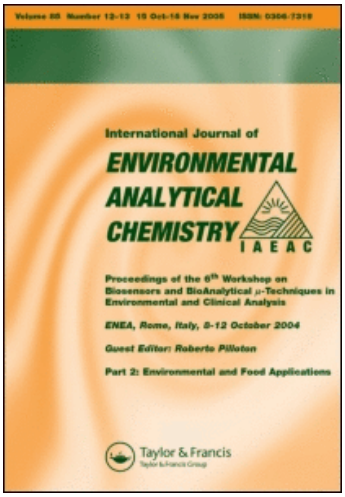

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Impact of soil quality on elemental uptake by *Zingiber officinal* (ginger rhizome)

Alisa Govender[a]; Andrew Kindness[a]; Sreekantha Babu Jonnalagadda
[a] School of Chemistry, University of KwaZulu-Natal, Westville campus, Durban, South Africa

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Impact of soil quality on elemental uptake by *Zingiber officinal* (ginger rhizome)

Alisa Govender, Andrew Kindness and Sreekantha Babu Jonnalagadda*

School of Chemistry, University of KwaZulu-Natal, Westville campus, Chiltern Hills, Durban, South Africa

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The elemental distribution in ginger rhizome and the impact of the soil quality on the elemental uptake by the rhizome were investigated. The focus of the study was on eight elements, i.e. Cu, Zn, Mn, Fe, Ni, Pb, Cr and Mg. Ginger and soil samples from four different farms of KwaZulu-Natal (South Africa) were collected and after microwave digestion, the elemental concentrations were estimated using ICP-OES. The method for the ginger analysis was validated by the analysis of a certified reference material (leaves of Poplar). The accumulation of the elements in the ginger rhizome was investigated as well as the metal–metal interactions that exist based on the total and the bioavailable concentrations of the elements were determined. It was found that the soil quality influences the elemental distribution within the ginger rhizome; however, the plant has the inherent ability to control the amount of each element entering the rhizome. The levels of Cd and As in the soil and ginger samples from all four sites were below the lower detection limits. The ginger 'flesh' tends to accumulate Mn and Mg. A synergistic relationship between Cr and Mn; and an antagonistic relationship between Fe and Cu; and Fe and Cr were noticed. The concentration of none of the elements exceeded the threshold upper intake levels, and thus does not pose toxicity issues.

Keywords: *Zingiber officinal*; ginger; Mn accumulation; Mg accumulation; soil quality

1. Introduction

Zingiber officinal is consumed by populace in all parts of the world, ranging from a taste enhancer in various cuisines to a vast number of medicinal uses. The elemental make-up of ginger is an important consideration, since it is edible and as elements play a role in both plant and human nutrition. Thus, such determinations will enable one to determine, if adequate nutrition is available for plant growth as well as the nutritional and toxicological implications of the consumption of the plant.

Zingiber officinal, more commonly known as ginger originating in the east, is an underground stem or rhizome. Since ancient times, ginger has been used for various medicinal uses in Asian, Indian and Arabic herbal traditions [1]. It is composed of volatile oils (sesquiterpenoids) and non-volatile phenylpropanoids-derived compounds (gingerols and shogaols) [1]. Ginger is a strong antioxidant and has been used for the treatment of

*Corresponding author. Email: jonnalagaddas@ukzn.ac.za

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stomach aches, nausea and diarrhoea, for the alleviation of post surgery nausea as well as for rheumatoid arthritis, osteoarthritis and for joint and muscle pain [2]. The major constituents in ginger are the pungent vanilloids, 6-gingerol and 6-paradol [3]. Ginger contains two other phenolic compounds, shogaols and zingerone in addition to 6-gingerol [4]. The antioxidant, antitumour and anti-inflammatory pharmacologic effects of ginger are mainly due to its pungent constituents (e.g. 6-gingerol). Ginger extract consumption is known to reduce plasma cholesterol, inhibits low-density lipoprotein (LDL) oxidation and attenuates development of atherosclerosis in atherosclerotic, apolipoprotein E-deficient mice [5]. Figure 1 shows the ginger rhizome.

The analysis of the chemical properties of soil entails the determination of the total, bioavailable and speciated forms of the element. Total content gives the overall composition of each element present in the soil. The total metal content is not an indication of the bioavailability of a metal or its speciation. An element is termed bioavailable, if it is present or can be transformed easily into the free-ion species and if it can move into the plant at a rate that is relevant to a plants life-cycle [6,7]. The bioavailable portion is a fraction of the total metal content that is available for uptake by an organism [7]. In order to determine whether a metal is present at a level, which is unsafe, its bioavailability and speciation must be determined. The bioavailability of a metal is a pollution indictor, whilst its speciation is a toxicity indicator. The potential toxicity of any element is very much dependent on its speciation and bioavailability. The information obtained from a bioavailability study is an approximation of the metals that can move into solution and become available over time and an indication of the manner in which metals are partitioned in soil [8]. Even the so-called essential elements are also characterised by a surprisingly narrow range of optimal activity. A scant 4- to 5-fold change in concentration is sufficient to convert signs of deficiency to overt signs of toxicity a further change of an order of magnitude is sufficient to cause fatality [9,10].

The dietary reference intake levels (DRIs) are a set of nutrient reference values for healthy populations that can be used for assessing and planning diets. The DRIs provide an insight to the current state of scientific knowledge with regards to nutrient requirements. The upper threshold intake levels (ULs) represent the maximum level of daily nutrient intake that is likely to pose no risk of adverse effects [11]. Once the intake

Figure 1. Ginger.

of an element exceeds the UL value, the risk of detrimental effect increases. The bioaccumulation factor (BAF) is the ratio of the total concentration of an element in the specimen component to its total concentration in the soil. This provides information pertaining to the amount of a substance accumulated in the various parts of the plant relative to as a function of the total concentration in the soil [4].

Although, high amounts of iron and calcium are reported in ginger rhizomes, little information is available on the elemental composition within the ginger rhizome [13]. This study reports the elemental composition within the ginger and the impact of the growth soil on their uptake by different parts of ginger. The 10 elements selectively investigated were As, Cd, Cr, Cu, Pb, Mn, Zn, Ni, Mg and Fe. While Mg is the macronutrient, As, Cd, Cr and Pb are toxic metals and the other five are the essential and micronutrients needed for plants, humans and animals.

2. Experimental

2.1 *Instrumentation*

Microwave digestion is used in sample preparation due to the advantages of a shorter acid digestion time, a better recovery of volatile elements, lower contamination levels, minimal volumes of reagents required, more reproducible procedures and a better working environment [14]. Due to the better detection limits affordable and multi-element standard solutions can be analysed and longer linear range. Inductively coupled plasma-optical emission spectroscopy (ICP-OES) is used to analyse the samples [15]. The wavelengths chosen for analysis of each element were verified by the CRM validation procedures. The final concentrations of each sample are expressed as microgram per gram taking into consideration the concentration in ppm, the volume of sample in litres and the mass of the sample used in grams.

2.2 *Sample collection*

Soil and ginger samples were collected from four farms situated in Sinembe, Tongaat area, which is located about 40–50 km north of Durban city in the KwaZulu-Natal coast of South Africa. A total of 5–6 samples of ginger and 10–12 samples of soil were collected from each sample site, and the soil was collected from points around the ginger sample location. The soil was collected from the plough depth (about 15 cm). The soil was quartered and mixed thoroughly. Both the ginger and soil samples were stored in plastic bags and kept frozen until analysis. Prior to freezing, the pH of the soil was recorded (1 : 2.5 soil–water suspension) using a pH meter.

2.3 *Analysis of a CRM*

The CRM used was leaves of Poplar (NCS DC 73350) obtained from China National Analysis Center for Iron and Steel 2004, with validated procedure [16]. The required amount of CRM was oven-dried at 105°C for 24 h. A mass of 0.5 g of dried CRM was placed in the TFM vessel. A volume of 5 mL concentrated nitric acid was added to the vessel. Five samples of CRM were prepared and each sample was analysed in triplicate ($n = 5$). The CRM samples were then microwave digested in a Perkin Elmer Paar Physica Multiwave Microwave Sample Preparation System. The leaf CRM TFM programme was

used where: the power was set at 500 W for 5 min, 500 W for a further 5 min, 650 W for 15 min and 0 W for 15 min. The digest obtained was filtered by gravity into a 50 mL volumetric flask and made to the mark using double-distilled water. The digests obtained were analysed by ICP-OES.

2.4 *Soil analysis*

The soil analysis consisted of a total metal content determination and a bioavailability determination.

2.4.1 *Total metal content determination*

The soil was oven-dried at 40°C for 24 h and thereafter sieved through a 75 μm sieve. This was done for the soil collected from each site. A mass of 0.5 g of the sieved soil was microwave digested using the soil. The digestions were performed using the Anton Paar Multiwave Microwave Sample Preparation System (1000 W) with six high-pressure Teflon fluoro methoxil (TFM)-Ceramic Vessels (HF 50) (Anton-Paar) [17]. A 5 mL of 69% HNO_3 was added to each vessel and sealed. For the microwave digestions heating program of the power set at 600 W for 10 min, 900 W for 12 min and 0 W for 15 min was used. The digest obtained was filtered by gravity using Whatman 41, 20–25 μm filter paper into a 25 mL volumetric flask and made up to the mark using double-distilled water [17]. The analysis was carried out in triplicate with each sample, which were prepared in five replicates ($n = 5$). The samples were analysed using ICP-OES (Perkin Elmer precisely Optical Emission Spectrometer Optima 5300 DV) using appropriate standards for the calibration. Based on statistical analysis, most of the results are within less than 5% relative coefficient of variation.

2.4.2 *Bioavailability determinations*

In this project, ammonium acetate is used to selective extract the easily exchangeable elements present in the soil. The use of this extracting solution is increasing since it is fast becoming recognised as the most appropriate extracting solution for different soil types analysed for a range of nutrients and contaminants [18,19]. This may be due to the high concentration and the metal complexing power of the acetate ion, which has the ability to prevent readsorption or precipitation of released metal ions. A mass of 2 g of sieved soil was placed in a centrifuge tube to which 20 mL of 1.0 M ammonium acetate solution was added. The solution was placed on a Labcon orbital shaker for 16 h at 270 rpm. The soil–ammonium acetate suspension was centrifuged in a Rotofix 32A Hettich Zentrifugen centrifuge at 25 rpm for 5 min. The liquid was decanted, whilst filtering by gravity, into a 50 mL volumetric flask using Whatman 41, 20–25 μm filter paper. The solution was made to the mark using double-distilled water and analysed by ICP-OES.

2.5 *Ginger analysis*

The ginger obtained was separated into three portions. The ginger was skinned, and the nodes removed. The ginger 'flesh' (referred as rhizome), skin and nodes were oven-dried at 40°C for 24 h. Each part was blended to obtain a powder. A mass of 0.5 g of dried sample was placed in the tetrafluoromethaxil (TFM) vessel. A volume of 5 mL concentrated

nitric acid was added to the vessel. The sample was then microwave digested in a Perkin Elmer Paar Physica Multiwave Microwave Sample Preparation System. The leaf CRM TFM programme was used where: the power was set at 500 W for 5 min, 500 W for a further 5 min, 650 W for 15 min and 0 W for 15 min. This was done in five replicates from each site ($n = 5$) and analysed in triplicate runs. The digest obtained was filtered by gravity into a 25 mL volumetric flask and made up to the mark using double-distilled water. The samples were analysed using ICP-OES [17,20].

3. Results and discussion

3.1 *CRM analysis*

The analysis of the CRM allows for method validation and accuracy confirmation. With reference to Table 1, the values indicated are within the certified value range. This indicates that the method used for the analysis is valid and can be used for the analysis of the ginger. In addition, the wavelength at which the concentration for each element was within the certified value range indicates that it would be appropriate to use these wavelengths for the analyses in order to obtain accurate and reliable results. No internal standard is used.

3.2 *Soil and ginger analysis*

From the analysis, As and Cd in all soil and ginger samples were found in insignificant concentrations below the lower detection limits ($<0.06\,\mu g\,g^{-1}$ Cd and $0.09\,\mu g\,g^{-1}$ As), hence not included in the further discussions. Tables 2–5 list the total metal content and bioavailable concentrations for the other eight elements investigated in the four soils under study. An observation of the data in tables shows that on statistical basis, most of the analytical data had with in less than 5% relative SD. A perusal of the total elemental and exchangeable concentrations in soils corresponding to the four sites summarised in Tables 2–5, indicate that all the soils are rich in Fe with concentrations ranging between

Table 1. Certified values for the elements in the leaves for Poplar (CRM) and measured mean concentration ($\mu g\,g^{-1}$) with SD (±) and RSD.

Element	Mean concentration with SD*	RSD (%)	Certified value and with SD
Cr	0.6 ± 0.1	19.3	0.55 ± 0.07
As	0.32 ± 0.06	19.65	0.37 ± 0.09
Cu	8.4 ± 0.2	1.95	9.3 ± 1.0
Zn	38 ± 4	11.23	37 ± 3
Mn	48 ± 3	5.51	45 ± 4
Fe	264 ± 10	3.73	274 ± 17
Cd	0.34 ± 0.02	5.88	0.32 ± 0.07
Ni	1.9 ± 0.4	20.19	1.9 ± 0.3
Pb	1.43 ± 0.06	4.33	1.5 ± 0.3
Mg	6693 ± 136	2.04	6500 ± 500

Notes: *Mean of replication experiments ($n = 5$) and each sample analysed in triplicate.
RSD = Relative standard deviation.

Table 2. Elemental concentrations ($\mu g\,g^{-1}$ dry weight) at site 1 (S1): total and exchangeable levels in soil and total in ginger flesh (rhizome), peel and nodes.*

	Soil			Ginger			
Metal	Total	Bioavailable	$[Soil]_{Ex}/[Soil]_T$	Rhizome	Peel	Node	BAF
Fe	$22{,}486 \pm 240$	28.7 ± 0.4	0.1×10^{-2}	36.4 ± 0.1	236 ± 1	205 ± 1	1.6×10^{-3}
Mg	1381 ± 40	59.2 ± 0.2	4.3×10^{-2}	2108 ± 28	3132 ± 60	2429 ± 42	1.53
Mn	113 ± 2	2.16 ± 0.04	1.9×10^{-2}	341 ± 4	73 ± 2	137 ± 9	3.02
Zn	35.7 ± 0.1	1.29 ± 0.03	3.6×10^{-2}	23.0 ± 0.1	17.8 ± 0.2	18.4 ± 0.2	0.65
Ni	26.8 ± 0.3	0.04 ± 0.01	0.2×10^{-2}	1.32 ± 0.01	1.22 ± 0.01	1.8 ± 0.1	0.05
Cu	15.1 ± 0.1	0.39 ± 0.01	2.6×10^{-2}	8.9 ± 0.1	9.7 ± 0.1	9.5 ± 0.1	0.58
Cr	141 ± 2	1.37 ± 0.04	1.0×10^{-2}	7.5 ± 0.1	6.6 ± 0.1	9.1 ± 0.4	0.05
Pb	6.3 ± 0.1	2.0 ± 0.1	31.5×10^{-2}	ND	ND	ND	

Notes: *Mean of replicate experiments ($n = 5$).
Rhizome = Flesh only with peel and nodes removed. $BAF = [Rhizome]/[Soil]_T$.
ND – Below lower detection limit (in $\mu g\,g^{-1}$) (Pb = 0.06, As = 0.09 and Cd = 0.06).

Table 3. Elemental concentrations ($\mu g\,g^{-1}$ dry weight) at site 2 (S2): total and exchangeable levels in soil and total in ginger flesh, peel and nodes.*

	Soil			Ginger			
Metal	Total	Bioavailable	$[Soil]_{Ex}/[Soil]_T$	Rhizome	Peel	Node	BAF
Fe	$17{,}292 \pm 185$	24.1 ± 0.1	0.1×10^{-2}	80 ± 1	409 ± 9	221 ± 5	4.6×10^{-3}
Mg	1157 ± 29	118 ± 4	10.2×10^{-2}	2662 ± 22	3722 ± 38	3027 ± 34	2.30
Mn	132 ± 1	12.5 ± 0.1	9.5×10^{-2}	629 ± 1	375 ± 8	456 ± 9	4.77
Zn	23.0 ± 0.2	0.79 ± 0.02	3.5×10^{-2}	18.2 ± 0.4	25.0 ± 0.5	20.3 ± 0.3	0.79
Ni	11.1 ± 0.1	0.076 ± 0.004	0.7×10^{-2}	1.21 ± 0.01	1.67 ± 0.06	1.55 ± 0.07	0.11
Cu	6.30 ± 0.05	0.20 ± 0.01	3.4×10^{-2}	5.2 ± 0.2	10.1 ± 0.3	5.9 ± 0.1	0.82
Cr	77.6 ± 0.1	0.98 ± 0.01	1.3×10^{-2}	6.0 ± 0.1	7.7 ± 0.2	10.4 ± 0.2	0.08
Pb	12.2 ± 0.1	0.75 ± 0.01	6.2×10^{-2}	ND	ND	ND	

Notes: *Mean of replicate experiments ($n = 5$).
Rhizome = Flesh only with peel and nodes removed. BAF = $[Rhizome]/[Soil]_T$.
ND – Below lower detection limit (in $\mu g\,g^{-1}$) (Pb = 0.06, As = 0.09 and Cd = 0.06).

Table 4. Elemental concentrations ($\mu g\,g^{-1}$ dry weight) at site 3 (S3): total and exchangeable levels in soil and total in ginger flesh, peel and nodes.*

	Soil			Ginger			
Metal	Total	Bioavailable	$[Soil]_{Ex}/[Soil]_T$	Rhizome	Peel	Node	BAF
Fe	$10{,}732 \pm 197$	9.0 ± 0.2	0.08×10^{-2}	58.6 ± 0.2	401 ± 10	162 ± 5	5.4×10^{-3}
Mg	902 ± 5	111 ± 1	12.3×10^{-2}	3942 ± 80	4049 ± 42	3210 ± 56	4.38
Mn	77 ± 1	5.6 ± 0.1	7.2×10^{-2}	153 ± 3	78.7 ± 0.3	92 ± 3	1.98
Zn	20.0 ± 0.1	1.21 ± 0.05	6.1×10^{-2}	21 ± 1	23.6 ± 0.5	20.5 ± 0.4	1.05
Ni	7.67 ± 0.02	0.36 ± 0.01	4.8×10^{-2}	1.56 ± 0.02	1.16 ± 0.02	1.39 ± 0.02	0.20
Cu	4.01 ± 0.05	0.32 ± 0.04	77.1×10^{-2}	6.56 ± 0.03	7.0 ± 0.2	9.2 ± 0.2	1.60
Cr	58.2 ± 0.1	1.50 ± 0.05	25.7×10^{-2}	11.6 ± 0.3	8.4 ± 0.1	12.0 ± 0.3	0.20
Pb	11.2 ± 0.1	4.15 ± 0.06	37.1×10^{-2}	ND	ND	ND	

Notes: *Mean of replicate experiments ($n = 5$).
Rhizome = Flesh only with peel and nodes removed. BAF = $[Rhizome]/[Soil]_T$.
ND – Below lower detection limit (in $\mu g\,g^{-1}$) (Pb = 0.06, As = 0.09 and Cd = 0.06).

Table 5. Elemental concentrations ($\mu g\,g^{-1}$ dry weight) at site 4 (S4): total and exchangeable levels in soil and total in ginger flesh, peel and nodes.*

	Soil			Ginger			
Metal	Total	Bioavailable	$[Soil]_{Ex}/[Soil]_T$	Rhizome	Peel	Node	BAF
Fe	$13{,}335 \pm 187$	10.4 ± 0.5	0.1×10^{-2}	53.1 ± 0.5	376 ± 1	135 ± 5	4.0×10^{-3}
Mg	1277 ± 26	6.7 ± 0.1	13.2×10^{-2}	2621 ± 44	3847 ± 70	2843 ± 32	2.05
Mn	146 ± 2	0.51 ± 0.09	8.7×10^{-2}	109 ± 1	48 ± 5	102 ± 3	0.75
Zn	22.9 ± 0.1	0.012 ± 0.004	1.3×10^{-2}	11.7 ± 0.2	$23.\ 7 \pm 0.5$	13.3 ± 0.3	0.51
Ni	9.5 ± 0.1	0.50 ± 0.01	0.5×10^{-2}	1.95 ± 0.02	1.60 ± 0.05	1.51 ± 0.07	0.21
Cu	6.0 ± 0.1	0.37 ± 0.01	7.1×10^{-2}	6.7 ± 0.2	7.9 ± 0.3	4.9 ± 0.2	1.10
Cr	71.8 ± 0.7	0.061 ± 0.002	2.1×10^{-2}	9.6 ± 0.1	7.3 ± 0.1	12.7 ± 0.6	0.13
Pb	13.5 ± 0.1	0.030 ± 0.001	5.6×10^{-2}	ND	ND	ND	

Notes: *Mean of replicate experiments ($n = 5$).
Rhizome = Flesh only with peel and nodes removed. $BAF = [Rhizome]/[Soil]_T$.
ND – Below lower detection limit (in $\mu g\,g^{-1}$) (Pb = 0.06, As = 0.09 and Cd = 0.06).

10,000 and 20,000 $\mu g\,g^{-1}$ of dry soil followed by magnesium in the range 900–1400 $\mu g\,g^{-1}$. Total Mn in soils is in the range 80–140 $\mu g\,g^{-1}$, followed by chromium in the range 60–130 $\mu g\,g^{-1}$. While zinc is about 20 $\mu g\,g^{-1}$ in most soils Cu and Ni were below a 10 $\mu g\,g^{-1}$ level. The soil sample from site 1 recorded relatively higher concentrations of Cu, Zn, Fe, Ni, Mg and Cr than the other sites, whilst Mn and Pb are found to be highest at site 4. At site 1, the Pb concentration is 6.29 $\mu g\,g^{-1}$, whilst at sites 2–4, the values ranged from 11 to 13 $\mu g\,g^{-1}$. Data also shows that for all elements, except Fe, Mg and Mn, the concentrations at all sites are broadly similar. A possible cause of deviations of Mg is that it may be a constituent of the regularly used chemical agents to adjust the pH of the soils. The variation in the total Fe and Mn concentrations at the sites could be due to differences in geological distributions across the sites. In addition, contamination is a possible reason. The total elemental levels in the soils at four sites were with in the threshold limits set by EEC [21].

Tables 2–5 also summarise the concentrations of the eight elements in three parts of the ginger namely, in the flesh of rhizome (R), peel (P) and nodes (N). Although flesh is the main component normally used in cooking, many use the whole ginger inclusive of peel and nodes. The concentrations of all elemental in the rhizome (only flesh) were significantly higher than the bioavailable concentrations in the soils, indicating that these elements get absorbed by the rhizome during its physiological growth. On further assessment of the analytical data, although bioavailable Mg is low, the bioaccumulation of the element is distinctly high in all the three parts of the ginger and in the range 2000–3700 $\mu g\,g^{-1}$ (Figure 2a). The BAF for Mg in the flesh of ginger was in the range 1.5–4.4 (Tables 2–5).

The bioavailability of an element is dependant on various factors including soil pH. The pH of the soil was within a narrow range of 4.64–4.68. To acquaint with the magnitude of the exchangeable fraction, the ratio of $[Soil]_{Ex}/[Soil]_T$ of exchangeable to total concentration of each element at each site calculated are integrated in Tables 2–5. An examination of the ratios shows that those values were relatively low and varied in the range 10^{-3}–10^{-1}. Cu, Cr and Pb only registered higher ratios.

Mg with high total levels and having the exchangeable fraction in the range 10^{-2} at all four sites, it recorded BAF values >1, exhibiting its accumulative characteristic (Figure 2a). With iron, although total Fe in soil is very high, its bioavailable levels are low (ratio $\approx 10^{-3}$) and its concentrations in the peel followed by nodes were higher than in the flesh. In the flesh, it was $\approx 50\,\mu g\,g^{-1}$, and in the peel it was in the range 200–400 $\mu g\,g^{-1}$ (Figure 2b). Even though exchangeable levels are low, Mn is the second element, which accumulated in all three parts, but with slight preference towards the flesh (Figure 2c). The BAF values ranged between 0.8 and 4.8, lowest being at site 4, which also recorded a lowest exchangeable Mn concentration. Zn levels in the three parts of the ginger, averaged about 20 $\mu g\,g^{-1}$ (Figure 2d), but BAF values were always lower than unity. Copper (Figure 2e), chromium (Figure 2f) and nickel (Figure 2g) in three parts of ginger were equally distributed. While Cu and Cr were in 6–9 $\mu g\,g^{-1}$ range, Ni was about 1.2–1.8 $\mu g\,g^{-1}$. Except for site 3, where Cu BAF was 1.6, it was <0.8 in other sites and the corresponding values for Ni and Cr were always below 0.2.

The concentrations of Cu, Fe and Mg present in the ginger skin are higher than that present in the ginger 'flesh'. This implies that the peel probably acts as a 'barrier' by controlling the entry of these elements into the 'flesh', or the peel may be a store for these elements and provide the 'flesh' and other parts of the ginger plant with these elements, when in need. The same is seen for the ginger nodes. These elements are associated with

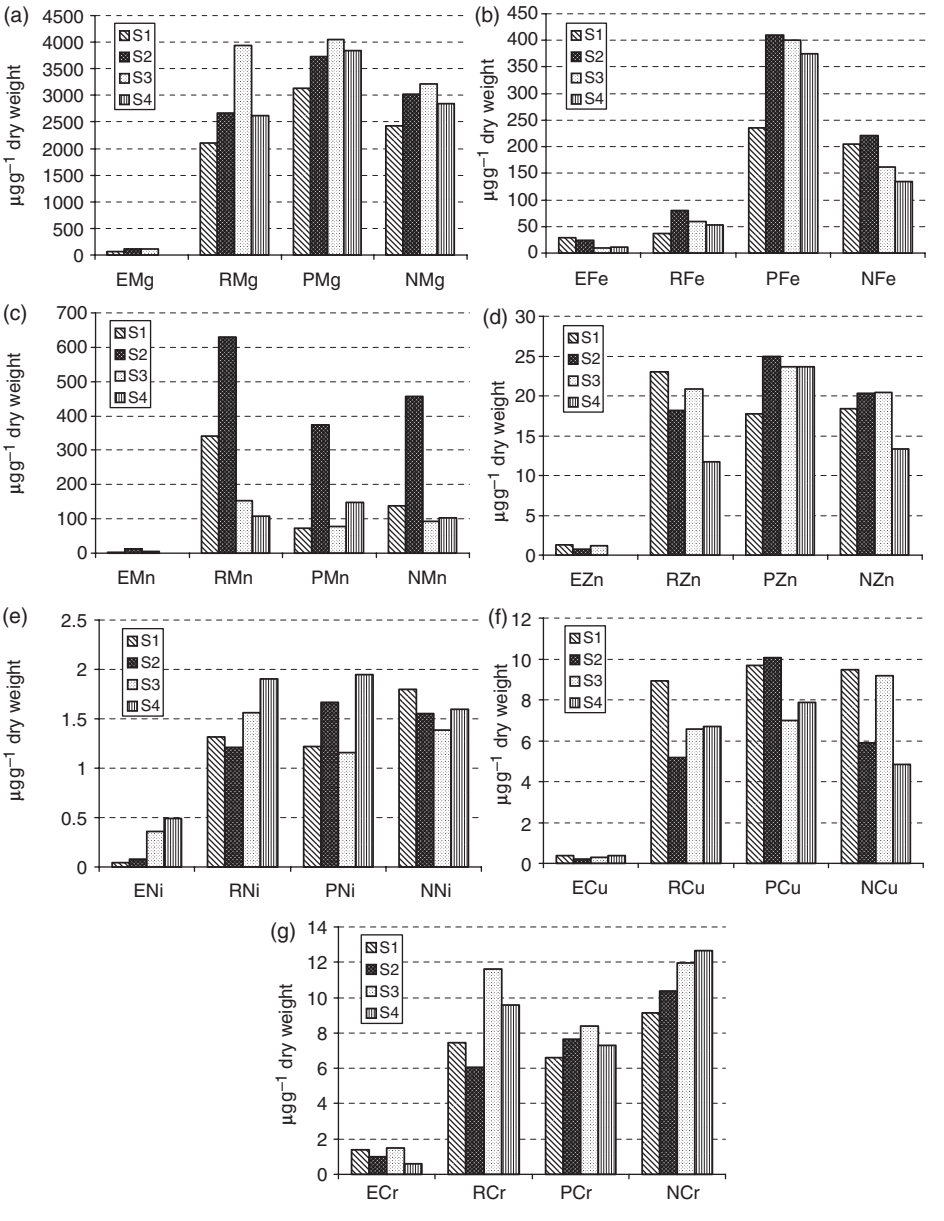

Figure 2. Elemental concentrations – Exchangeable in soil (E_E), total in ginger rhizome (R_E), ginger peel (P_E) and ginger nodes (N_E). Subscript E indicates the metal illustrated: (a) Mg, (b) Fe, (c) Mn, (d) Zn, (e) Ni, (f) Cu and (g) Cr.

various enzymatic processes. Thus, the high concentration of these elements in the ginger node implies that the processes, which require these elements are necessary for the growth of the ginger rhizome. Since the concentration of these elements decrease in the ginger flesh, it indicates that these elements were utilised during the growth of the ginger rhizome and the excess present is possibly stored in the ginger skin. The concentration of Cr in the

ginger node is also high. However, the essentiality of Cr to plants is not yet established, thus there is uncertainty for this observation. From the analytical data on the ginger flesh and skin, it could be possible that Cr may have a physiological role and hence the less restricted entry, unlike Pb, which had difficulty to entry ginger. Although exchangeable Pb existed in the soils, Pb was below the detection limit in any part of the ginger. Possibly, the plant possess the inherent ability to exclude Pb. This is assumed, since Pb is a toxic element and could play no positive role in the growth of the ginger plant. Further, no detectable levels of cadmium and arsenic, which are known toxic elements, were observed neither in the soils nor in the ginger.

3.3 *Correlation analysis*

In the correlation analysis, the significant relations are described based on the correlation coefficients, >0.8 as strong, >0.6 to <0.8 as good. Values >−0.8 as strongly antagonistic and >−0.6 to <−0.8 as antagonistic.

3.3.1 *Total elements in soil*

The association and antagonistic relations between the elements to the exchangeable cations and elemental levels in rhizome were mainly focused. With exception of Mg, in all cases the total (T) and corresponding exchangeable (E) concentrations are correlated. Total Fe is strongly correlated with total Zn, Ni, Cu and Cr (>0.8). The total Mg had good correlation with total Fe, Mn, Zn, Ni and Cr (>0.6–<0.8). While total zinc and Ni had good correlation with exchangeable Fe, total Mg and Mn were were antagonistic to Cr. Negra *et al.* [22] observed similar trends with reference to Mn correlation with other metals. Total Fe and Zn were antagonistic to rhizome elemental levels of Mg, and total Mn was strongly antagonistic to rhizome Zn.

3.3.2 *Exchangeable cations*

Exchangeable Mg and Mn were strongly correlated and both were strongly antagonistic to exchangeable copper. Exchangeable Zn had good correlation with exchangeable Fe and Mg. A strong correlation between exchangeable and rhizome concentrations for Mn, Ni and Cu was observed. Both exchangeable Fe and Zn levels were antagonistic to Ni and Cr in the rhizome. The observed trends for zinc were in accordance with literature reports [23,24].

3.3.3 *Rhizome(flesh)*

Generally a good correlation was observed between the levels observed in rhizome (R) and corresponding elemental levels in peel (P) and nodes (N). A strong correlation was observed between the levels of Zn and Mg in rhizome. Fe had good correlation with Zn, Mg, but strongly antagonistic with Cu. Zn, Mg, Ni and Cr were well correlated. Mn, the major element found in the rhizome, was strongly antagonistic to Ni and Cr.

The ranges of requirements or typical daily intakes of essential trace elements by humans in mg per day are Fe (10–18), Zn (6–15), Mn (1.25–6.5), Cu (1.0–3.8), Cr^{3+} (0.06–0.36), Se (0.03–0.05) and Co (0.015–0.160) [19]. Tables 6 and 7 summarise the literature reported dietary reference intakes (DRI) and the tolerable upper intake

Table 6. DRIs for individuals [11].

Life stage	Chromium (μg/day)	Copper (μg/day)	Iron (μg/day)	Magnesium (μg/day)	Manganese (μg/day)	Zinc (μg/day)
Infants						
0–6 months	0.2*	200*	0.27*	30*	0.003*	2*
7–12 months	5.5*	220*	11	75*	0.6*	3
Children						
1–3 years (y)	11*	340	7	80	1.2*	3
4–8 y	15*	440	10	130	1.5*	5
Males						
9–13 y	25*	700	8	240	1.9*	8
14–18 y	35*	890	11	410	2.2*	11
19–30 y	35*	900	8	400	2.3*	11
31–50 y	35*	900	8	420	2.3*	11
51–70 y	30*	900	8	420	2.3*	11
>70 y	30*	900	8	420	2.3*	11
Females						
9–13 y	21*	700	8	240	1.6*	8
14–18 y	24*	890	15	360	1.6*	9
19–30 y	25*	900	18	310	1.8	8
31–50 y	25*	900	18	320	1.8	8
51–70 y	20*	900	8	320	1.8*	8
>70 y	20*	900	8	320	1.8*	8

Notes: The adequate intakes (AIs) is indicated in ordinary type followed by an asterisk (*), whilst all other values indicated are the recommended daily allowance (RDA) values. RDA's and AIs may both be used as goals for individual intake [11].

Table 7. Tolerable ULs [11].

Life stage group	Cr	Cu (μg/day)	Fe (mg/day)	Mg (mg/day)[a]	Mn (mg/day)	Zn (mg/day)
Infants						
0–6 months	ND	ND	40	ND	ND	4
7–12 months	ND	ND	40	ND	ND	5
Children						
1–3 y	ND	1000	40	65	2	7
4–8 y	ND	3000	40	110	3	12
Males, Females						
9–13 y	ND	5000	40	350	6	23
14–18 y	ND	8000	45	350	9	34
19–70 y	ND	10,000	45	350	11	40
>70 y	ND	10,000	45	350	11	40

Notes: UL represents the maximum level of daily nutrient intake that is likely to pose no risk of adverse effects. Unless otherwise specified, the UL represents total intake from food, water and supplements. Due to the absence of ULs for arsenic and chromium care must be taken in consuming levels above recommended intakes.

[a]The ULs for magnesium represent intake from a pharmacological agent only and do not include intake from food and water.

ND indicates that the value for that element was not determinable due to lack of data of adverse effects in this age group and concern with regard to lack of ability to handle excess amounts [11].

levels, respectively, for certain elements investigated [11]. A comparison of this data with the total concentration present in the three parts of the ginger in the current studies will allow for the determination of the nutritional value of the ginger rhizome. A comparison of the total concentration of the elements present in the ginger with the DRI values show that the Cu, Fe and Zn concentration levels present in each part of the ginger are within the dietary reference intake levels for all life stages. This is based on the consumption of about 1 g of the ginger and the exclusion of other sources of these elements. In addition, a 1 g consumption of ginger shows that the Cr dietary reference levels are exceeded for infants, children, male and females, the Mg dietary reference levels are exceeded for infants in the age group 0–6 months and the Mn dietary reference levels are exceeded for infants in the age group 0–6 months. It is imperative that care is taken when consuming ginger in conjunction with other sources of these elements to ensure that the levels consumed are kept within the DRI levels. Thus, from this comparison it is noted that ginger does have nutritional value; however, the consumption of this plant is not entirely ideal for infants in the age group 0–6 months.

The comparison of the total concentration of the elements present in the ginger 'flesh', ginger skin and ginger node indicate that the concentrations present are within the tolerable upper intake levels. This implies that a 1 g consumption of ginger will not pose toxicological effects and is therefore not harmful to human health. This deduction, once again, excludes any other source of these elements.

The BAF for each element can be plotted against the concentration of the element in the soil. According to Timperly *et al.* [25] the shape of the plot obtained will provide information pertaining to the essentiality and non-essentiality of the element to the plant. A linear plot of the BAF as a function of the soil concentration should yield a shape approximating to a rectangular hyperbola, if the element is essential to the plant. If the plot of BAF against the soil content yields a graph parallel to the x-axis, it indicates that the element is not essential to the plant. However, only four points is insufficient to obtain a valid plot, thus, it is necessary to analyse more sites to obtain a greater number of points on the graph. This would yield a more conclusive deduction of the elements, which are essential or non-essential.

4. Conclusions

It can be concluded that the soil quality does have an impact on the elemental distribution within the ginger rhizome; however, the ginger rhizome has the inherent ability to control the amount of elements entering it. Ginger exhibited bioaccumulating characteristic towards Mg and Mn. It also contains significant levels of Fe and Mn, which are essential for body. No Pb in ginger was detected, despite of soil having lead. Low levels of nickel were found in the rhizome. A strong correlation between soil exchangeable and corresponding rhizome concentrations of Mn, Ni and Cu was observed. Exchangeable Fe and Zn were antagonistic with rhizome Ni and Cr. A strong to good correlation was observed between Zn, Mg and Fe levels in rhizome which were antagonistic to Cu. Mn was strongly antagonistic to Ni and Cr in rhizome. The amount of elements present in the soils is within the allowed limits and poses no toxicity threats. A 1 g consumption of ginger provides an amount of Cr, Cu, Fe, Mg, Mn and Zn that is within the dietary reference intake levels for almost all life stages. In addition, the concentration of these elements does not exceed the threshold upper intake levels and thus does not pose toxicity issues.

As bulk of the elements in the vegetables will be bioavailable, it is important to reduce the levels of toxic metal to protect the health risks through diet. The toxic metal pollution of water cycles and food chains can be prevented by implementing the guiding principles and regulations for acceptable levels. Thus, the soils polluted with toxic metals should be avoided from growing species that have tendency to accumulate such metals. Finally, it should be noted that this is a small study involving limited number of samples and the results are indicative. An increased number of sites and larger number of samples from each site should be assessed to validate the conclusions drawn.

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