1.6	0.9 ± 1.6	0.8 ± 1.9	0.3 ± 1.6
Peanut shell	473.8 ± 90	6.8 ± 1.3	2.5 ± 1.6	26.7 ± 1.6	1.5 ± 1.2	0.8 ± 1.9	1.8 ± 1.2	0.3 ± 1.3
Pistachio shell	467.1 ± 32	5.0 ± 0.5	0.05 ± 1.8	1.4 ± 1.9	0.3 ± 1.5	0.06 ± 1.7	0.09 ± 1.2	5.3 ± 2.1
d. Beverages								
Spent coffee grounds	524.1 ± 41	21.6 ± 1.0	0.7 ± 1.9	3.9 ± 1.5	1.1 ± 1.9	1.1 ± 1.2	0.8 ± 1.0	0.1 ± 0.9
Spent tea leaves	494.8 ± 21	36.1 ± 0.2	2.6 ± 1.1	6.4 ± 1.9	11.6 ± 1.3	1.3 ± 1.9	1.8 ± 2.1	1.5 ± 0.2

Values are mean ± standard deviation ($n = 3$)

onion peel, followed by watermelon rind were also observed to contain substantial levels of macronutrients and could be used as nutrient-rich feed additives for livestock or as dietary supplements for humans. The lowest concentrations of macroelements were detected in apple and plum pomace (428 and 431 mg g^{-1}, respectively).

The order of elemental concentrations in the food wastes was $C > K > N > Ca > P > Na > Mg > S$ (Table 1).

Clearly, there exists a significant variability in the elemental composition of different food wastes tested. These substantial differences in the elemental composition of food wastes strongly account for their distinct beneficial activities when exploited. The highest levels of C were found in spent coffee grounds and tea leaves. Caetano et al. (2012) observed a similar C content for spent coffee grounds. These wastes can be used as substrates in fermentations, compost or biofertilizer preparations to stimulate the growth of microbes involved in those processes, as C is the most significant element that accelerates microbial activity and diversity.

Watermelon rind recorded the maximum NPK concentrations followed by radish peel. Both were also observed to be the rich sources of Mg and S. These food wastes can be applied as soil amendments as they could possibly elevate limiting soil nutrients such as N, P, K and S. A dual role of increasing soil health by nutrient cycling as well as reducing the cost involved in the agricultural production by replacing the use of synthetic fertilizers with these natural wastes could be achieved. This could also be an economically sound waste management strategy. The highest Ca and Na concentrations were found in onion (12.9 ± 1.2 mg g^{-1}) and carrot (9.0 ± 1.1 mg g^{-1}) peel. Pistachio shell had low concentrations of K and Mg. Further, the least Ca and S concentrations were found in apple and plum pomaces. The Ca content reported by Er and Ozcan (2010) for apple pomace was 31 × higher than our observations made in the present analysis. A similar report with threefold higher Ca values was made by Joshi and Attri (2006). The variability in the elemental composition among the food wastes can be attributed to the different digestion methods, and also to dissimilar varieties and harvest season of the samples analysed by us, as these parameters affect the accumulation of the mineral elements in plant parts.

The data on concentrations for the essential trace and toxic elements in the selected fruit, vegetable, oilseed and beverage wastes are presented in Table 2 and Fig. 2. The trace elements in the food wastes decreased in the order: Fe > Mn > Cu > Zn > Cr > Ni > Co. In general, the concentration of essential trace elements in the wastes ranged from 9 to 635, 20–552, 1–106 and 60–632 mg kg^{-1} for fruit, vegetable, oil seed and beverage (Fig. 2a), respectively, and this trend are quite similar to that observed for the total macronutrient concentrations. Of the 19 food wastes considered, pineapple skin and spent tea leaves were shown to contain the highest amounts of essential trace elements, whereas pistachio shell and apple pomace had the least. Spent tea leaves are a rich source of most of the essential trace elements including Mn, Ni, and Cr (295 ± 28, 5 ± 1.5, and 21 ± 3 mg kg^{-1}, respectively) (Table 2). One of the significant findings of our study is that the prime sources of Fe among the food wastes are pineapple skin and radish peel (with 13–67 × higher values than the other food residues tested). Radish peel was also observed to be a rich source of Cu and Co (46 ± 3.2 and 0.5 ± 1 mg kg^{-1}, respectively). Er and Ozcan (2010) found somewhat different concentrations of essential trace element for the apple pomace than our present values. The only report available in the literature (Mussatto et al. 2011) for the essential trace element composition of spent coffee grounds is 20 × lower than the data reported in our study.

In general, toxic/non-essential elements have no biological role and it is necessary to determine their levels before recommending as natural resources for utility. For this group of elements, most of the food wastes contained Al followed by Pb, Cd and As. Pineapple skin tended to accumulate Al ($590 \pm$ mg kg^{-1}), As (0.2 ± 0.1 mg kg^{-1}) and Pb (6.4 ± 2.1 mg kg^{-1}). The highest concentrations of As were also found in apple pomace (0.2 ± 0.1 mg kg^{-1}) (Table 2). Also, Cd was high in olive pomace (2.9 ± 1.6 mg kg^{-1}). The total toxic metal contents were high in pineapple skin (597 mg kg^{-1}) followed by spent tea leaves (568 mg kg^{-1}) (Fig. 2b). However, no traces of toxic metals were detected in pistachio shell, so it might be safe to use as an additive while preparing human/livestock feeds from this waste material. Reports are not available in the literature to compare the above data as toxicity of the food wastes has so far been unexplored in the detailed way as in our study.

It was observed that the toxic metal and metalloid concentrations were generally above the tolerable monthly intake levels for most of the food wastes (WHO 2015). These toxic elements might have come from the soil as the soils from where these food crops grew may have been polluted. Also, the results of the study reveal that the peels/rinds/skin/pulp or pomace of food components tend to preferentially accumulate the toxic elements and it is thus a safer practice in our day-to-day life to discard them without consumption. However, their bioavailability depends on the acidity. When food wastes are formulated by following a certain process, by maintaining the alkalinity, the toxic elements can be rendered non-bioavailable. The ranges found in our study are high only with regard to the monthly intake level (2 mg kg^{-1} for Al; 21 µg kg^{-1} for As and Pb; 25 µg kg^{-1} for Cd) (WHO 2015), and are not barred from consumption. Hence, one can formulate dietary supplements or nutritive additives combining two or more wastes so that their toxic elemental level is kept below regulatory health limits. It is noteworthy that banana peel, plum pomace and pistachio shell had toxic elemental concentrations below the human intake limits. Therefore, these three wastes are perceived to be ecologically safe for human/livestock utility. On the other hand, the concentration of toxic metals and metalloids (As, Cd and Pb) were below the environmental safety limits (NEPM 2011). The ubiquitous element, Al, which was detected at higher

Table 2 Concentrations (mg kg^{-1} dry weight) of trace and toxic elements in food wastes

Food class and waste	Essential trace elements							Toxic/non-essential trace elements			
	Mn	Cu	Zn	Fe	Ni	Co	Cr	Al	As	Cd	Pb
a. Fruits											
Orange peel	4.2 ± 1.2	2.1 ± 2.2	BDL	19.5 ± 0.3	0.1 ± 2.0	BDL	0.1 ± 2	7.5 ± 1.0	BDL	BDL	BDL
Watermelon rind	34.2 ± 5.2	9.0 ± 1.2	BDL	45.4 ± 0.1	2.0 ± 2.9	0.02 ± 1.4	0.3 ± 1.1	3.2 ± 0.3	BDL	0.01 ± 0.2	BDL
Honeydew peel	19.3 ± 2.1	4.1 ± 1.6	BDL	34.1 ± 0.1	0.3 ± 1.9	0.05 ± 2.3	BDL	10.8 ± 0.2	0.06 ± 0.4	0.07 ± 1.1	BDL
Banana peel	70.3 ± 1.1	2.1 ± 2.2	BDL	15.4 ± 0.1	BDL	BDL	BDL	1.1 ± 1.1	BDL	BDL	BDL
Butternut peel	21.9 ± 1.9	2.8 ± 3.8	39.6 ± 4.0	44.8 ± 0.9	0.3 ± 2.9	0.05 ± 0.2	BDL	4.9 ± 1.9	BDL	BDL	BDL
Apple pomace	2.4 ± 2.8	1.0 ± 5.0	BDL	5.2 ± 0.1	BDL	BDL	BDL	0.04 ± 1.2	0.2 ± 0.1	0.01 ± 0.5	BDL
Strawberry pomace	3.3 ± 1.7	1.3 ± 4.1	BDL	27.1 ± 0.1	0.3 ± 0.2	BDL	BDL	18.9 ± 0.6	0.004 ± 0.9	0.02 ± 0.2	BDL
Plum pomace	2.8 ± 0.06	2.3 ± 1.8	BDL	9.0 ± 3.1	0.03 ± 0.1	BDL	BDL	2.4 ± 2.4	BDL	BDL	BDL
Grape pomace	6.6 ± 1.2	2.0 ± 0.9	BDL	12.6 ± 2.2	0.3 ± 0.1	BDL	BDL	4.9 ± 4.5	BDL	0.01 ± 1.1	BDL
Pineapple skin	9.5 ± 0.2	4.5 ± 2.1	12.3 ± 2.6	604.3 ± 3.2	1.9 ± 0.9	0.3 ± 1.7	2.6 ± 0.8	590.3 ± 7.1	0.2 ± 0.1	0.04 ± 2.8	6.4 ± 2.1
b. Vegetables											
Potato peel	8.3 ± 3.2	2.7 ± 1.9	BDL	25.2 ± 0.1	0.02 ± 2.2	0.06 ± 2.0	BDL	5.8 ± 0.6	BDL	0.6 ± 0.3	BDL
Onion peel	59.3 ± 2.3	0.8 ± 1.6	BDL	27.0 ± 0.2	0.03 ± 1.0	BDL	BDL	18.4 ± 0.1	BDL	0.4 ± 1.5	BDL
Carrot pulp	4.6 ± 3.6	2.4 ± 2.6	BDL	11.2 ± 0.1	1.5 ± 1.9	BDL	BDL	BDL	0.05 ± 1.2	0.1 ± 1.9	BDL
Radish peel	25.1 ± 2.2	46.5 ± 3.2	BDL	477.1 ± 5.1	1.9 ± 0.5	0.5 ± 1.0	1.3 ± 1.9	469.5 ± 1	0.1 ± 0.4	0.08 ± 0.2	BDL
c. Oilseeds											
Olive pomace	5.3 ± 2.1	5.9 ± 0.5	BDL	29.1 ± 6.1	0.8 ± 0.02	BDL	BDL	344.7 ± 7.5	0.1 ± 1.2	2.9 ± 1.6	BDL
Peanut shell	53.9 ± 8.2	2.2 ± 1.2	BDL	48.2 ± 1.8	0.9 ± 1.2	0.04 ± 0.1	1.2 ± 0.6	20.5 ± 3.9	BDL	BDL	0.2 ± 0.5
Pistachio shell	0.6 ± 0.03	0.3 ± 0.9	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
d. Beverages											
Spent coffee grounds	19.8 ± 3.4	9.1 ± 0.8	BDL	30.7 ± 0.6	0.4 ± 0.09	0.01 ± 0.4	BDL	38.5 ± 2.7	BDL	0.03 ± 0.9	BDL
Spent tea leaves	295.0 ± 28	9.7 ± 1.6	BDL	301.7 ± 1.3	4.9 ± 1.5	0.2 ± 0.9	20.9 ± 3.2	567.8 ± 4.9	BDL	0.04 ± 1.1	0.1 ± 0.8

Values are mean ± standard deviation ($n = 3$). *BDL* Below detection limit of ICPMS (Zn = 0.2 μg L^{-1}; Fe = 50 μg L^{-1}; Ni = 0.3 μg L^{-1}; Co = 0.1 μg L^{-1}; Cr = 1 μg L^{-1}; Al = 0.7 μg L^{-1}; As = 0.1 μg L^{-1}; Cd = 0.1 μg L^{-1}; Pb = 0.1 μg L^{-1})

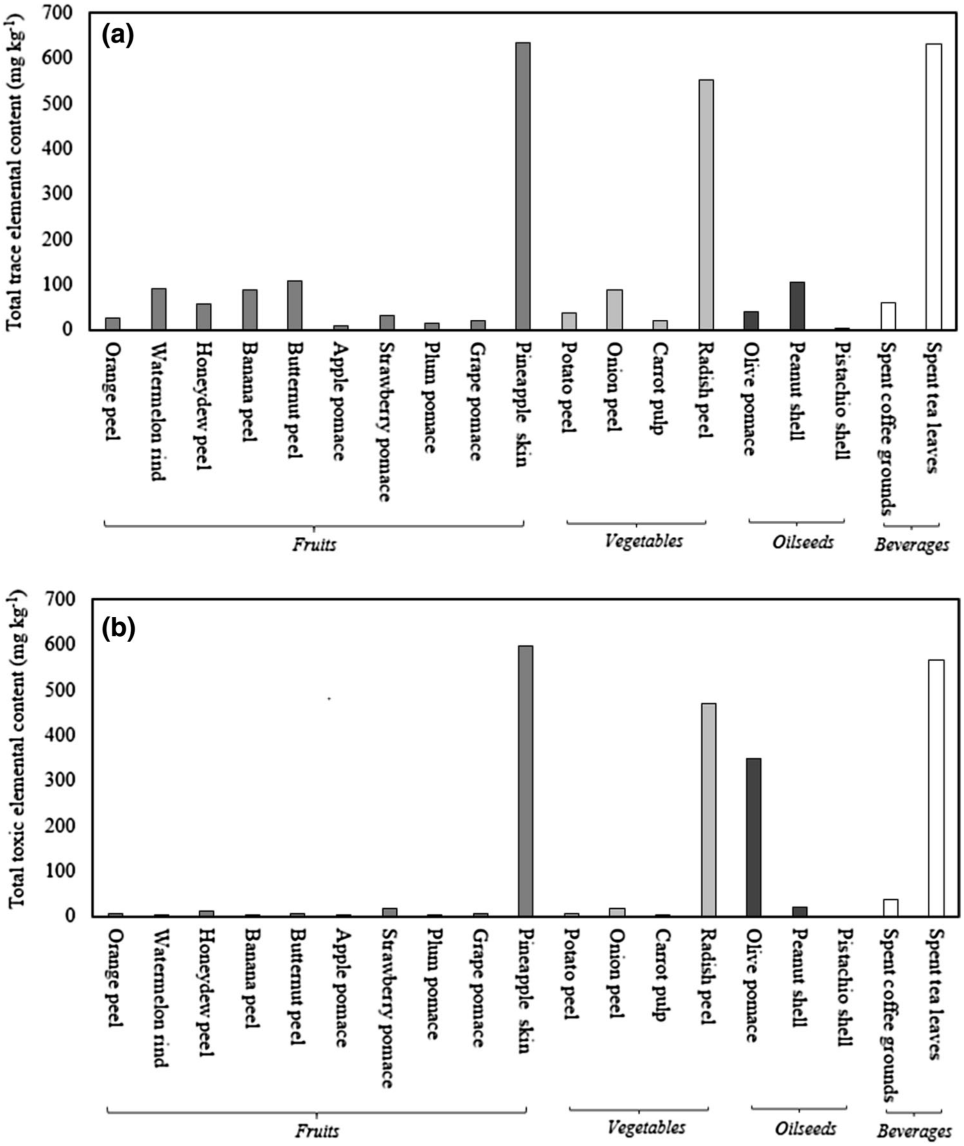

Fig. 2 Concentration of total trace (**a**) and toxic (**b**) elements (dry weight basis) in different food wastes

concentrations, only becomes available to plants when the soil pH falls below 5.5. This would be unusual as the soil most suited for crop production is managed to be a circumneutral pH (Silva 2012). The food wastes screened in this study could, therefore, be used as amendments to upgrade soil fertility and crop productivity (Pellejero et al. 2017; Fidelis and Rao 2017). Apart from the agro sectors, food wastes can even be used in the environmental remediation sector as bioadsorbents of toxic pollutants (Kuppusamy et al. 2015, 2016a, b, 2017).

Conclusion

Our study confirms that food wastes are rich sources of essential nutrients and the need of the hour is to harness the potential of these natural resources in real industrial systems. Hopefully, the result of this study will help other researchers to further understand the essential macronutrient composition of commonly available food wastes, especially those newly reported. This study should form a basis to selectively identify the most appropriate nutrient-rich, less toxic food wastes. Furthermore, research is recommended for the food wastes that are confirmed to be the best nutritive sources to extend their exploitation in the agro-food and pharmaceutical sectors and so avoid treating them as landfill wastes. Such studies should identify the cumulative effects of individual or mixtures of food wastes on soil and plant health when used as soil amendments as well as in the remediation of soil toxicities. Future work could also focus on the extraction of novel nutrient-rich bioactive compounds from the food wastes suitable for human consumption.

Acknowledgements The authors acknowledge the Australian government in association with Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) for the International Postgraduate Research Scholarship and CRC CARE top-up fellowship.

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