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SHORT COMMUNICATION

Evaluation of mineral bioavailability and heavy metal content in indigenous food plant wild yams (*Dioscorea* spp.) from Koraput, India

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Abstract Wild yam (*Dioscorea* spp.) tubers, an indigenous food makes a significant contribution to the diets of tribal people of Koraput, India. However, there is dearth of documented information of their mineral bioavailability and heavy metal content. To know their quality and safety concerns about their use, minerals and heavy metal concentrations were evaluated in eight wild and one cultivated yam species from Koraput. The samples were further investigated for their antinutrients to determine bioavailability of minerals. The majority of the wild yam tubers were rich in some of the essential minerals like calcium (18.08–74.79 mg/100 g), iron (11.15–28.61 mg/100 g), zinc (2.11–6.21 mg/100 g) and phosphorous (179–248 mg/100 g). The heavy metals concentration (mg/100 g) ranged from: cobalt (1.06–1.98), nickel (0.30–0.89), chromium (2.10–4.53) and lead (0.11–0.93) among the studied yam species. These values were lower than the recommended tolerable levels proposed by WHO Expert Committee on Food Additives. Based on these results of molar ratio between phytate and Fe, Zn and Ca were below the suggested critical values indicating the bioavailability of Fe, Zn and Ca to be high. The study also suggests these wild yam species as the safe food sources for mass consumption and can be beneficial for health.

Keywords Anti-nutrient · Heavy metal · Mineral composition · Wild yam species

Introduction

Yam (*Dioscorea* spp.) is a high value crop that forms about 10% of the total roots and tubers produced worldwide (FAO 2002). Wild yams make a significant contribution both as root crops and vegetables to the diets of tribal people in the world especially in the tropics and sub tropics (Bhandari et al. 2003; Ngo Ngwe et al. 2015). There is an enormous diversity in the wild and cultivated yam species that are being used by tribal communities as indigenous food (Dansi et al. 1999; Behera et al. 2009; Adepoju et al. 2018). These species are unique for their food, medicinal and economic values due to the presence of different bioactive constituents (Padhan and Panda 2016). However their wider utilization is limited due to the presence of anti-nutritional compositions (Behera et al. 2009; Adepoju et al. 2018), which are associated with irritation, inflammation and gastrointestinal disturbances (Bhandari et al. 2003) and may have adverse effects on bioavailability of useful minerals (Gemede et al. 2015). In contrast to cultivated tubers, little is known about the mineral/metal composition of wild tubers and its chemical profiling is essential in order to integrate them in developmental interventions.

Koraput is one of the tribal dominated districts of Odisha state in India, harbouring rich genetic diversity of tuberous plants (Mishra and Chaudhury 2012). There are several wild *Dioscorea* species have been used as traditional food by the tribal people of Koraput (Mishra et al. 2011). The tribal people have been consuming these wild tubers in different forms, mainly boiled, fried, or baked (Padhan and Panda 2016). In spite of their importance as an

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indigenous food, to the best of our knowledge there is no published study on the mineral bioavailability and anti-nutrients of wild yam species of Koraput. As trace elements have certain health benefits at lower concentrations, but at higher levels, they can be toxic and pose health risks (Bhat et al. 2010). Thus, it is important to determine the levels of these compounds in these under-utilised wild tubers for safety concerns about their use. Therefore, the major objective of this study was to evaluate and provide baseline information on the mineral composition and heavy metal contents in different high value wild yam tubers of Koraput.

Materials and methods

The study was conducted with eight edible wild yam tubers namely *Dioscorea oppositifolia*, *D. hamiltonii*, *D. bulbifera*, *D. pubera*, *D. pentaphylla*, *D. wallichii*, *D. glabra* and *D. hispida* along with one cultivated species *D. alata*, which have been frequently used as traditional food by the tribal people of Koraput. The mature tubers of different species were collected from the medicinal garden of Central University of Orissa, Koraput, grown under the same climatic and agronomic condition. After collection, the tubers were washed, peeled, made into small slices and shade dried for 4–6 days at 25 ± 2 °C in the laboratory. The dried tuber samples were mechanically ground into powder (2 mm particle size) and stored in airtight containers for further analysis.

Minerals and heavy metals content analysis was determined according to AOAC (2012). The trace elements such as calcium, iron and zinc and the heavy metals such as nickel, cobalt, chromium and lead were determined by di-acid digestion method with a mixture of nitric and perchloric acid (6:2) at 100 °C. The digested sample was used for measurement of above minerals by using an Atomic Absorption Spectrophotometer (Parkin Elmer AAS, Analyst AA-200). Phosphorus contents were estimated using potassium dihydrogen phosphate as the standard in a spectrophotometer (BIO Spectrophotometer, Eppendorff, Germany) according to the method of James (1995).

The oxalate content was determined by extraction of the samples with water for about 3 h and the standard solutions of oxalic acid prepared and read on spectrophotometer (BIO Spectrophotometer, Eppendorff, Germany) at 420 nm following the method of Meena et al. (1987). Phytate was determined spectophotometrically according to the method described by Wheeler and Ferrel (1971). Briefly, phytate was extracted with TCA and treated with ferric chloride. The precipitate was washed with NaOH followed by dissolved in nitric acid. The solution was mixed with potassium thiocyanate and the colour was measured spectophotometrically (BIO Spectrophotometer, Eppendorff, Germany) at 480 nm. The molar ratio between anti-nutrients and minerals was obtained after dividing the mole of anti-nutrient with the mole of minerals with its atomic weight (phytate: 660 g/mol; Fe: 56 g/mol; Zn: 65 g/mol; Ca: 40 g/mol). The phytate phosphorous was calculated by assuming phytate contains 28% phosphorus following the method Woldegiorgis et al. (2015).

The data reported in all the tables are average values of triplicate determinations ($n = 3$). Differences between various parameters were compared by one way analysis of variance (ANOVA) using CROPSTAT (International Rice Research Institute, Philippines) software. The statistical significance of the parameter means were determined by performing the *Fisher's* least significance difference (LSD) test.

Results and discussion

Mineral compositions

The mineral compositions of different yam (*Dioscorea*) tubers from Koraput are presented in Table 1. There was significant ($P < 0.05$) differences of mineral compositions were observed among samples. Such variation among the yam species might be related to their genetic origin and geographical sources where they are grown. Minerals are considered to be essential in human nutrition and helps in the maintenance of acid–base balance, response of nerves to physiological stimulation and blood clotting (Valvi and Rathod 2011; Otegbayo et al. 2018). The results showed that phosphorus were the abundant minerals, ranging from 179 to 248 mg per 100 g dry weight. The level of values was higher than those reported for several cultivated yam species (FAO 1990). Zinc was the least abundant minerals, which ranged from 2.11 to 6.21 mg per 100 g dry weight among the studied yam species. The values of iron and calcium content of different *Dioscorea* species ranged from 11.15 to 28.61 mg/100 g and 18.08 to 74.79 mg/100 g dry weight, respectively. Some wild species such as *D. hamiltonii*, *D. pubera*, *D. oppositifolia* and *D. wallichi* showed significantly higher calcium and phosphorous content compared to the cultivated (*D. alata*) species. The levels of trace metals, such as iron, calcium and zinc in the studied yam tubers were consistent with the values reported for different tropical yam species from Nepal (Bhandari et al. 2003), south pacific region (Bradbury and Holloway 1988) and yam species from Sri Lanka (Wanasundera and Ravindran 1994). Based on these results, some wild yam species, such as *D. hamiltonii*, *D. pubera* and *D. oppositifolia* showed significantly ($P < 0.05$) higher mineral compositions and indicated their nutritional superiority

Table 1 Mineral and heavy metal compositions (mg/100 g) in different yam tubers from Koraput, India

Species	Fe	Ca	Zn	P	Co	Ni	Cr	Pb
D. oppositifolia	26.61 ± 0.27[b]	52.32 ± 0.33[b]	4.70 ± 0.27[b]	235.37 ± 2.01[b]	1.43 ± 0.21[b]	0.61 ± 0.06[b]	3.31 ± 0.14[b]	0.58 ± 0.08[c]
D. hamiltonii	28.61 ± 0.85[a]	46.17 ± 0.20[b]	3.60 ± 0.31[c]	214.63 ± 1.85[c]	1.98 ± 0.16[a]	0.68 ± 0.05[b]	3.60 ± 0.23[b]	0.30 ± 0.01[d]
D. pubera	24.18 ± 0.62[b]	74.79 ± 0.40[a]	6.21 ± 0.18[a]	248.27 ± 2.00[a]	1.59 ± 0.24[b]	0.57 ± 0.03[b]	3.15 ± 0.07[b]	0.18 ± 0.06[d]
D. wallichii	17.09 ± 0.57[d]	69.28 ± 0.31[a]	5.45 ± 0.33[b]	213.93 ± 2.35[c]	1.22 ± 0.16[c]	0.79 ± 0.11[a]	4.25 ± 0.15[a]	0.93 ± 0.02[a]
D. hispida	11.15 ± 0.29[f]	18.08 ± 0.17[d]	2.55 ± 0.55[d]	179.23 ± 2.15[e]	1.65 ± 0.10[b]	0.30 ± 0.03[c]	4.38 ± 0.21[a]	0.15 ± 0.07[a]
D. pentaphylla	19.61 ± 0.31[c]	40.73 ± 0.31[c]	2.11 ± 0.22[d]	200.93 ± 2.11[d]	1.06 ± 0.04[c]	0.50 ± 0.01[b]	4.53 ± 0.41[a]	0.38 ± 0.05[d]
D. bulbifera	13.50 ± 0.13[e]	32.16 ± 0.32[e]	2.53 ± 0.16[d]	205.97 ± 3.28[c]	1.11 ± 0.14[c]	0.31 ± 0.02[c]	4.30 ± 0.39[a]	0.25 ± 0.01[d]
D. glabra	13.66 ± 0.03[e]	31.20 ± 0.11[e]	2.56 ± 0.14[d]	184.83 ± 1.68[e]	1.58 ± 0.03[b]	0.89 ± 0.04[a]	4.08 ± 0.11[a]	0.73 ± 0.04[b]
D. alata	19.75 ± 0.24[c]	43.13 ± 0.16[c]	3.43 ± 0.21[c]	218.20 ± 1.64[c]	1.16 ± 0.15[c]	0.37 ± 0.17[c]	2.10 ± 0.14[c]	0.11 ± 0.02[d]
Mean	19.35	45.32	3.68	211.26	1.42	0.55	3.74	0.40
LSD ($P < 0.05$)	1.39	8.66	0.70	10.17	0.27	0.16	0.60	0.20
CV (%)	3.10	0.60	8.30	0.90	9.5	9.0	1.6	6.3
Critical limit[a] (mg/kg)					1.5	67	2.3	0.3

Data are the mean of three replications ± SD. Means followed by a common letter in the same column are not significantly different at the 5% level by *Fisher's* least significance difference (LSD) test

CV coefficient of variance

[a]WHO (2001)

compared to the cultivated (*D. alata*) species. Deficiency of calcium, zinc and iron in the diet is a widespread problem and a matter of great concern, especially in developing countries where people rely more on vegetarian diets (Hemalatha et al. 2007; Bhat et al. 2010). These essential trace elements play a significant role in neurochemical transmission and also serve as constituents of biological molecules as a cofactor for various enzymes and in a variety of different metabolic processes (Bhat et al. 2010). Hence, this tuber might be a useful dietary supplement to provide calcium, zinc and iron, especially for vegetarians. Plant materials with high concentrations of the above-mentioned mineral elements will definitely play an important role in maintenance of human health as reported earlier by Bhat et al. (2010) and Otegbayo et al. (2018).

Heavy metal compositions

The heavy metals such as cobalt, nickel, chromium and lead content in studied yam (*Dioscorea*) tubers are presented in Table 1. There was significant ($P < 0.05$) differences of heavy metal compositions were observed among the samples. The levels of heavy metal contents were significantly ($P < 0.05$) higher in wild yam species compared to the cultivated species (*D. alata*). Such variation among the yam species might be related to their genetic factors, geographical variations in the level of soil fertility, efficiency of mineral uptake, and the analytical procedures employed (Bhat et al. 2010; Otegbayo et al. 2018). The heavy metals concentration ranged from: cobalt (1.06–1.98 mg/100 g), nickel (0.30–0.89 mg/100 g), chromium (2.10–4.53 mg/100 g) and lead (0.11–0.93 mg/100 g) among the studied yam species. These values were lower than the recommended tolerable levels proposed by WHO Expert Committee on Food Additives (WHO 2001). The permissible limit recommended by WHO (2001) were 2.3 mg/kg for Cr, 67 mg/kg for Ni and 0.3 mg/kg for Pb and 1.5 mg/kg for Co in the edible plants. Monitoring the presence and concentrations of heavy metals in food plants used by the human being is crucial because of safety concerns about their use and at higher levels, they can be toxic and pose health risks (Bhat et al. 2010; Otegbayo et al. 2018). Hence consumption of these tubers may not have any health risk for consumers and as the safe food sources for mass consumption.

Anti-nutrients compositions

The anti-nutrient (phytate and oxalate) content in different wild and cultivated yam tubers are shown in Fig. 1. The level of anti-nutrient (phytate and oxalate) was significantly ($P < 0.05$) higher in some wild *Dioscorea* species compared to the cultivated one (Fig. 1). The range of oxalate and phytate content varied from 0.135 to 0.512 mg/

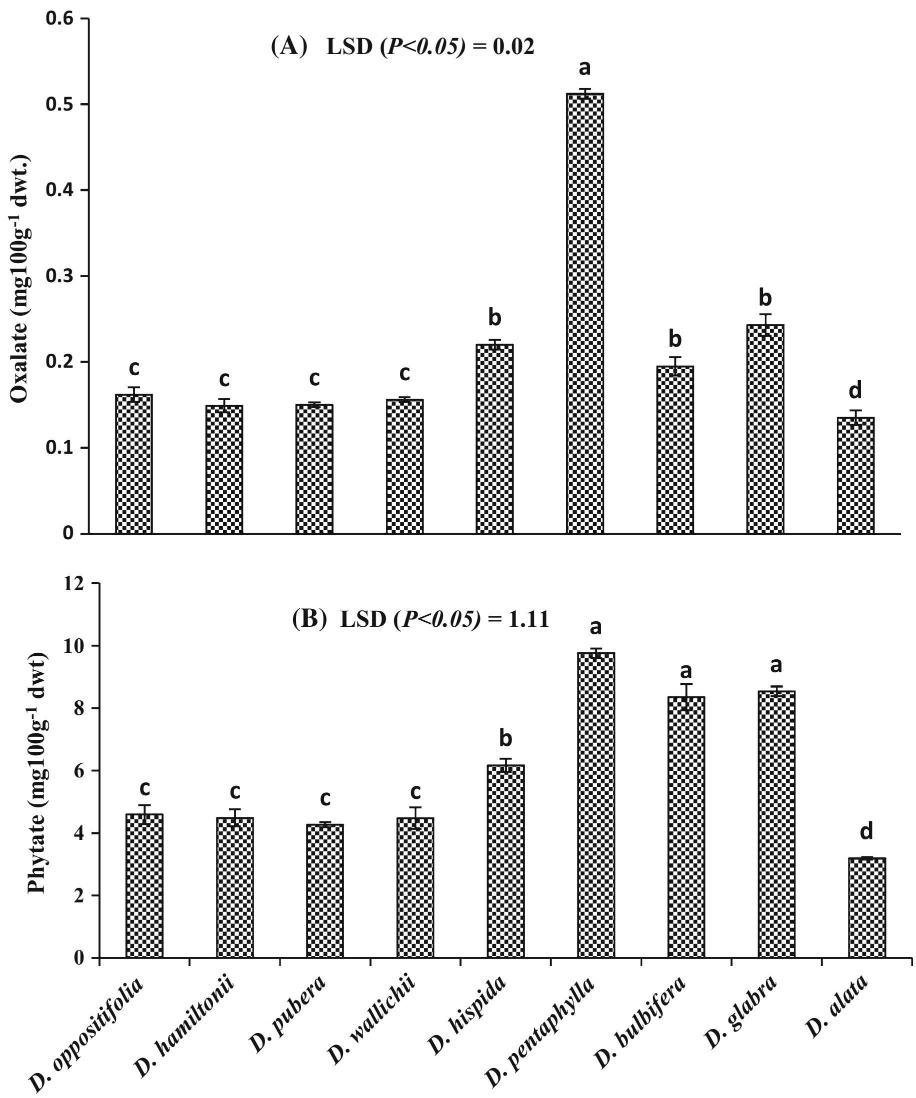

Fig. 1 Anti-nutrients, such as oxalate (**a**) and phytate (**b**) content in different wild and cultivated yam tubers from Koraput, India. Data are the mean of three replications with vertical bar represents standard deviation. Means followed by a common letter are not significantly different at the 5% level by *Fisher's* least significance difference (LSD) test

100 g and 3.19 to 9.76 mg/100 g dry weight, respectively. The level of phytate and oxalate in the studied tuber is lower than the value reported by Polycarp et al. (2012) in Ghanaian yam tubers. The critical limiting range for intake of oxalate and phytate in the diet is below 50–60 mg/day and 10–60 mg/day respectively (Massey et al. 2001). Anti-nutrients are the chemical compounds synthesized in natural food by normal metabolism which decreases the nutritive value of food (Woldegiorgis et al. 2015). The range of dietary phytate at low level may have beneficial role as an antioxidant, anticarcinogens and likely play an important role in controlling hypercholesterolemia and atherosclerosis (Phillippy et al. 2004). Since, yams are usually consumed after cooking and the phytate and oxalate content would have been reduced during food processing (Otegbayo et al. 2018). If these anti-nutrients are consumed over a long period of time results in decrease bioavailability of minerals (Woldegiorgis et al. 2015). The anti-nutrients (phytate and oxalate) have the ability to form insoluble complexes with positively charged food components such as protein, carbohydrate, minerals and trace elements. These complexes lead to reduced bioavailability of calcium, zinc and iron (Otegbayo et al. 2018).

Molar ratios and bioavailability of minerals

The molar ratios for phytate, oxalate, zinc, iron and calcium were calculated to evaluate the effects of elevated levels of oxalate and phytate on the bioavailability of these minerals (Table 2). Bioavailability is the ability of the body to digest and absorb the mineral from the dietary food (Fekadu et al. 2013). Phytate:Ca molar ratio has been proposed as an indicator of Ca bioavailability as phytate decreases the absorption of Ca by forming insoluble complexes with them (Woldegiorgis et al. 2015). The critical molar ratio of phytate:Ca is reported to be < 0.24

Table 2 Molar ratio between anti-nutrients and minerals in different yam tubers from Koraput, India

Species	Phytate:Ca (molar ratio)	Phytate:Fe (molar ratio)	Phytate:Zn (molar ratio)	Oxalate:Ca (molar ratio)	Phytate P (mg/100 g)
D. oppositifolia	0.0042 ± 0.0001[d]	0.011 ± 0.001[c]	0.074 ± 0.010[c]	0.0031 ± 0.0001[b]	1.01 ± 0.09[bc]
D. hamiltonii	0.0045 ± 0.0001[d]	0.010 ± 0.001[c]	0.096 ± 0.001[b]	0.0032 ± 0.0002[b]	0.98 ± 0.07[c]
D. pubera	0.0034 ± 0.0001[d]	0.015 ± 0.001[b]	0.068 ± 0.003[c]	0.0020 ± 0.0001[b]	1.19 ± 0.02[b]
D. wallichi	0.0039 ± 0.0001[d]	0.022 ± 0.003[b]	0.084 ± 0.012[c]	0.0012 ± 0.0001[c]	1.25 ± 0.10[b]
D. hispida	0.0173 ± 0.0005[b]	0.039 ± 0.001[a]	0.217 ± 0.008[b]	0.0012 ± 0.0002[c]	1.45 ± 0.06[b]
D. pentaphylla	0.0145 ± 0.0001[bc]	0.042 ± 0.001[a]	0.437 ± 0.051[a]	0.0061 ± 0.0002[a]	2.73 ± 0.04[a]
D. bulbifera	0.0157 ± 0.0006[b]	0.052 ± 0.002[a]	0.319 ± 0.035[a]	0.0011 ± 0.0003[c]	2.34 ± 0.12[a]
D. glabra	0.0244 ± 0.0004[a]	0.014 ± 0.001[bc]	0.328 ± 0.012[a]	0.0032 ± 0.0006[b]	2.39 ± 0.04[a]
D. alata	0.0045 ± 0.0003[d]	0.029 ± 0.001[b]	0.093 ± 0.005[bc]	0.0062 ± 0.0002[a]	0.90 ± 01[c]
Mean	0.0103	0.029	0.191	0.0062	1.58
LSD ($P < 0.05$)	0.001	0.014	0.121	0.0016	0.39
CV (%)	3.8	5.8	16.0	4.4	4.7
Critical limit[a]	< 0.24	> 0.15	15.0	1.0	

Data are the mean of three replications ± SD. Means followed by a common letter in the same column are not significantly different at the 5% level by *Fisher's* least significance difference (LSD) test

CV coefficient of variance

[a]Otegbayo et al. (2018)

for good calcium bioavailability (Woldegiorgis et al. 2015; Otegbayo et al. 2018). In the present study, the molar ratio of phytate:Ca of studied yam species were less than the reported critical value, which indicated that the absorption of calcium would not be adversely affected by phytate as earlier reported in Nigerian yam tubers (Otegbayo et al. 2018). Phytate have inhibitory effect on iron absorption when phytate:Fe molar ratios greater than 0.15 regarded as indicative of poor iron bioavailability (Hurrel et al. 2003). The phytate:Fe molar ratios in the studied yam tubers had lower than the critical limits, which implies the bioavailability of Fe in these yam tubers was high and the absorption of iron may not inhibited by phytate. Similarly, the phytate:Zn molar ratio is considered as better indicator of zinc bioavailability than total dietary phytate levels alone (Woldegiorgis et al. 2015; Otegbayo et al. 2018). Our result was lower than the critical value of phytate:Zn (15:1) indicating that the bioavailability of Zn in these yam tubers was high and it was not likely to be affected by phytate (Otegbayo et al. 2018). Oxalate can have deleterious effects on human nutrition and health, particularly by decreasing the calcium absorption to the body (Bhandari and Kawabata 2004). The plant product with the molar ratio of oxalate:Ca is greater than one showed chronic deficiency of dietary calcium (Frontela et al. 2009; Otegbayo et al. 2018). The oxalate:Ca molar ratio in the studied yam tubers had lower than the reported critical value (1.0). These results suggested that the low level of oxalate in the yam tuber have no adverse effects on bioavailability of dietary calcium as reported earlier in Nigerian yam tuber (Otegbayo et al. 2018). In addition, the proportion of phytate phosphorus was ranged from 0.90 to 2.73 mg/100 g among the studied yam tuber (Table 2). However, the high proportion of phosphate as phytate has consequences for bioavailability of minerals and trace elements (Woldegiorgis et al. 2015). In the studied yam species the proportion of phosphate as phytate is low as phosphorus was the abundant minerals in the tuber and hence bioavailability of phosphorous is more.

In conclusion, wild yam tubers were found to be fairly good sources of dietary minerals such as calcium, iron, zinc and phosphorus, which are known to be beneficial for health. The levels of heavy metal concentrations were lower than the recommended tolerable levels proposed by WHO Expert Committee on Food Additives. Hence it is suggested that the consumption of these tubers may have certain health benefits without any health risk for consumers. This result also suggested that these less familiar wild tubers can be used as a good alternative source of food to alleviate hunger and malnutrition.

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Author contributions BP and DP designed the experiments, collected the tuber. BP and MB performed the biochemical analysis. NKD performed the metal analysis. DP analyzed the data and wrote the paper. All authors read and provided helpful discussions for the manuscript.

Compliance with ethical standards

Conflict of interest The authors report no conflicts of interest.

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