Biological Trace Element Research (2020) 198:303–314
https://doi.org/10.1007/s12011-020-02048-4

Elemental Distribution and Health Risk Assessment of the Edible Fruits of Two *Ficus* Species, *Ficus sycomorus* L. and *Ficus burtt-davyi* Hutch

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Received: 20 November 2019 / Accepted: 15 January 2020 / Published online: 21 January 2020

Abstract

Edible fruits of two indigenous medicinal *Ficus* species (*Ficus sycomorus* L. and *Ficus burtt-davyi* Hutch) collected from eight different sites in South Africa were assessed for nutritional value, elemental concentration, and the possible risk associated with their consumption. The metal concentrations in the fruits and growth soil were determined by inductively coupled plasma-optical emission spectrometry (ICP-OES). The results showed elemental concentrations in the fruits to contribute significantly to recommended dietary allowances and were found to be in decreasing order of Ca > Mg > Fe > Zn > Mn > Cu > Cr and Ca > Mg > Fe > Mn > Zn > Cu for both *F. sycomorus* and *F. burtt-davyi* fruits. The results for proximate composition of *F. sycomorus* fruits were (in %) 55.8 for moisture, 25.3 for carbohydrates, 5.6 for protein, 8.9 for fats, 55.8 for crude fiber, and 4.4 for ash; for *F. burtt-davyi* fruits, it was (in %) 78.9 for carbohydrates, 5.0 for protein, 8.4 for lipids, 4.0 for crude fiber, and 3.7 for ash. The health risk assessment showed target hazard quotient, and hazard indices for all the studied heavy metals in the fruits for all the sites were to be less than one and the target carcinogenic risk values to be within the acceptable regulatory cancer risk range. This study confirms that the fruits of *F. sycomorus* and *F. burtt-davyi* are safe for human consumption due to low non-carcinogenic and carcinogenic adverse health effects.

Keywords Heavy metals · *Ficus sycomorus* L · *Ficus burtt-davyi* hutch · Recommended dietary allowance · Human health risks

Introduction

Trees have been an essential part of human survival from the earliest time, providing basic needs such as shelter, firewood, medicine, and food. The use of indigenous plant foods to treat medical conditions of people dates back to time immemorial. Many Southern African trees have edible fruits, most of which are yet to be domesticated and developed into commercial crops [1]. Wild fruit trees are important to rural people, especially children, as they introduce nutrient diversity to the diet in an environment where food choices are limited. In addition, the vitality of fruits to the human diet is linked to health-promoting components such as vitamins, essential minerals, antioxidants, and prebiotics (fibers) [2]. Epidemiological studies have shown an inverse correlation between the consumption of fruits and the incidence of chronic diseases such as cancer [3, 4], diabetes [5], and heart disease [6].

Food safety is a major public health concern, and increased awareness has motivated research into the risks associated with the consumption of contaminated food products, particularly, plant-based food products [7]. The occurrence of heavy metals in soils (natural geological occurrences and anthropogenic inputs) and plant-based foods has been the focus of a number of studies as soil to plant transfer is a major route of contamination [8–11].

Although the efficacy of medicinal plants as a therapeutic agent is a result of the phytochemical constituents, prolonged ingestion can result in elemental accumulation, if at elevated levels in the plant [12, 13]. Heavy metals have been linked with toxicity associated with environmental pollution due to them being nonbiodegradable, having long biological half-lives (high residence time) and their potential to accumulate in different parts of plants [14–16]. Based on this, elemental screening of medicinal plants is paramount for quality control and safety [17, 18].

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Phytochemical studies on *F. burtt-davyi* have shown its fruits to contained chemotherapeutic agents [19]. Furthermore, the fruits of *F. burtt-davyi* and *F. sycomorus* are regularly utilized by rural communities in Venda and Eastern Cape, South Africa, for the management of tuberculosis [20] and as a laxative [21], respectively. However, to the best of our knowledge, there have been no reports on the elemental composition and nutritional value of *F. burtt-davyi* and *F. sycomorus* fruits. Hence, this study aimed to investigate the elemental distribution and concentrations of 13 elements in the edible fruits of *F. burtt-davyi* and *F. sycomorus* and to assess for their nutritional value. Additionally, this study also evaluated the potential health risks associated with the toxic elements via the consumption of the fruits.

Materials and Methods

Sample Collection

Tree-ripened fruit samples were randomly picked from eight different sampling sites within KwaZulu-Natal, South Africa, between February and August for *F. sycomorus* and *F. burtt-davyi* (Fig. 1A and B), respectively. Fruit samples were then placed in sealed plastic bags and taken to the laboratory for further analyses. A single flowering plant specimen each for each species was collected at each sampling site for identification. Soil samples at a depth of 15–20 cm from six points along the drip line of each tree were collected randomly from the eight different sampling sites from which the fruits were picked.

Sample Preparation

A botanist, Prof. H. Baijnath, authenticated the plants, and voucher specimens were deposited in the WARD Herbarium of the School of Life Sciences, University of KwaZulu-Natal, Westville Campus, South Africa. Voucher specimen numbers were Ogunlaja, O1 for *F. burtt-davyi*, and Ogunlaja, O2 for *F. sycomorus*. All fruit samples were washed thoroughly with doubly distilled water and oven-dried at 50 °C, overnight. Dried fruit samples were crushed using a food processor (Kenwood Compact Blender, BL380), and resultant powder samples were stored in a refrigerator in sealed polyethylene bags until analyzed. A thoroughly mixed representative soil sample was taken from each site and was air-dried then passed through a 2-mm mesh sieve to remove organic matter and gravel. About 10 g of this soil was crushed with a mortar and pestle to reduce particle size for microwave digestion. Samples were stored in sealed plastic bags and kept in a refrigerator until analyzed.

Fig. 1 Sampling sites for *Ficus sycomorus* (.) and *Ficus burtt-davyi* (x)

Reagents and Chemicals

All chemicals used were supplied by Merck (Kenilworth, USA) and Sigma-Aldrich (St. Louis, USA) Chemical Companies and were of analytical-reagent grade. Elemental calibration standards were prepared from spectroscopic grade stock standard solutions of 1000 mg L^{-1} (Sigma-Aldrich, Buchs, Switzerland).

Quality Control and Analytical Quality Assurance

All plastic containers were washed with laboratory liquid detergent then soaked in 1 M HNO_3, overnight. Glassware and other equipment were cleaned with 6 M HNO_3 and rinsed off with Millipore™ water (Billerica, MA, USA) to minimize the risk of contamination before use. Millipore™ water was used throughout the experiments. Working standards were made up with Millipore™ water and 10 mL of 70% HNO_3 to match the sample matrix. Blank reagents and certified reference material (CRMs) for plant (BCR-402) certified by the European Commission under the responsibility of the Institute for Reference Materials and Measurements (IRMM, Brussels, Belgium) and for soil (D081–540, ERA, A waters Company, Milford, MA, USA) were used to verify the accuracy, precision, and efficiency of the analytical method.

Extraction of Exchangeable Metals and Total Metals

The extracting solution was prepared by diluting 38.542 g ammonium acetate ($NH_4CO_2CH_3$), 25 mL acetic acid (CH_3COOH, 96%), and 37.225 g ethylenediaminetetraacetic acid (EDTA) to 1 L in double-distilled water. Exactly 50 mL of extracting solution was added to 5.0 g of dry soil samples in 250 mL polyethylene bottles and shaken in a laboratory shaker for 2 h. Thereafter, solutions were filtered through Whatman No. 1 filter papers and then Millipore 0.45 μm filter membranes to permit analysis of extracted metals. All samples were stored in plastic bottles and kept in a refrigerator until analyzed.

Microwave-assisted closed-vessel technology was used to digest samples as described by Ogunlaja et al. [19] in the dry fruit, soil, and the certified reference material (CRM) samples. Dried fruit, CRM, and soil samples (0.25 g each) were placed in different 50 mL liners with 10 mL of 70% HNO_3 and allowed to predigest for 1 h [19]. Digestions were performed using the CEM Microwave Accelerated Reaction System (MARS) 6, (CEM Corporation, Matthews, North Carolina, USA). Digests were transferred to 50 mL volumetric flasks, diluted to the mark with Millipore™ water, and stored in polyethylene bottles prior to elemental analysis. All digestions were performed in triplicate.

Soil pH, Cation Exchange Capacity (CEC), and Soil Organic Matter (SOM)

The pH of soil was determined by measuring the pH of the solution, 1:2.5, dry wt/v using a pH meter (Aqualytica, Model pH 17) fitted with a glass electrode. The cation exchange capacity (CEC) of soil was determined using the pH 7.0 ammonium acetate method [22], while soil organic matter (SOM) was measured according to the procedure adopted from Walkley and Black [23].

Determination of Proximate Chemical Composition

The proximate chemical composition of the fruits (moisture, crude protein, fat, fiber, and crude ash) was determined according to standard methods of analysis, as described by the Association of Official Analytical Chemists [24]. Total carbohydrate content was obtained by difference. All determinations were done in triplicate.

Elemental Analysis

All extracted and digested samples were analyzed for As, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Se, and Zn by inductively coupled plasma-optical emission spectrometry (ICP-OES) using the Perkin Elmer Optima™ 5300 Dual View ICP-OES (Billerica, Massachusetts, USA) due to its multielement determination capability, dynamic linear range, and low detection limits. Analytical wavelengths were chosen from the three most sensitive lines that showed no interfering elements and that had minimal spectral or matrix interferences.

Bioaccumulation Factor (BAF)

Generally, elements are persistent in the environment and tend to accumulate in plant tissues. In this study, elemental bioaccumulation was evaluated by comparing their concentration in the fruit against that in the growth soil.

$$BAF = [Fruit]/[Soil]_{Exchangeable} \quad (1)$$

Statistical Analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences (PASW version 24, IBM Corporation, Cornell, NY, USA). Pearson's correlation analysis was applied to the dataset to quantitatively analyze and confirm the relationship between soil quality parameters and heavy metal concentrations. Principal component analysis was also done [25].

Human Health Risk Assessment

Health risk assessments consist of the identification of hazard, assessment of exposure, dose-response, and characterization of the risk [26]. The health risk assessment of each potentially toxic element (PTE) was quantified using the two toxicity risk indices expressed in terms of carcinogenic risk characterization using the slope factor (SF) and a non-carcinogenic risk characterization using the reference dose (RfD) [27]. In this study, elemental concentrations were used to calculate the estimated daily intake (EDI) of elements, target hazard quotients (THQ), hazard index (HI), and target cancer risk (TCR) separately for adult and children.

Estimated Daily Intake of Toxic Chemical Elements

The daily human exposure was evaluated using the estimated daily intake (EDI) of each element as expressed in Eq. 2 [28]

$$\mathrm{EDI} = [\mathrm{MC}_{.} \times \mathrm{CF} \times \mathrm{IR}]/[\mathrm{BW} \times 1000] \tag{2}$$

where, MC, CF, IR, and BW represent the metal concentrations in fruits, the conversion factor (0.208), daily fruit ingestion rate, and average body weight (adult = 60 kg and children = 16 kg), respectively. Fruit ingestion rate (g/person/day) is 50.59 (for adults) and 25.33 (for children) [28, 29].

Target Hazard Quotient

The non-carcinogenic hazard was evaluated by the THQ using Eq. 3 which represents the health risk level by the consumption of fruits.

$$\mathrm{THQ} = \mathrm{EDI}/\mathrm{RfD} \tag{3}$$

where RfD is the oral reference dose (mg kg^{-1}/day) for individual heavy metals that humans can be exposed to and for this study were obtained from USEPA [30–32]. If THQ < 1 consumption of fruits is considered safe for human health (no possible health risk) but if THQ ≥ 1, there is an unacceptable risk of adverse non-carcinogenic effects on human health [27]. The risk assessments of PTE mixture were computed as the sum of individual THQs to form hazard index (HI):

$$\text{Hazard index } (\mathrm{HI}_i) = \Sigma \mathrm{THQ}_i \tag{4}$$

Target Carcinogenic Risk

The lifetime exposure to the incremental risk of an individual developing cancer was evaluated using the lifetime target carcinogenic risk (TCR) and computed by the excess lifetime cancer risk equation:

$$\mathrm{TCR} = \mathrm{CSF} \times \mathrm{EDI} \tag{5}$$

where the cancer slope factor (CSF) (Table 1) converts the estimated daily intake (EDI) of the PTE in the body over a lifetime of exposure directly to the incremental risk of an individual developing cancer [34]. If TCR > 1×10^{-4}, then it is considered unacceptable and intolerable [31].

Results and Discussion

Proximate Chemical Composition

The proximate chemical composition of *F. sycomorus* fruits showed high levels of moisture (55.8 ± 0.3%) and carbohydrates (25.3 ± 1.1%) yet lower than that of *Ficus sur* fruits with 88.8% moisture and 65.6% carbohydrates [19]. The fruits of *F. sycomorus* also contained 5.6 ± 0.2% protein, 8.9 ± 0.5% fats, 55.8 ± 0.9% crude fiber, and 4.4 ± 0.4% ash. The values for protein and fat were similar to those previously reported [35]. The fruits of *F. sur* contained lower crude fiber (7.7%) compared to *F. sycomorus* [19]. Based on the intake level observed to protect against coronary heart disease, the American Heart Association (AHA) set the Adequate Intake (AI) for crude fiber in foods at 38 and 25 g per day for young men and women, respectively [36]. Dietary fiber may play a role in modulating the immune system, which may lead to decreased risk of cardiovascular disease, diabetes, cancer, and obesity [37–39]. The proximate chemical data showed that the fruits of *F. sycomorus* might contribute significantly towards the AI for crude fiber. Similarly, the moisture content of the fresh fruit of *F. burtt-davyi* was 23.7 ± 0.20%. Based on dry mass, the protein content was 5.0 ± 0.30%, 8.4 ± 0.40% for lipids, 78.9 ± 0.55% for carbohydrates, 4.0 ± 0.70% for crude fiber, and 3.7 ± 0.10% for ash. The results show the fruits of *F. burtt-davyi* to be high in energy and low in fats.

Elemental Concentration

Method Validation

The precision of the analytical procedure was authenticated by concurrent analysis of CRMs. The experimental mean values

Table 1 The toxicity responses to heavy metals as the oral reference dose (RfD) [30] and oral slope factor (SF) [30, 31, 33]

Metals	Oral RfD (mg kg^{-1}/day)	Oral SF (mg kg¯1/day)
Cr	3.0×10^{-3}	0.5
Cu	4.0×10^{-2}	ND[a]
Mn	1.4×10^{-1}	ND
Zn	3.0×10^{-1}	ND

[a] ND – not determined

compared well to certified values ($P < 0.05$) with recovery percentages being within acceptable limits (Table 2).

For the macro-elements, concentrations in the fruit of *F. sycomorus* ranged from 4447 ± 777 to 6963 ± 227 mg kg^{-1} for Ca and from 1766 ± 42.43 to 2676 ± 141 mg kg^{-1} for Mg. The bioaccumulation factors (BAFs) for the exchangeable form of macro-elements ranged from 6.7 to 49 and 3.5 to 23 for Ca and Mg, respectively, indicating the tendency of the plant to accumulate these metals.

Total soil Pb ranged from 4.8 ± 0.01 to 44.0 ± 0.22 mg kg^{-1} across the study sites. This elevated concentration is above the South African maximum permissible level of 6.6 mg kg^{-1} set for agricultural soil [40]. Previously, similar results for total soil Pb were also obtained, which may be due to vehicular emissions [19]. At all study sites, the concentrations of Pb in the fruit samples were found to be below the instrument detection limits.

Total soil Cr ranged from 31.8 ± 2.25 to 110 ± 25.27 mg kg^{-1} and < 1.9% was in mobile form. The concentration in the fruits was within a small range of variation (0.04 ± 0.03 to 0.39 ± 0.01 mg kg^{-1}) suggesting the plant controls Cr uptake. This is in agreement with other reports [41, 42]. The available Cr ranged from 0.39 ± 0.12 to 0.76 ± 0.11 mg kg^{-1}, which is less than the phytotoxicity range of 1–5 mg kg^{-1} for available Cr in soil [41]. Chromium is an essential element to humans, and its deficiency includes impaired glucose tolerance, elevation in serum insulin, glycosuria, impaired growth, and altered immune function. Although total soil As, Cd, Co, and Ni ranged (in mg kg^{-1}) from 7.4 ± 0.01 to 8.9 ± 0.3, 0.9 ± 0.05 to 6.7 ± 0.72, 1.8 ± 0.10 to 27.6 ± 0.50, and 4.5 ± 0.05 to 12.1 ± 1.11, respectively, concentrations in the fruits were found to be below the instrument detection limits. This showed that the fruits of *F. sycomorus* do not accumulate these toxic metals.

The elemental concentrations in soil (total and exchangeable) and fruits for the other microelements in *F. sycomorus* are summarized in Table 3. Total soil Cu ranged from 5.4–44.0 mg kg^{-1} which exceeded the South African maximum permissible level of 6.6 mg kg^{-1} for agricultural soil at most sites [40]. Except for sites 1, 4, and 5, Cu concentration in the fruits exceeded the WHO permissible limit of 10 mg kg^{-1} for plants [43], although the fruits did not tend to bioaccumulate Cu (BAF < 1 .0 for most sites) (Table 3). Copper is essential for humans, and it is necessary for the formation of hemoglobin and red blood cells [44]. Elevated levels in the food chain can result in diarrhea, vomiting, liver damage, fatigue, and depression. In this study, the concentrations of elements in the fruits were found to be in decreasing order of Ca > Mg > Fe > Zn > Mn > Cu > Cr, and the toxic metals (As, Cd, Co, and Pb) were below the instrument detection limits.

For the macro-elements, Ca in soil (in mg kg^{-1}, total and exchangeable) ranged from 496 to 8405 and 245 to 4399, respectively, with highest the concentration (14,530 mg kg^{-1}) obtained for the fruit from site 8, where 490 mg kg^{-1} was in exchangeable form (BAF = 29.2), and lowest concentration (7921 mg kg^{-1}) obtained for fruit from site 3. Calcium in fruits may delay ripening and can contribute about 2% towards the total body weight of many fruits [45]. There was an accumulation of Mg in fruits at all sites with Mg in soil (total and exchangeable) and fruits (in mg kg^{-1}) ranging from 214 to 1035, 199 to 340, and 2461 to 3728, respectively. For Ca and Mg, soil concentrations were lower than fruit concentrations, indicating the plants ability to bio-concentrate and bioaccumulate these metals to meet physiological requirement levels.

The concentrations of microelements in soil (total and exchangeable) and fruits of *F. burtt-davyi* are presented in Table 4. Elemental concentrations that were below the instrument detection limit were omitted from the table. The

Table 2 Validation of the analytical method using plant and soil certified reference materials (CRMs)

Metals	Fruit CRM			Soil CRM		
	Measured[a]	Certified[b]	Recovery (%)	Measured[a]	Certified[b]	Recovery (%)
As	0.091 ± 0.011	0.093 ± 0.010	97.8	101 ± 1	101 ± 6	99.5
Cd	ND	ND		140 ± 1	143 ± 6	97.8
Co	0.175 ± 0.004	0.178 ± 0.008	98.3	201 ± 6	199 ± 4	100
Cr	5.18 ± 0.065	5.19[c]	99.8	90 ± 3	87 ± 6	104
Fe	245 ± 2.42	244[c]	100	12,823 ± 20	12,800 ± 18	100
Mn	ND	ND		432 ± 9	425 ± 10	101
Se	6.72 ± 0.21	6.70 ± 0.25	100	130 ± 2	127 ± 5	102
Ni	8.25 ± 0.590	8.25[c]	100	241 ± 10	236 ± 4	102
Zn	25.3 ± 0.002	25.2[c]	100	129 ± 6	130 ± 12	99.2

[a] Values are in mg kg^{-1}, dry mass (mean ± standard deviation, $n = 3$, − not determined), [b] values are in mg kg^{-1}, dry mass (mean ± standard deviation, 95% confidence interval, $n = 3$), [c] indicative values (without uncertainty)

Table 3 Elemental concentrations (mg kg^{-1}) in fruits of *Ficus sycomorus* and soil (total (T) and exchangeable (Ex)) (mean (standard deviation), 95% confidence interval, n = 3), and bioaccumulation factors (BAFs)

Site	Element	Fruit	Soil (T)	Soil (E)	BAF		
					$[F]/[S]_T$[a]	$[F]/[S]_{Ex}$[b]	Ex%[c]
1	Cu	8.1 ± 0.59	12.4 ± 0.19	11.8 ± 0.16	0.6	0.7	95.2
2		10.7 ± 1.31	5.4 ± 0.48	5.1 ± 0.05	2	2.1	94.1
3		10.2 ± 0.26	40.5 ± 1.00	15.4 ± 0.32	0.3	0.7	38.1
4		9.3 ± 1.17	44.0 ± 4.62	16.0 ± 0.24	0.2	0.6	36.4
5		9.9 ± 0.63	19.2 ± 1.90	16.4 ± 0.15	0.5	0.6	85.5
6		10.5 ± 0.80	22.7 ± 0.87	16.8 ± 0.20	0.5	0.6	74.0
7		10.8 ± 1.75	15.1 ± 0.58	12.4 ± 2.23	0.7	0.9	82.6
8		10.8 ± 0.11	12.3 ± 1.82	11.7 ± 0.26	0.9	0.9	95
1	Fe	18.6 ± 14.95	11,695 ± 121	234 ± 26.74	0	0.08	2
2		65.4 ± 16.19	8849 ± 844	418 ± 359	0.01	0.2	4.7
3		45.1 ± 8.44	36,700 ± 1900	437 ± 53.42	0.	0.1	1.2
4		55.7 ± 9.97	9194 ± 1319	438 ± 64.91	0.01	0.1	4.8
5		64.1 ± 17.74	12,159 ± 1046	436 ± 17.46	0.01	0.1	3.6
6		13.3 ± 3.25	14,416 ± 1322	399 ± 58.49	0	0.03	2.8
7		22.0 ± 12.56	9302 ± 310	298 ± 92.88	0	0.07	3.2
8		9.4 ± 1.15	13,715 ± 1980	324 ± 146	0	0.03	2.4
1	Mn	15.4 ± 0.41	213 ± 4.35	184 ± 21.52	0.01	0.08	86
2		65.7 ± 1.94	55.8 ± 5.98	33.9 ± 3.02	1.2	1.9	60.7
3		14.4 ± 0.53	1615 ± 114	207 ± 3.45	0.01	0.07	12.8
4		6.0 ± 0.33	293 ± 44.33	20.8 ± 0.33	0.02	0.3	7.1
5		6.5 ± 0.16	278 ± 27.14	20.8 ± 0.12	0.02	0.3	7.5
6		14.9 ± 0.98	346 ± 36.14	20.6 ± 0.14	0.04	0.7	6.0
7		3.3 ± 0.10	179 ± 12.29	20.1 ± 0.50	0.02	0.2	11.2
8		9.7 ± 0.23	198 ± 29.20	16.3 ± 0.44	0.05	0.6	8.2
1	Zn	42.5 ± 21.11	62.7 ± 12	36.7 ± 0.31	0.7	1.2	58.5
2		17.7 ± 1.71	54.6 ± 58.28	29.6 ± 26.33	0.3	0.6	54.1
3		41.6 ± 8.93	134 ± 38.68	57.4 ± 7.07	0.3	0.7	42.9
4		35.5 ± 12.48	170 ± 28.95	36.2 ± 11.23	0.2	1.0	21.3
5		24.7 ± 3.18	90.4 ± 43.17	22.9 ± 4.93	0.3	1.1	25.4
6		35.5 ± 13.72	62.6 ± 19.35	16.7 ± 4.60	0.6	2.1	26.7
7		44.8 ± 9.32	80.1 ± 30.80	19.3 ± 7.93	0.6	2.3	24.1
8		35.2 ± 0.11	55.2 ± 14.50	15.2 ± 1.04	0.6	2.3	27.5

[a] $[F]/[S]_T$-$[Fruit]/[Soil]_{Total}$, [b] $[F]/[S]_A$-$[Fruit]/[Soil]_{Exchangeable}$, [c] Ex% - $[Soil]_{Exchangeable}/[Soil]_{Total}$

S1 – Umgeni Park, S2 – Burman Bush, S3 – Pigeon Valley, S4 – Bird Park, S5 – Umbilo Park, S6 – UKZN, Howard College, S7 – Pietermaritzburg, and S8 – Tugela Ferry

maximum concentration of Fe in the fruit (103 mg kg^{-1}) was observed at site 8. Iron is known to play very essential role in many metabolic and synthetic pathways such as DNA synthesis, oxygen transport and storage, mitochondrial respiration, and citric acid cycle in the human body [46]. The BAFs (exchangeable) for Fe were relatively low (< 0.3 at all sites), suggesting that Fe uptake is controlled. This observation is similar to our previous report on the fruits of *F. sur* [19]. Overall, about 5.3% of total soil Fe was in exchangeable form.

About 77.4% of total soil Mn was in exchangeable form, but the BAFs (exchangeable) ranged from 0.1 to 1.2 (site 8). This may be due to the lowering of the rate of Mn uptake due to the presence of Mg [47, 48]. The plant tends to regulate the uptake of Mn, based on metabolic requirements. The concentration of Mn in fruits ranged from 9.51 to 54.8 mg kg^{-1}, which are below the maximum limits of 2000 mg kg^{-1} [49]. Total soil Cu ranged from 4.60 to 25.7 mg kg^{-1}, while exchangeable concentrations ranged from 4.14 to 13.0 mg kg^{-1} with an

Table 4 Elemental concentrations (mg kg^{-1}) in fruits of *Ficus burtt-davyi* and soil (total (T) and exchangeable (Ex)) samples (mean (standard deviation), 95% confidence interval, $n = 3$), and bioaccumulation factors (BAFs)

Site	Element	Fruit	Soil (T)	Soil (E)		BAF	
					$[F]/[S]_T$ [a]	$[F]/[S]_{Ex}$ [b]	Ex% [c]
1	Cu	11.3 ± 4.50)	13.3 ± 1.98	8.89 ± 0.92	0.8	1.3	66.7
2		9.83 ± 5.83	13.1 ± 8.05	11.9 ± 1.10	0.7	0.8	90.4
3		11.5 ± 2.04	12.0 ± 0.90	9.00 ± 0.97	1.0	1.3	75.2
4		13.2 ± 1.33	6.06 ± 1.55	5.98 ± 0.99	2.2	2.2	98.7
5		13.7 ± 2.58	25.7 ± 5.37	13.0 ± 1.22	0.5	1.1	50.6
6		14.4 ± 0.59	6.09 ± 0.97	5.77 ± 0.78	2.4	2.5	94.7
7		11.9 ± 5.55	5.38 ± 1.41	5.12 ± 1.02	2.2	2.3	95.2
8		12.7 ± 1.29	4.60 ± 3.77	4.14 ± 0.65	2.8	3.1	90.1
1	Fe	34.8 ± 7.04	7254 ± 1151	379 ± 11	0	0.1	5.2
2		63.2 ± 5.23	7679 ± 1558	590 ± 41	0	0.1	7.7
3		78.6 ± 3.30	7556 ± 484	476 ± 24	0	0.2	6.3
4		15.9 ± 1.50	7804 ± 3602	246 ± 34	0	0.1	3.1
5		50.3 ± 2.88	5908 ± 1589	429 ± 17	0	0.1	7.3
6		19.0 ± 8.37	11,680 ± 421	308 ± 94	0	0.1	2.6
7		18.0 ± 7.70	9438 ± 207	246 ± 28	0	0.1	2.6
8		103 ± 14	5075 ± 549	395 ± 29	0	0.3	7.8
1	Mn	24.9 ± 1.10	147 ± 19	127 ± 31	0.2	0.2	86.7
2		20.4 ± 1.73	140 ± 30	129 ± 12	0.1	0.2	92.1
3		43.6 ± 2.86	173 ± 7.84	140 ± 11	0.3	0.3	81.0
4		53.8 ± 3.21	85.1 ± 44	59.9 ± 10	0.6	0.9	70.4
5		9.51 ± 0.20	137 ± 37	121 ± 20	0.1	0.1	88.5
6		54.8 ± 1.92	123 ± 5.77	62.9 ± 14	0.4	0.9	51.2
7		28.9 ± 1.36	246 ± 50	125 ± 21	0.1	0.2	50.8
8		46.0 ± 2.55	37.4 ± 3.82	37.0 ± 12	1.2	1.2	98.8
1	Zn	49.0 ± 3.0	34.2 ± 11	30.0 ± 9.0	1.4	1.6	87.6
2		27.8 ± 7.41	41.8 ± 4.97	20.8 ± 8.0	0.7	1.3	49.6
3		27.9 ± 2.80	24.0 ± 2.11	9.89 ± 0.91	1.2	2.8	41.2
4		25.3 ± 1.32	18.5 ± 13	10.0 ± 1.0	1.4	2.5	54.2
5		42.3 ± 2.54	79.2 ± 23	20.0 ± 2.0	0.5	2.1	25.2
6		25.9 ± 1.48	20.2 ± 1.84	19.0 ± 1.5	1.3	1.4	93.9
7		25.4 ± 0.68	27.4 ± 5.74	15.3 ± 2.1	0.9	1.7	55.7
8		28.4 ± 2.41	45.0 ± 11	21.6 ± 3.4	0.6	1.3	48.0

[a] $[F]/[S]_T$-$[Fruit]/[Soil]_{Total}$, [b] $[F]/[S]_A$-$[Fruit]/[Soil]_{Exchangeable}$, [c] Ex% - $[Soil]_{Exchangeable}/[Soil]_{Total}$

S1 – Bluff, S2 – Treasure Beach, S3 – Marine Drive. S4 – Umhlanga, S5 – Brighton Beach, S6 – UKZN, Westville, S7 – River Palace, and S8 – Foreshore

average of 82.7% in exchangeable form. The high exchangeable value for Cu may be due to the high stability of the Cu complex formed with EDTA [50]. Copper concentrations in the fruits were all above the WHO permissible limit of 10 mg kg^{-1} [43] for plants. Elevated concentrations of Cu are known to cause anemia (via Mn depletion, which leads to Fe deficiency anemia), liver and kidney damage, and stomach and intestinal irritation in humans [51].

Generally, Zn concentration in fruits (25.3 to 49.0 mg kg^{-1}) was higher than total and exchangeable soil concentrations. Although, about 56.9% of Zn was available for uptake by the fruit; the BAF was less than 1 for the studied sites. The concentration of Zn in the fruits at sites 1 (49.0 mg kg^{-1}) and 5 (42.3 mg kg^{-1}) were above the maximum levels for plants set by the Department of Health, South Africa, which is 40 mg kg^{-1} [52]. Data from this study showed that the elemental concentration in the fruits of *F. burtt-davyi* was the highest for Ca, followed by Mg, Fe, Mn, Zn, and Cu. In addition, the concentrations of trace essential elements (Co, Cr, Ni, and Se) and toxic metals (As, Cd, and Pb) were found to be below the instrument's detection limits.

Estimated Contribution of Elements in Fruits to the Diet

Fruits are vital to the human diet as they contain micronutrients, which can contribute beneficially to recommended dietary allowances (RDAs) and may help meet the nutritional needs of impoverished rural communities where nutritionally deficient diseases are common. In this study, the elemental concentrations in the edible fruits were compared to the dietary reference intakes (DRIs) for most individuals (Table 5) to determine the contribution of the consumption of 20.0 g each of *F. sycomorus* and *F. burtt-davyi* fruits to the diet.

Consumption of 20.0 g of *F. sycomorus* fruits may contribute between 9.4–12.2% and 13.1–13.5% towards the RDA for Ca and Mg, respectively, and may also contribute about 4.5–10.1% towards the RDA for Fe and > 22.0% towards the RDAs for Cu and Mn. The fruits of *F. sycomorus* were richer in the nutrients Ca, Mg, Mn, and Zn compared to fruits of *F. sur* (11%, 9%, 4%, and 3%, respectively, towards the RDA) [19]. An intake of 0.024–0.035 mg of Cr per day is recommended, and consumption of approximately 20.0 g of *F. sycomorus* fruits may contribute approximately 0.0043 mg (12.3–19.9%) towards its RDA. Chromium is known to improve the efficiency of insulin, and it is needed in the metabolism of proteins, fats, and carbohydrates [54].

Similarly, 20.0 g of fruit of *F. burtt-davyi* may contribute up to 43.8% towards the RDA for Mn, thereby making the fruit a good source of Mn. Some Mn-rich, plant-based foods include pineapple (raw and juice), spinach, peanuts, sweet potatoes, brown rice, and pecan nuts [55]. Manganese is a component of the powerful antioxidant enzyme, manganese superoxide dismutase (MnSOD), which neutralizes free radicals in the human body [56–58]. A diet rich in Mn may prevent cancer and other diseases such as arthritis, osteoporosis, diabetes, and epilepsy [59, 60].

Principal Component Analysis (PCA)

Principal component analysis (PCA) was applied to assist in the identification of elemental sources in soil, and the results for the two species are presented in Table 6. The preliminary results of the KMO test (0.8) further validated the results of the PCA. For the *F. sycomorus* soil samples, three components were obtained, accounting for 86.3% of the total variance. Component 1 was dominated by Cd (0.98), Co (0.95), Cr (0.95), Fe (0.97), Mn (0.96), Ni (0.90), and Pb (0.81) accounting for 56.6% of the total variance. The high loadings of these metals suggest a common anthropogenic input. Previously, we reported similar patterns in soils from KwaZulu-Natal [19, 61]. Component 2, dominated by Ca and Mg, accounted for 20.7% of the total variance indicating that the elements originated from soil mineral forming processes. Component 3 was dominated by As, Cu, and Zn accounting for 9.0% of the total variance. A 3-D plot of the PCA loadings is presented in Fig. 2A, and the relationships among the 12 metals are clearly seen.

The growth soil from *F. burtt-davyi* was dominated by four principal components, which were extracted based on

Table 5 Dietary reference intakes (DRIs)[a] (recommended dietary allowance (RDA) and tolerable upper intake level (UL)) and average concentration (n = 3) of elements for most individuals after consumption of 20 mg day^{-1} (dry mass (DM)) of two *Ficus* species

Fruit		Average concentration (mg per 20 g, DM)	DRI (mg day^{-1}) RDA	UL	Contribution to RDA (%)
F. sycomorus	Ca	122.35	1000–1300	2500	12
	Cr	0.0043	0.024–0.035	NA	20
	Cu	0.20	0.9	8	22
	Fe	0.81	8–18	45	10
	Mg	42.00	310–320	350	14
	Mn	0.36	1.6–2.3	9	23
	Zn	0.69	8–11	34	9
F. burtt-davyi	Ca	223.15	1000–1300	2500	17.2–22.3
	Cu	0.25	0.9	8	27.8
	Fe	0.96	8–18	45	5.3–12.0
	Mg	62.34	310–320	350	19.5–20.1
	Mn	0.70	1.6–2.3	9	30.4–43.8
	Zn	0.63	8–11	34	5.7–7.9

[a] Sourced from Food and Nutrition Board, Institute of Medicine, National Academies [53]

NA – data not available

Table 6 Rotated component matrix for elemental concentrations of growth soil samples obtained for the *Ficus* species

F. sycomorus

Element	Component		
	1	2	3
Co_T	**0.95**	0.17	0.12
Cd_T	**0.98**	0.00	0.00
Cr_T	**0.95**	−0.12	0.00
Fe_T	**0.97**	0.00	0.00
Ca_T	0.12	**0.94**	0.14
Cu_T	0.48	0.41	**0.71**
Mg_T	0.00	**0.91**	0.19
Zn_T	0.29	0.32	**0.64**
Pb_T	**0.81**	−0.11	0.00
As_T	−0.31	0.00	**0.81**
Ni_T	**0.90**	0.31	−0.11
Mn_T	**0.96**	0.17	0.16
Eigenvalues	6.8	2.5	1.1
% Total variance	56.6	20.7	9.0
Cumulative %	56.6	77.3	86.3

F. burtt-davyi

Element	Component			
	1	2	3	4
Co_T	**0.97**	−0.03	0.05	0.12
Cd_T	**0.92**	−0.08	0.09	0.29
Cr_T	**0.91**	0.02	0.11	−0.26
Fe_T	**0.90**	−0.16	−0.04	0.32
Ca_T	−0.08	**0.90**	0.35	0.05
Cu_T	−0.10	**0.90**	−0.04	0.03
Mg_T	0.11	**0.87**	0.27	0.37
Zn_T	−0.14	**0.74**	0.07	−0.06
Se_T	0.28	0.55	−0.54	−0.41
As_T	−0.03	0.32	**0.87**	0.01
Ni_T	0.28	0.11	**0.84**	0.01
Mn_T	0.31	0.17	0.03	**0.90**
Eigenvalues	3.9	3.7	1.7	1.1
% Total variance	32.9	30.8	14.4	9.3
Cumulative %	32.9	63.7	78.1	87.4

Extraction method: principal component analysis. Rotation method: Varimax with Kaiser. Normalization. Bold figures indicate values > 0.7

eigenvalues > 1 and explained over 80% of the total variability, which described the overall elemental pattern, signifying different sources (Table 6). The first component explained 32.9% of the total variance; high loadings were obtained for Cd, Co, Cr, and Fe (Table 6) which could suggest common anthropogenic sources (vehicular emissions). Elevated levels of these trace metals have been reported in areas with high traffic density in South Africa [62]. The second principal component was strongly represented by Ca, Cu, Mg, and Zn, contributing 30.8% of the total variance. A quasi-independent behavior was also observed within the group due to Se having a loading of 0.55, which was further corroborated by a large distance in the 3-D PCA loading plot (Fig. 2B), which may suggest different sources. The third principal component contributed 14.4% to the total variance and had high loading of As and Ni, suggesting a common origin, while the fourth principal component was dominated by Mn (0.90), accounting for 9.3% of the total variance, suggesting that it came from a different source. A similar occurrence was reported previously [61].

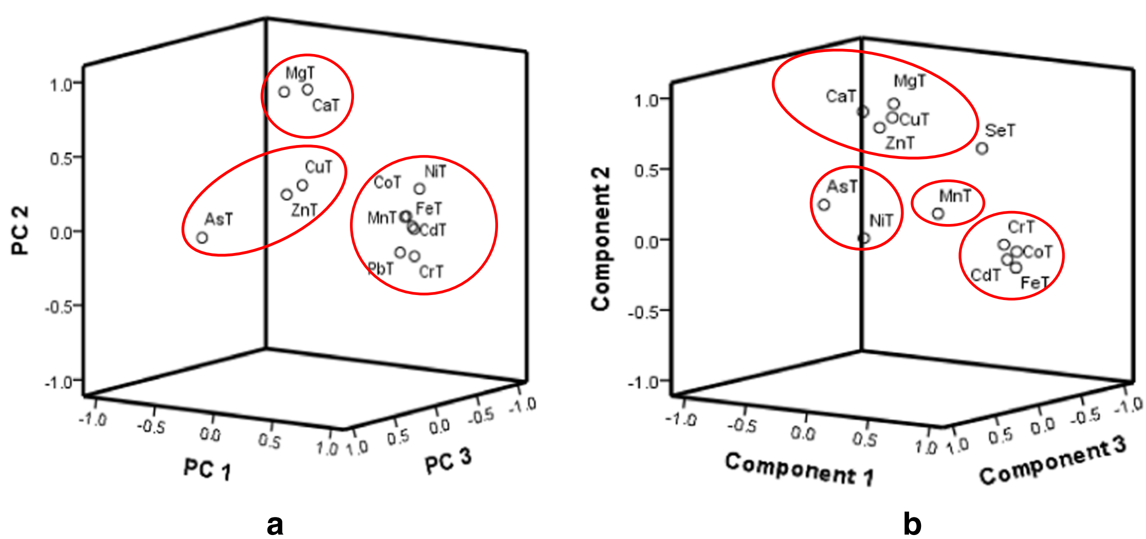

Fig. 2 3-D principal component analysis (PCA) loading plot for heavy metals in *F. sycomorus* soil samples (A) and *F. burtt-davyi* soil samples (B), respectively

Human Health Risk Assessment: Target Hazard Quotient (THQ)

Table 7 summarizes the non-carcinogenic risk, expressed as target hazard quotient (THQ) for Cr, Cu, Mn, and Zn for children. The ranges of THQ values for the fruits of *F. sycomorus* were 00.001 to 0.011 for Cr, 0.014 to 0.067 for Cu, 0.002 to 0.41 for Mn, and 0.005 to 0.066 for Zn. Similarly, the ranges of THQ estimates for the fruits of *F. burtt-davyi* were 0 to 1.0×10^{-5} for Cr, 0.012 to 0.093 for Cu, 0.006 to 0.059 for Mn, and 0.007 to 0.054 for Zn (Table 7). Elemental THQ values in the fruits of *F. sycomorus* were in the decreasing order of Cu > Zn > Mn > Cr, and for fruits of *F. burtt-davyi*, it was in decreasing order of Cu > Mn > Zn > Cr.

THQ values for heavy metals in the fruits for all sites were less than 1, indicating an acceptable non-carcinogenic risk to human health which confirms that consumption of the fruits by rural communities is safe. This result is consistent with the mean elemental concentrations as well as the multivariate results from this study. These results showed that consumption of the fruits of *F. sycomorus* and *F. burtt-davyi* by children is safe and will not lead to non-carcinogenic exposure or adverse health effects, which would make it safe for the rest of the population.

Table 7 Non-carcinogenic risk (target hazard quotient, THQ), overall toxic risk (hazard index, HI) and average lifetime target carcinogenic risk (TCR) for Cr in children

Site	THQ				HI	TCR
	Cr	Cu	Mn	Zn		Cr
Ficus sycomorus						
1	0.011	0.067	0.036	0.047	0.161	1.6×10^{-5}
2	0.010	0.023	0.041	0.005	0.08	1.4×10^{-5}
3	0.005	0.022	0.009	0.012	0.049	7.5×10^{-6}
4	0.011	0.020	0.004	0.010	0.046	1.7×10^{-5}
5	0.006	0.022	0.004	0.007	0.039	8.8×10^{-6}
6	0.004	0.023	0.009	0.010	0.046	5.3×10^{-6}
7	0.001	0.024	0.002	0.013	0.040	1.8×10^{-6}
8	0.003	0.014	0.024	0.066	0.107	1.5×10^{-5}
Ficus burtt-davyi						
1	0	0.093	0.059	0.054	0.205	0
2	0	0.022	0.013	0.008	0.043	0
3	0	0.027	0.027	0.008	0.063	0
4	0	0.029	0.034	0.007	0.070	0
5	0	0.030	0.006	0.012	0.048	0
6	0	0.032	0.034	0.008	0.074	0
7	0	0.026	0.018	0.007	0.052	0
8	1.0×10^{-5}	0.012	0.015	0.046	0.073	7.9×10^{-8}

Furthermore, the elemental additive effect for non-carcinogenic risk was also used to predict the possible effects on human health. The elemental hazard indices (HI) of the studied heavy metals in fruits were less than 1, indicating no additive adverse non-carcinogenic health risk to humans through the consumption of metals in the fruits of both species.

The average lifetime target carcinogenic risk (TCR) for Cr through the consumption of fruits of the two species from the study area ranged from 7.9×10^{-8} to 1.7×10^{-5} which were within the USEPA recommended safe limit for cancer risk (1.0×10^{-4}) [63, 64] confirming no carcinogenic risk to the exposed population.

Conclusion

Many rural communities, especially in South Africa, often consume the fruits from *Ficus* species. This study provides information on the nutritive value of the fruits of *F. sycomorus* and *F. burtt-davyi*. The results indicate that the fruits are good for health and do not tend to accumulate toxic elements (As, Cd, and Pb); therefore, vulnerable communities would not be exposed to non-carcinogenic and carcinogenic adverse health risks through their consumption. The fruits were also found to be rich in Mn, which may be beneficial in maintaining a healthy immune system if consumed by people living in impoverished communities. The results showed site to influence elemental distribution; however, statistical analyses showed uptake of elements to be controlled by the plant to meet physiological needs as evidenced by bioaccumulation factors.

Acknowledgments The authors would like to acknowledge the School of Chemistry and Physics, University of KwaZulu-Natal, for the research facilities.

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflict of interest.

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