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Mineral content of tropical fruits and unconventional foods of the Andes and the rain forest of Colombia

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Abstract

A total of 68 species of starchy foods, tropical fruits, leaves and tubers (101 samples), were collected on the foothills of the Colombian Andes and in the rain forests of the Colombian Pacific coast. Their edible portion was analyzed for mineral content (Ca, P, Mg, K, Na, Cl, S, Mn, Zn, Fe, Cu, Se, Co, Ni). The foods were generally high in K (36–1.782 mg K/100 g edible portion) and low in sodium (<45 mg Na/100 g edible portion). The tree foliages had the highest contents in most of the elements, especially in calcium (280–1242 mg Ca/100 g edible portion, i.e., up to 62 g Ca/kg dry matter) and iron (0.7–8.4 mg Fe/100 g edible portion). Correlations ($P < 0.001$) were observed between total ash and many elements, especially Ca and Mg ($r =$ 0.77 and 0.73, respectively). High correlations were also obtained between Ca and Mg ($r = 0.93$).

Keywords: Mineral content; Fruit; Tree foliage; Tuber; Colombia; Tropics

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1. Introduction

Many current human health problems relate to diets. Micronutrients are involved in numerous biochemical processes and an adequate intake of certain micronutrients relates to the prevention of deficiency diseases. Malnutrition is of major concern for many tropical developing countries. Iron deficiency anaemia, for example, affects one third of the world population (Kumari, Gupta, Lakshmi, & Prakash, 2004).

Fruits and vegetables are valuable sources of minerals (Milton, 2003; Smolin & Grosvenor, 2000). Diets high in fruits and vegetables are also linked to decreased risk of diseases (diabetes, cancer, etc) and their consumption should be encouraged (Bernstein et al., 2002; Leterme, 2002).

The tropics produce a very large number of edible fruits. Paradoxically, the number of species consumed extensively is limited, due to low availability, lack of inversion, poor knowledge of the production or conservation systems and is also related to fruit quality.

New initiatives in agroforestry are seeking to promote poverty alleviation, environmental rehabilitation and people welfare, through the integration of indigenous trees into farming systems (Leakey, 1999). This integration aims to provide people's needs for food and nutritional security. However, this implies a better knowledge of the nutritional quality of these products. Currently, little information is available on that topic.

The present work aimed to study the mineral composition of a large number of fruits and unconventional foods (nuts, leaves and tubers) produced in agroforestry

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farming systems in the Andes and in the rain forests of Colombia.

2. Material and methods

2.1. Sampling

All the samples of fruits, leaves and tubers were collected in the Colombian Andes, around and in the Cauca river valley as well as in the rain forests of the Colombian Pacific coast. In the latter case, the fruits came mainly from the valley of the Baúdo river and were bought to farmers along the river (Ocampo, Leterme, & Buldgen, 2005). They were collected in the morning, sent by boat to Qu͘ibdo and sent the next day by airmail to the Lab of the National University of Colombia. The rotten fruits or those contaminated by mould (0–60% according to the species) were discarded. The amount of fruit collected ranged from 1 to 3 kg, depending on the species. They were kept at −15 °C. The leaves were collected in small farms on the foothills of the Andes. The samples (±1 kg fresh leaves) were immediately kept in cold boxes, sent to the laboratory and kept at −15 °C. Before any processing, the scientific name of the species was determined, sometimes with the help of botanists.

2.2. Processing

The fresh fruits were processed in order to separate the endocarp (seeds, stone), mesocarp (pulp) and exocarp (husk, skin, etc). Only the edible portion (pulp) was considered for analysis. The pulp was then freeze-dried and ground through a 1 mm-mesh screen by means of a Pulverisette-14 Fritsch lab mill (Idar-Oberstein, Germany). The leaves were immediately frozen, freeze-dried and ground. The skin of the tubers was thoroughly washed, removed and the tuber cut in small pieces of 1 cm^3, freeze-dried and ground. All the samples were then sealed in plastic bags and sent by express mail to the Lab of Analytical Chemistry of the Faculty of Gembloux (Belgium).

2.3. Analyses

For the analysis of Ca, P, Mg, K, Na, Zn and Cr, the samples (1 g), placed in platinum crucibles, were calcined in a furnace at 450 °C for 6 h. The ash was then weighed and put in solution in 5 ml $HNO_3/HClO_4$ (2/1). The solution was filtered for elimination of the silica, recovered in a 250 ml flask, added with pure HNO_3, heated and diluted. The minerals were then analyzed by atomic absorption spectrophotometry using a Perkin Elmer AAS-800 (Wellesley, MA), with the exception of P, which was analyzed by the colorimetric method using molybdovanadate reagent.

For the analysis of Fe, Mn, Ni, Cu, Se and Co, the samples (0.5 g) were placed in a 100 ml-flask with 5 ml HCl/HNO_3 (3/1), boiled for 2 h with a flowing back system and the solution was then filtered and recovered in a 50 ml flask. The minerals were then analyzed by atomic absorption spectrophotometry, with the exception of Se, which was analyzed, after reduction in a KI solution, with a spectrophotometer coupled to an hybride generator (FIAS-MHS).

Cl was analyzed after fusion of ash with CaO and dilution in a HNO_3 20% solution by titrimetry and S after addition of 1 g $MgNO_3$ to 1 g sample, calcination for 6 h at 450 °C and recovery of the ash in a HNO_3 solution, by turbidimetry.

The laboratory has the Statement of Good Laboratory Practices Compliance of the OECD and the European Union and uses reference samples provided by the Institute for Reference Materials and Measurements of the European Commission. The analysis (10 repetitions) of the reference sample (Beech leaves, IRM 100-463), compared to the lab, gave the following results (IRM vs. lab, respectively): Ca (5.30 ± 0.05 vs. 4.95 ± 0.10 g/kg DM), P (1.55 ± 0.04 vs. 1.45 ± 0.09), K (9.94 ± 0.20 vs. 9.63 ± 0.50), Mg (0.878 ± 0.017 vs. 0.886 ± 0.028), S (2.69 ± 0.04 vs. 2.36 ± 0.21), Cl (1.49 ± 0.06 vs. 1.38 ± 0.15). The limits of quantification (LOQ) for the mineral analyses were: ash 0.05%; Ca 0.003%; P 0.001%; Mg 0.003%; K 0.005%; Na 0.005%; S 0.005%; Cl 0.01%; Zn 0.5 mg/kg DM; Ni 0.1 mg/kg DM; Cu 0.5 mg/kg DM; Mn 0.5 mg/kg DM; Fe 5 mg/kg DM; Se 0.01 mg/kg DM and Co 0.01 mg/kg DM.

2.4. Statistical analyses

Relationships between mineral contents were tested by means of the Pearson correlation test, using the Instat 3.0 statistical software of GraphPad, San Diego, CA.

3. Results

The composition in macrominerals of the fruits and unconventional foods is detailed in Table 1. K presented the highest content in the majority of the cases and represented, on average, 32 ± 10% of the total mineral content. On the contrary, Na and Cl presented low concentrations. The leaves, in particular those of the *Trichanthera* tree, distinguished themselves from the other foods by a higher concentration in most of the elements, especially in Ca. Globally, the starchy foods, the tubers and the fleshy fruits presented a similar pattern, with the exception of K, which concentration was variable but high in tubers. The nuts, such as *Pachira aquatica*, *Sterculia apetala* and *Caryodendron orinocence* also

Table 1
Macro-mineral content of tropical fruits and unconventional foods of Colombia (mg/100 g edible portion)

Scientific name	Common name	Family name	DM (%)	Ash	Ca	P	K	Mg	Na	Cl	S
*Starchy foods, nuts (**N**) and palms (**P**)*											
Artocarpus communis Forst.	Breadfruit	Moraceae	41.1	1146	31	80	618	44	27	<0.1	31
Artocarpus communis Forst.	Breadfruit	Moraceae	39.8	1315	40	116	519	53	22	<0.1	22
Artocarpus communis Forst.	Breadfruit	Moraceae	43.0	1221	49	89	471	49	5	<0.1	22
Artocarpus communis Forst.	Breadfruit	Moraceae	42.1	1185	54	7	618	49	16	2	20
Bactris gasipaes Kunth.	Peach palm	Aracaceae	46.1	918	45	2	365	29	12	18	32
Bactris gasipaes Kunth.	Peach palm	Aracaceae	46.2	813	44	1	369	28	16	41	41
Bactris gasipaes Kunth.	Peach palm	Aracaceae	32.1	713	47	1	290	28	16	34	53
Bactris gasipaes Kunth.	Peach palm	Aracaceae	42.0	502	29	1	213	20	7	67	37
Caryodendron orinocense Karsten **N**	Inchi	Euphorbiaceae	91.7	2650	300	361	572	202	35	53	90
Erythrina edulis Triana ex. Micheli	Basul	Leguminosae	20.6	1124	12	68	502	38	12	10	24
Erythrina edulis Triana ex. Micheli	Basul	Leguminosae	19.4	1220	20	60	584	38	8	6	16
Manicaria saccifera Gaertn. **P**	Troolie palm	Aracaceae	56.1	1686	158	3	445	55	20	212	78
Musa acuminata Colla	Banana	Musaceae	28.0	942	26	3	400	27	10	28	4
Musa acuminata Colla	Banana	Musaceae	30.8	742	20	2	334	48	9	17	3
Musa acuminata Colla	Banana	Musaceae	29.4	1044	19	3	470	42	9	14	7
Musa acuminata Colla	Banana	Musaceae	32.8	1162	25	2	524	54	10	24	20
Musa paradisiaca L.	Plantain	Musaceae	25.0	1132	30	4	516	52	10	34	5
Oenocarpus bataua Mart. **P**	Milpesos	Aracaceae	18.7	328	30	1	138	12	6	14	17
Pachira aquatica Aubl. **N**	Guiana chesnut	Bombacaceae	94.6	3694	194	230	1782	503	27	71	81
Pachira aquatica Aubl. **N**	Guiana chesnut	Bombacaceae	93.2	3441	117	510	1081	412	45	52	53
Pachyrhizus erosus (L.) Urban	Yam bean, jicama	Fabaceae	33.1	496	317	83	150	38	31	<0.1	15
Sterculia apetala (Jacq.) H. Karsten **N**	Panama tree, chicha	Sterculiaceae	92.1	3108	50	403	1420	227	8	25	109
Sterculia apetala (Jacq.) H. Karsten **N**	Panama tree, chicha	Sterculiaceae	91.8	3377	84	286	1294	252	17	8	67
Wettinia quinaria (Cook & Doyle) Burret **P**	Palma meme	Aracaceae	56.2	575	100	40	220	60	10	35	75
Zea mays L.	Maize	Poaceae	85.8	1274	75	4	338	92	35	10	31
Zea mays L.	Maize	Poaceae	85.8	1274	75	4	338	92	35	10	31
Zea mays L.	Maize	Poaceae	86.2	1200	43	2	362	85	19	34	24
Zea mays L.	Maize	Poaceae	87.0	1211	24	13	131	50	17	52	17
Fleshy fruits											
Anacardium occidentale L.	Cashew fruit	Anacardiaceae	14.4	383	9	4	65	30	2	<0.1	10
Ananas comosus (L.) Merr.	Pineapple	Bromeliaceae	10.7	255	21	2	39	9	1	1	4
Annona muricata L.	Soursop	Annonaceae	13.6	1458	38	30	523	25	20	20	16
Annona reticulata L.	Custard apple	Annonaceae	16.0	1062	39	41	264	33	3	4	24
Annona squamosa L.	Sugar apple	Annonaceae	25.0	1397	68	10	551	60	19	2	28
Annona squamosa L.	Sugar apple	Annonaceae	22.1	991	47	18	368	34	8	3	13
Anonna cherimola Miller	Cherimoya	Annonaceae	26.0	1059	37	37	414	21	3	11	13
Averrhoa carambola L.	Star fruit, Carambola	Oxalidaceae	7.9	374	10	8	102	13	3	1	12
Borojoa sorbilis (Ducke) Cuter.	Borojo	Rubiaceae	40.5	1187	76	3	410	56	11	5	16
Calocarpum mammosum Pierre	Marmalade tree	Sapotaceae	27.7	1106	45	7	478	14	8	125	15
Carica papaya L.	Papaya	Caricaceae	10.1	320	16	5	85	10	7	47	5
Chrysophyllum cainito L.	Caimo dorado	Sapotaceae	16.6	691	27	3	245	11	7	28	5
Crescentia cujete L.	Calabash tree	Bignoniaceae	25.1	1195	30	7	593	46	17	22	11
Cucurbita maxima Duchesne	Pumpkin, squash	Cucurbitaceae	15.0	722	36	51	502	26	5	47	14
Cyphomandra betacea (Cav.) Sendt.	Tomate tree	Solanaceae	18.3	1260	26	9	524	20	6	18	15
Eugenia malaccensis L.	Malaya apple	Myrtaceae	10.5	623	15	6	164	25	10	1	9
Eugenia stipitata Mc Vaugh	Araza	Myrtaceae	14.0	388	25	7	78	9	2	<0.1	14
Eugenia uniflora L.	Surinam cherry	Myrtaceae	13.2	815	48	28	165	38	<0.1	<0.1	15
Feijoa sellowiana Berg	Feijoa, Guava	Myrtaceae	16.2	800	72	5	139	17	2	1	21
Flacourtia indica (Burm.f.) Merrill	Governor's plum	Flacourtiaceae	22.7	745	47	4	167	15	2	6	11
Gustavia superba (Kunth.) O. Berg	Paco	Lecythidaceae	20.7	1188	28	56	568	48	20	56	44
Gustavia superba (Kunth.) O. Berg	Paco	Lecythidaceae	19.8	1272	32	68	596	48	24	84	40
Gustavia superba (Kunth.) O. Berg	Paco	Lecythidaceae	20.3	1324	44	68	624	64	4	104	48
Hylocereus triangularis (L.) Britt. & Rose	Pitaya, Pitahaya	Cactaceae	21.0	367	31	5	207	23	8	2	9
Laetia americana L.	Manteco	Flacourtiaceae	20.1	1607	87	8	616	11	11	107	8
	Manteco	Flacourtiaceae	20.1	1607	87	8	616	11	11	107	8
Malpighia glabra L.	Acerola	Malpighiaceae	11.0	888	38	38	202	56	<0.1	33	16
Mammea americana L.	Mamey	Clusiaceae	9.7	246	29	8	36	9	<0.1	<0.1	5
Mangifera indica L.	Mango	Anacardiaceae	15.4	1104	79	5	176	31	4	1	20
Mangifera indica L.	Mango	Anacardiaceae	16.0	995	72	41	315	28	3	<0.1	19

Table 1 (*continued*)

Scientific name	Common name	Family name	DM (%)	Ash	Ca	P	K	Mg	Na	Cl	S
Matisia cordata H. & B	Zapote	Bombacaceae	15.8	883	50	14	371	15	3	46	8
Matisia cordata H. & B	Zapote	Bombacaceae	15.0	917	50	20	368	16	4	44	10
Meliococcus bijugatus Jacq.	Mamoncillo	Sapindaceae	22.8	1082	44	6	171	38	2	1	10
Morinda citrifolia L.	Noni	Rubiaceae	16.2	983	43	8	374	17	13	84	11
Myrciaria cauliflora (Mart.) O. Berg	Jaboticaba	Myrtaceae	15.8	479	22	2	213	16	5	5	9
Ocotea tenera Mez & Donn. Sm. ex Mez	Tenera	Lauraceae	14.1	1042	269	35	276	214	14	104	90
Passiflora edulis Sims	Passion fruit	Passifloraceae	13.9	595	28	35	100	26	30	14	16
Passiflora edulis Sims	Passion fruit	Passifloraceae	17.9	1887	53	26	764	16	16	128	18
Passiflora ligularis Juss	Sweet granadilla	Passifloraceae	26.3	1239	37	50	379	27	<0.1	44	16
Passiflora mollisima (H.B.K.) Bailey	Curuba	Passifloraceae	19.6	806	37	14	337	14	4	26	12
Phyllanthus acidus(L.) Skeels	Malay gooseberry	Euphorbiaceae	9.1	226	9	14	48	7	1	8	7
Physalis peruviana L.	Capegooseberry	Solanaceae	17.8	1155	23	27	467	19	6	1	10
Pourouma cecropiaefolia Mart.	Uvilla, Caimaron	Moraceae	15.0	860	96	10	116	50	1	1	18
Psidium guajava L.	Guava	Myrtaceae	15.3	928	29	5	366	17	7	4	12
Psidium guajava L.	Guava	Myrtaceae	18.9	670	20	46	332	12	5	17	9
Punica granatum L.	Granado	Punicaceae	30.0	950	35	2	411	19	10	108	10
Rheedia madruno (Kunth) Planch. & Triana	Madroño	Clusiaceae	15.6	984	60	3	400	17	5	13	39
Rubus glaucus Benth.	Andean raspberry	Rosaceae	13.2	515	49	7	95	25	1	1	7
Sechium edule (Jacq.) Sw.	Chayote	Cucurbitaceae	9.2	776	18	36	203	21	1	41	36
Solanum quinoense Lam.	Lulo, Naranjilla	Solanaceae	14.6	1247	22	22	264	31	2	22	16
Spondias mombin L.	Yellow mombin, Jobo	Anacardiaceae	21.2	333	23	20	140	12	3	4	5
Zizyphus jujuba Miller	Chinese date	Rhamnaceae	14.3	532	385	5	107	11	4	9	40
Leaves											
Trichanthera gigantea (H & B) Nees	Nacedero	Acanthaceae	12.6	5065	972	72	634	180	11	104	67
Trichanthera gigantea (H & B) Nees	Nacedero	Acanthaceae	20.6	5498	1136	27	508	164	6	124	79
Trichanthera gigantea (H & B) Nees	Nacedero	Acanthaceae	15.7	5564	1242	41	416	202	11	98	86
Trichanthera gigantea (H & B) Nees	Nacedero	Acanthaceae	18.3	5542	1080	32	461	153	6	158	102
Xanthosoma saggitifolium Schott	Elephant ear, giant taro	Araceae	12.3	2045	318	57	520	55	6	78	12
Xanthosoma saggitifolium Schott	Elephant ear, giant taro	Araceae	10.4	2242	372	36	493	104	4	65	14
Xanthosoma saggitifolium Schott	Elephant ear, giant taro	Araceae	11.0	1748	280	102	596	53	6	82	10
Tubers											
Alocasia macrorrhiza Schott	Upright elephant ear	Araceae	33.4	1106	33	135	495	228	10	2	4
Arracacia xanthorrhiza Brancroft	Arracacha	Apiaceae	24.1	783	36	68	453	12	10	1	15
Colocasia esculenta (L.) Schott	Wild taro, dasheen	Araceae	33.0	1045	30	20	287	33	36	3	7
Colocasia esculenta (L.) Schott	Wild taro, dasheen	Araceae	31.2	738	37	13	183	37	7	4	9
Colocasia esculenta (L.) Schott	Wild taro, dasheen	Araceae	29.8	905	50	50	277	27	10	2	30
Discorea alata L.	Winged yam, uvi	Dioscoreaceae	27.7	914	25	31	385	17	14	16	16
Discorea alata L.	Winged yam, uvi	Dioscoreaceae	24.3	881	36	33	488	20	6	11	3
Manihot esculenta L.	Cassava	Euphorbiaceae	40.0	1152	48	104	400	28	12	4	24
Maranta arundinacea L.	Arrowroot	Marantaceae	11.3	832	13	28	347	11	4	33	14
Oxalis tuberosa Mol.	Oca	Oxalidaceae	14.2	523	12	13	236	10	4	3	6
Solanum tuberosum L.	Potato	Solanaceae	26.6	906	16	47	296	16	2	34	10
Solanum tuberosum L.	Potato	Solanaceae	18.9	796	14	37	241	16	2	2	2
Ullucus tuberosus Caldas	Ulluco	Basellaceae	12.4	631	8	38	247	11	1	2	13
Xanthosoma saggitifolium Schott	Elephant ear, giant taro	Araceae	14.2	1577	71	51	876	26	4	49	5
Xanthosoma saggitifolium Schott	Elephant ear, giant taro	Araceae	9.5	1100	20	86	322	18	3	06	10
Xanthosoma saggitifolium Schott	Elephant ear, giant taro	Araceae	13.1	1592	66	19	517	24	3	55	06

contained more P, Mg, Zn, Fe and Cu than the fruits and the other starchy foods.

The composition in microminerals is presented in Table 2. The highest contents were observed for iron, especially in tree leaves, followed by Zn and Mn. The Cu contents were markedly lower. The content in some trace elements such as Co, Cr or Se were often below the detection levels (0.01 mg/kg DM).

Table 2
Micro-mineral content of tropical fruits and unconventional foods of Colombia (mg/100 g edible portion)

Scientific name	Mn	Zn	Fe	Cu	Se	Co	Ni	Cr
Starchy foods, nuts and palms								
Artocarpus communis	0.33	0.49	1.48	0.16	nd	nd	0.08	nd
Artocarpus communis	0.16	0.45	1.44	0.12	nd	nd	0.04	nd
Artocarpus communis	0.04	0.49	2.2	0.2	nd	nd	0.08	nd
Artocarpus communis	0.21	0.53	1.89	0.25	nd	nd	nd	nd
Bactris gasipaes	0.13	0.25	2.23	0.17	nd	nd	0.21	0.29
Bactris gasipaes	0.21	0.29	2.65	0.17	nd	nd	0.29	0.46
Bactris gasipaes	0.17	0.34	0.80	0.13	nd	nd	0.04	0.08
Bactris gasipaes	0.13	0.38	1.1	0.13	nd	nd	0.04	0.38
Caryodendron orinocense	1.66	2.94	4.23	1.10	nd	nd	nd	nd
Erythrina edulis	0.36	0.58	0.98	0.08	nd	nd	0.06	nd
Erythrina edulis	0.40	0.54	0.86	0.16	nd	nd	nd	nd
Manicaria saccifera	14.40	1.57	9.71	1.52	0.01	0.02	0.28	0.34
Musa acuminata	0.36	0.36	0.76	0.20	nd	nd	0.03	0.03
Musa acuminata	0.40	0.20	0.49	0.06	nd	nd	0.03	nd
Musa acuminata	0.32	0.25	2.62	0.09	nd	nd	0.03	nd
Musa acuminata	0.13	0.30	0.53	0.07	nd	nd	0.03	0.03
Musa paradisiaca	0.13	0.15	0.30	0.05	nd	nd	nd	nd
Oenocarpus bataua	0.32	0.26	1.40	0.15	nd	nd	nd	nd
Pachira aquatica	0.85	2.46	3.03	2.84	0.03	0.01	nd	0.04
Pachira aquatica	0.19	1.86	7.36	1.87	0.16	0.28	nd	0.02
Pachyrhizus erosus	1.35	2.34	10.44	0.27	0.03	0.01	0.27	0.18
Sterculia apetala	0.46	5.69	1.93	0.83	0.10	0.11	0.33	0.02
Sterculia apetala	0.56	5.70	1.87	1.21	0.09	0.09	0.37	0.01
Wettinia quinaria	2.02	2.42	16.35	1.80	nd	0.11	0.12	0.25
Zea mays	0.69	2.15	3.00	0.26	0.01	0.01	0.09	0.12
Zea mays	0.86	2.58	3.02	0.17	0.04	nd	0.17	0.17
Zea mays	0.87	2.87	8.00	0.44	0.04	nd	0.17	0.09
Fleshy fruits								
Anacardium occidentale	0.12	0.10	0.23	0.13	0.01	nd	0.01	0.01
Ananas comosus	0.26	0.09	0.32	0.01	nd	nd	0.11	0.01
Annona muricata	0.07	0.11	0.38	0.10	nd	nd	0.03	nd
Annona reticulata	0.11	0.40	0.88	0.19	0.05	nd	0.05	0.05
Annona squamosa	0.15	0.50	1.30	0.25	0.04	nd	0.05	0.03
Annona squamosa	0.16	0.55	1.38	0.30	0.08	0.01	0.07	0.07
Anonna cherimola	0.15	0.20	0.56	0.11	0.02	nd	0.22	0.02
Averrhoa carambola	0.08	0.48	1.72	0.19	nd	nd	0.13	0.17
Borojoa sorbilis	0.24	2.47	0.10	0.81	nd	0.01	0.05	nd
Calocarpum mammosum	0.15	0.19	0.57	0.02	0.01	nd	nd	nd
Carica papaya	0.03	0.09	0.37	0.01	nd	nd	nd	nd
Chrysophyllum cainito	0.05	0.08	0.18	0.03	nd	nd	nd	nd
Crescentia cujete	0.25	0.63	2.80	0.45	0.03	0.03	0.13	0.10
Cucurbita maxima	0.02	0.18	0.08	1.31	0.02	0.02	nd	nd
Cyphomandra betacea	0.20	0.02	0.41	0.11	nd	nd	0.02	nd
Eugenia malaccensis	0.06	0.07	0.15	0.03	nd	nd	0.03	0.01
Eugenia stipitata	0.08	0.18	0.38	0.07	nd	nd	0.01	0.01
Eugenia uniflora	0.11	0.19	0.49	0.07	nd	nd	0.03	0.01
Feijoa sellowiana	0.15	0.15	0.75	0.03	nd	0.02	0.16	0.07
Flacourtia indica	0.43	0.45	0.45	0.14	nd	0.01	0.05	0.05
Gustavia superba	0.10	0.58	1.76	0.19	0.03	nd	0.02	0.06
Gustavia superba	0.16	0.44	1.08	0.40	0.03	nd	0.01	0.04
Gustavia superba	0.05	0.49	1.46	0.41	0.02	nd	0.02	0.05
Hylocereus undatus	0.11	0.34	0.50	0.15	nd	nd	nd	nd
Laetia americana	0.24	0.36	0.60	0.38	nd	nd	0.04	0.04
Malpighia glabra	0.09	0.19	0.47	0.04	nd	nd	0.02	0.01
Mammea americana	0.06	0.17	1.46	0.08	nd	nd	0.04	0.01
Mangifera indica	0.45	0.14	0.55	0.18	nd	nd	0.03	0.02
Mangifera indica	0.14	0.11	0.29	0.05	nd	nd	0.05	nd
Matisia cordata	0.25	0.24	0.30	0.19	nd	nd	0.03	0.02
Matisia cordata	0.12	0.15	0.59	0.11	nd	nd	0.02	0.02
Meliococcus bijugatus	0.16	0.34	0.39	0.03	nd	nd	0.02	nd
Morinda citrifolia	0.28	0.21	0.57	0.11	nd	nd	0.02	0.02

Table 2 (*continued*)

Scientific name	Mn	Zn	Fe	Cu	Se	Co	Ni	Cr
Myrciaria cauliflora	0.28	0.19	0.33	0.06	nd	nd	0.03	nd
Ocotea tenera	0.03	0.20	2.10	0.28	nd	nd	nd	nd
Passiflora edulis	0.12	0.20	0.61	0.06	nd	0.02	nd	nd
Passiflora edulis	0.16	0.43	0.66	0.05	nd	nd	0.04	0.02
Passiflora ligularis	0.18	0.42	0.66	0.13	nd	nd	0.03	0.03
Passiflora mollisima	0.18	0.29	0.73	0.14	0.01	nd	0.04	0.02
Phyllanthus acidus	0.07	0.15	0.36	0.03	0.01	0.01	0.03	0.03
Physalis peruviana	0.20	0.28	0.09	0.64	nd	nd	0.02	nd
Pourouma cecropiaefolia	0.54	0.17	0.48	0.06	nd	nd	0.05	0.03
Psidium guajava	0.09	0.20	0.28	0.08	nd	nd	0.02	nd
Psidium guajava	0.17	0.19	1.49	0.11	0.08	nd	0.11	0.10
Punica granatum	0.18	0.33	0.57	0.15	nd	nd	0.03	nd
Rheedia madruno	0.19	0.63	2.24	0.15	0.08	0.13	nd	nd
Rubus glaucus	0.32	0.28	2.20	0.84	nd	nd	0.18	0.08
Sechium edule	0.07	0.11	0.33	0.04	nd	0.02	nd	nd
Solanum quinoense	0.22	0.25	0.63	0.19	nd	nd	0.03	0.02
Spondias mombin	0.02	0.17	0.74	0.02	nd	nd	nd	nd
Zizyphus jujuba	0.13	0.66	3.37	0.10	nd	nd	0.07	0.19
Leaves								
Trichanthera gigantea	1.55	0.62	2.15	0.21	0.04	nd	0.11	0.06
Trichanthera gigantea	1.85	0.95	7.83	0.29	0.06	nd	0.13	0.08
Trichanthera gigantea	3.64	0.72	3.31	0.22	0.05	nd	0.14	0.09
Trichanthera gigantea	0.86	0.53	8.42	0.44	0.02	0.01	0.02	0.04
Xanthosoma saggitifolium	1.30	0.57	6.42	0.28	nd	nd	0.18	0.18
Xanthosoma saggitifolium	0.38	0.34	2.58	0.24	nd	nd	0.02	0.01
Xanthosoma saggitifolium	0.43	0.32	0.66	0.08	nd	nd	nd	nd
Tubers								
Alocasia macrorrhiza	0.23	0.47	0.50	0.13	nd	nd	0.03	nd
Arracacia xanthorrhiza	0.07	0.17	0.46	0.02	nd	nd	0.02	nd
Colocasia esculenta	0.20	1.35	2.15	0.06	nd	0.02	0.04	0.01
Colocasia esculenta	0.31	1.37	3.09	0.19	nd	0.04	nd	nd
Colocasia esculenta	1.40	0.89	2.29	0.15	nd	nd	0.03	nd
Discorea alata	0.11	0.53	0.94	0.17	nd	nd	0.06	0.06
Discorea alata	0.80	0.44	0.90	0.05	nd	nd	nd	nd
Manihot esculenta	0.12	0.28	0.76	0.04	nd	nd	0.04	nd
Maranta arundicancea	0.09	0.23	1.66	0.15	nd	nd	0.01	nd
Oxalis tuberosa	0.07	0.13	0.30	0.04	nd	nd	0.01	0.02
Solanum tuberosum	0.29	0.45	0.74	0.11	0.01	0.01	0.02	nd
Solanum tuberosum	0.13	0.23	0.40	0.06	0.01	nd	0.02	nd
Ullucus tuberosus	0.11	0.36	0.40	0.04	0.01	nd	nd	nd
Xanthosoma saggitifolium	0.38	0.41	1.09	0.11	nd	nd	0.01	0.01
Xanthosoma saggitifolium	0.11	0.48	0.89	0.13	nd	nd	nd	nd
Xanthosoma saggitifolium	0.35	0.43	3.25	0.24	nd	nd	0.03	nd

nd, not detected.

On average, the starchy foods, the tubers and the fleshy fruits presented low levels in minerals, with some exceptions for some fruits rich in Ca (*Pourouma cecropiaefolia*, *Matisia cordata*, *Cucurbita maxima*), P (*Cucurbita maxima*, *Hylocereus triangularis*) or oligoelements (*Manicaria saccifera*).

Different samples of a same species (*Bactris gasipaes*, *Trichanthera gigantea*, among others) were also analyzed to evaluate the intraspecific variability (Tables 1 and 2). On average, the macromineral content was quite stable (Table 1). Higher variations were observed for some microminerals, especially for iron, such as in the leaves (Table 2).

The matrix of correlations between the element concentrations is detailed in Table 3. One part of the table presents the correlation coefficients whereas the other mentions the level of significance of the correlations, according to Pearson's test. Se, Co, Ni and Cr were not considered because their concentration was often below the detection level. High correlations ($P < 0.001$) were obtained between total ash and most of the elements, with the exception of Na and trace elements such as Co, Ni and Cr. The correlation with Ca and Mg was particularly high ($r = 0.77$ in both cases). These elements were also highly correlated with those correlated to total ash. Other high correlations were observed between

Table 3
Linear correlations (r) between total ash and the element concentrations in the tropical fruits and unconventional foods and level of significance of the correlation according to the Pearson analysis

	Ash	Ca	P	K	Mg	Na	Cl	S	Mn	Zn	Fe	Cu
Ash		***	***	***	***	NS	***	***	**	***	***	**
Ca	0.77		NS	***	***	NS	***	***	***	**	***	**
P	0.27	0.12		***	*	NS	NS	NS	NS	**	NS	NS
K	0.59	0.39	0.55		***	NS	***	*	NS	**	***	*
Mg	0.73	0.93	0.22	0.44		NS	***	***	***	***	***	***
Na	−0.01	0.01	−0.07	0.03	0.06		NS	NS	NS	NS	NS	NS
Cl	0.60	0.62	0.07	0.56	0.57	0.10		***	**	NS	***	***
S	0.65	0.88	0.02	0.19	0.76	0.01	0.46		**	*	***	*
Mn	0.28	0.39	0.01	0.16	0.35	−0.02	0.30	0.28		**	***	NS
Zn	0.33	0.31	0.30	0.30	0.39	−0.01	0.12	0.22	0.31		***	***
Fe	0.56	0.69	0.09	0.36	0.65	0.03	0.55	0.48	0.50	0.53		***
Cu	0.29	0.30	0.07	0.22	0.36	0.01	0.24	0.20	0.38	0.44	0.58	

NS, not significant.
[*] $P < 0.05$.
[**] $P < 0.01$.
[***] $P < 0.001$.

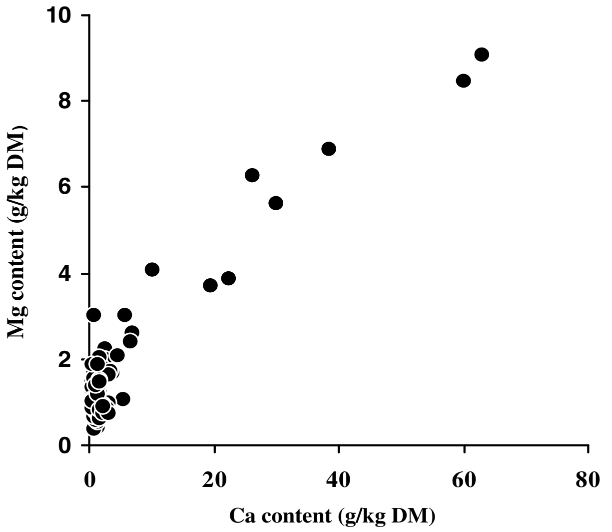

Fig. 1. Relationship between the calcium (Ca) and magnesium (Mg) contents of tropical fruits and unconventional foods.

elements, for example between Ca and Mg ($r = 0.93$) or S ($r = 0.88$) and Mg and S ($r = 0.76$). On the contrary, Na was totally independent and correlated with none of the other elements ($P > 0.05$), whereas P was correlated with K, Mg and Zn only. The high correlations were obtained thanks to the inclusion of leaves in the samples, because their high mineral content allowed a wider range of variation of the contents (Fig. 1).

4. Discussion

Globally, the mineral profile content obtained for the fruits, tubers and leaves is comparable to that obtained for other African and Mexican tropical plant foods by Glew et al. (1997), Sanchez-Castillo et al. (1998), Cook et al. (2000) and Boukari et al. (2001). Among the foods evaluated, the leaves appear as outstanding mineral sources, especially those of *Trichanthera*, which have the highest contents in Ca, Mg, S, Fe, Mn and Cu (Tables 1 and 2). Their Ca content (62 g Ca/kg DM on average) is higher than the highest values ever mentioned for African tree leaves used in human nutrition (38 g/kg DM; Boukari et al., 2001) or even tree foliage in general (Leterme, Londoño, Estrada, Souffrant, & Buldgen, 2005b). The nuts are also good mineral sources.

The high intraspecific variability observed here has also been mentioned by other authors (Hakala, Lapvetelainen, Huopalahti, Kallio, & Tahvonen, 2003; Hardisson et al., 2001; Hofman, Vuthapanich, Whiley, Klieber, & Simons, 2002; Underwood & Schuttle, 1999). It is ascribable to differences in cultivation conditions, such as soil fertility and pH, water supply, climate and seasonal variations (Alfaia, Ribeiro, Nobre, Luizão, & Luizão, 2003; Hofman et al., 2002; Underwood & Schuttle, 1999). This variation can have nutritional implications, as long as the mineral bioavailability is not low. The latter has not been studied extensively in tropical foods but literature reports low values. Iron availability in African and Indian green leaves, for example, ranges from 2.5% to 27% (Agte, Tarwadi, Mengale, & Chiplonkar, 2000; Kumari et al., 2004; Tatala, Svandberg, & Mduma, 1998), whereas those of Zn and Cu range from 11% to 26% and 18% to 47%, respectively, in Indian green vegetables (Agte et al., 2000). In the case of *Xanthosoma*, the leaves and tubers must have a low Ca bioavailability because in the Araceae family, Ca is mainly found in oxalate form, which makes the element unavailable (Sefa-Dedeh & Kofi-Agyir, 2002).

Fruit production is encouraged in the tropics because, among other things, fruits are good sources of nutrients. The average daily meal of the rural population in the Andes is mainly composed of starchy foods (300–700 g/d of maize, cassava or banana), followed by fruits and vegetables (80–190 g/d), pulses (47–64 g/d), meat and eggs (30–90 g/d) and milk (10–200 ml/d) (Leterme & Muñoz, 2002). In the rain forest of the Colombian Pacific coast, the staple foods are banana, maize, peachpalm and cassava, i.e., starchy foods (Leterme et al., 2005a). The meal is completed with fruits (mango, mombin, paco, etc) but meat is scarce and milk inexistent (Ocampo et al., 2005). In this region, malnutrition is a main concern and some people suffer from deficiencies in calcium or iron (Emilio Arenas, personal communication).

The daily requirements of an adult man are as follows (mg/d): 800–1200 Ca, 700–800 P, 300–400 Mg, 500 Na, 10–15 Fe, 12–15 Zn, 2–3 Cu (Berdanier, 1998; Smolin & Grosvenor, 2000; Wildman & Medeiros, 2000). If intake in pulses, meat or eggs and milk are sufficient, the daily mineral requirements of the Andean population should be met, with the exception of Na, but salt is now available everywhere. On the contrary, the staple foods consumed by the rain forest population are poor in important elements such as Ca, P or Fe (Tables 1 and 2) and the consumption of fruits could not bring the amount required to meet the requirements either. Among the other foods studied here, only the tree leaves and possibly the nuts could improve the situation. However, our survey in the region showed that people do not consume leaves (Ocampo et al., 2005). Moreover, the nuts come from the rain forest and supply is limited for several reasons: the number of trees is limited, the access to the nuts is difficult, the wild fauna also eat them and the edible portion is often small. Moreover, many of them, like the Guiana chesnut (*Pachira aquatica*) and the nut of the Panama tree (*Sterculia apetala*), contain high amounts of toxic and antinutritional factors (Oliveira et al., 2000), which limits their interest. Moreover, they are generally surrounded by hard husks. Among the different nuts evaluated here, only the inchi (*Caryodendron orinocence*) has a good potential for human nutrition, thanks to its good composition and low antinutritional factor content (Padilla, Alvarez, & Alfaro, 1996). The limited edible portion of numerous fruits also limits their interest as nutrient sources. Many of them have a thick skin and large seeds or a large number of seeds. It is for example the case of cherimoya (*Annona cherimola*), zapote (*Matisia cordata*) or granadilla (*Passiflora ligularis*). It is also the case of the palm trees (*Oenocarpus batau*, *Wettinia quinaria*, *Manicaria saccifera*): the mesocarp of their fruit has a good mineral content (Tables 1 and 2) but it represents a very thin part of the whole fruit. Thus, the fact that wild fruit species have higher mineral contents than cultivated ones (Guil-Guerrero, Gimenez-Martinez, & Torija-Isasa, 1998; Milton, 2003) is not an advantage since, in many cases, their edible portion is small.

The concentration in various elements increases with the total mineral content (Table 3). The latter is thus a good indicator of the mineral value of the feeds, as long as it does not, actually, reflect the presence of silica. Special attention was paid here to avoid any contamination of the fruits and leaves by dust and of the tubers by soil. The presence of silica was checked in the leaf and tuber samples (unpublished data) and no case of contamination was detected.

A significant correlation between Ca and Mg was also observed by Jodral-Segado, Navarro-Alarcon, Lopez de la Serrana, and Lopez-Martinez (2003) in batches of Spanish cereals, legumes and fruits. High correlations were observed thanks to the wide range of contents of the feeds and, in particular, the high concentrations found in the tree leaves (Fig. 1). However, when the latter were discarded from the data bank, the correlation between Ca and Mg reached 0.58 and was still very significant ($P < 0.001$).

Some other high correlations were observed, such as those between Fe and Cu or Ca and S. Few information is available in literature on that matter. Sikora and Cieslik (1999) and Dundar, Bahçivanci, and Muslu (2002) also obtained positive correlations between Fe and Cu within varieties of potato tubers ($r = 0.33$; $P < 0.01$) and hazelnut ($r = 0.32$; $P > 0.05$) but at a lower level than in the present case. Our correlations remained high, even without taking the leaves into account ($r = 0.70$).

5. Conclusions

Many fruits and unconventional foods are available in the tropics and represent valuable minerals sources. Green leaves appear as outstanding mineral sources, especially in calcium and iron, followed by nuts. Since many elements are positively and significantly correlated to the total ash content, the latter seems a simple criterion for selecting good mineral sources. However, the interest for a fruit or a food will depend on its availability, the proportion of its edible portion and its taste.

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