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Macro and microminerals: are frozen fruits a good source?

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ABSTRACT

Fruits are rich in minerals, which are essential for a wide variety of metabolic and physiologic processes in the human body. The use of frozen fruits has greatly spread in the last years not only in the preparation of juices, but also as raw material for yogurts, candies, cookies, cakes, ice creams, and children's food. However, up to now there is no data about the mineral profile of frozen fruits. This is the first database to quantify the levels of minerals in 23 samples of frozen fruits, including the most used around the world and some native fruits from the Amazon rainforest in Brazil. Considering the Dietary Reference Intakes, 100g of frozen fruits can provide 0.2 to 2.8% of macro and 2.5 to 100% of microminerals for adults (31-50 years old). Although geographical differences should be considered, these data can help to plan diets and to develop population interventions aiming to prevent chronic diseases.

Key words: diet, dietary recommendations, Dietary Reference Intakes, frozen fruits, minerals.

INTRODUCTION

Many of the current diets are rich in fat, salt, and sugar, and poor in complex carbohydrates, vitamins and minerals, and are responsible for an increase in diet-related diseases such as obesity, diabetes, cardiovascular problems, hypertension, osteoporosis, and cancer. It is believed that the ingestion of fruits and vegetables helps to prevent these diseases. Fruits are important components of diet, responsible not only for adding a variety of color and texture to meals, but also for providing essential nutrients. Fruits are low-fat and low-calorie foods, with relatively small amounts of protein and carbohydrates. However, they are rich in fibers and add a lot of significant micronutrients to the human diet (Zhi et al. 2003).

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Among the micronutrients found in fruits, minerals represent a class of inorganic substances that is present in all kinds of fruits. The human body needs about twenty different minerals in order to function properly (Williams 2006). These elements can be classified into macro and microminerals. Macro minerals are needed in amounts higher than 100 mg/day and include calcium (Ca), phosphorus (P), magnesium (Mg), sulfur (S), sodium (Na), chloride (Cl) and potassium (K). Microminerals (needed in amounts lower than 100 mg/day) include elements such as iron (Fe), zinc (Zn), iodine (I), selenium (Se), manganese (Mn), chromium (Cr), copper (Cu), molybdenum (Mo), fluorine (F), boron (B), cobalt (Co), silicon (Si), aluminum (Al), arsenic (Ar), tin (Sn), lithium (Li) and nickel (Ni) (Mahan and Escott-Stump 2005). Fruits are the most important source of both macro and microminerals (Pellerano et al. 2008), which are indispensable for the maintenance of life, growth, and reproduction (Alsafwah et al. 2007).

Nowadays, a diet that is rich in fruits is associated with a reduced risk of many diseases (Genkinger et al. 2004). However, it is difficult to find fruits *in natura* – which are perishable – during all year round and/or in places far from the harvesting field. The intake of frozen fruits has widely spread in many countries. They are easy to commercialize and are an important source of raw material. They can be used in yogurts, candies, cookies, cakes, ice creams, fresh drinks and children's food (Hassimotto et al. 2005). In a recent work (Spada et al. 2008), it was demonstrated that fruits, even frozen, are rich in carotenoids, ascorbic acid and phenolic compounds and present an important antioxidant activity. However, to our knowledge, there is no data about mineral levels in frozen fruits. Therefore, the aim of this study was to determine the mineral levels in 23 samples of frozen fruit through PIXE (Particle Induced X-ray Emission) technique. The results can be important to help the population to achieve the recommended dietary allowance (RDA) threshold for minerals.

MATERIALS AND METHODS

FROZEN FRUITS

Frozen pulp of acerola (*Malpighia glabra* L.), apple (*Malus domestica* B.), acai (*Euterpe oleracea* L.), black mulberry (*Morus nigra* M.), cashew apple (*Anacardium occidentale* L.), coconut (*Cocos nucifera* L.), cupuacu (*Theobroma grandiflorum* W.), kiwi fruit (*Actinidia chinensis* P.), mango (*Mangifera indica* L.), melon (*Cucumis melo* L.), papaya (*Carica papaya* L.), passion fruit (*Passiflora alata* C.), peach (*Prunus persica* L.), pineapple (*Ananas sativus* L.), raspberry (*Rubus idaeus* L.), red guava (*Psidium guajava* L.), soursop (*Annona muricata* L.), strawberry (*Fragaria vesca* L.), Surinam cherry (*Eugenia uniflora* L.), and frozen juice of red grape (*Vitis vinifera* L.), lemon (*Citrus limon* B.), orange (*Citrus aurantium* L.) and tangerine (*Citrus reticulata* L.) were obtained from the company Mais Fruta (Antonio Prado, RS, Brazil). Pulps and juices were produced with fresh and clean fruits, free of filthy substances, parasites, and plant or animal debris. Only edible portions of the fruits were pressed in order to prepare pulps and juices. With regard to red grape, lemon, orange, and tangerine juices, flesh was separated from the fluid that was obtained from pressing. Pulps and juices were divided into 100 g aliquots and kept frozen at –20°C. No organophosphorus or carbamate pesticides were detected in the samples, through assay described by Bastos et al. (1991) and de Lima et al. (1996).

PARTICLE INDUCED X-RAY EMISSION ANALYSIS

Quantification of mineral compounds that are present in frozen fruits was carried out using PIXE. This technique has a truly multielemental capability, that is, all elements with atomic number higher than 11 can be simultaneously detected in a single measurement on the same target (Johansson et al. 1995). The sensitivity is very good (of about a few parts per million) and ranges smoothly as a function of atomic number. It is important to note that PIXE sensitivity depends on the sample being analyzed. The analysis is relatively fast and usually takes a few minutes. Since this technique is nondestructive, it preserves the original samples, allowing additional measurements if required. Sample preparation in its solid form (for a variety of samples) does not require any sophisticated handling or chemical treatment, thus drastically reducing any chance of contamination. Nowadays, PIXE is widely used to characterize a variety of materials, including biological, geological and environmental samples (Kern et al. 2005, Franke et al. 2006). For PIXE analysis, fruit samples were dried, crushed and pressed into pellets, as described by (Franke et al. 2006). Measurements were carried out at the Ion Implantation Laboratory of the Physics Institute of the Federal University of Rio Grande do Sul. A 3 MV Tandetron accelerator provided a 2 MeV proton beam with an average current of 2 nA at the targets. The characteristic X-rays induced by the proton beam were detected by a lithium doped silicon detector with an energy resolution of 155 eV at 5.9 keV, positioned at an 135° angle considering the beam direction. The data were analyzed using the GUPIX code (Maxwell et al. 1989, Campbell et al. 2000). The standardization procedure was carried out using an apple leaf standard from NIST (SRM-1515). All assays were performed in triplicate and results were expressed in mg% (w/w).

Statistical Analysis

Data were subjected to analysis of variance and means were compared using Tukey's *post-hoc* test using the SPSS program, version 12.0 (SPSS, Chicago, IL).

RESULTS AND DISCUSSION

This is the first work to evaluate the mineral content of 23 frozen fruits, including the most used around the world and some native fruits from the Amazon rainforest in Brazil. Frozen fruits are used not only in the preparation of juices, but also as raw material for yogurts, candies, cookies, cakes, ice creams, and children's food (Spada et al. 2008).

The mineral content found in fruits is presented as macro (Table I) and microminerals (Table II). The Dietary Reference Intakes (DRI), defined as the average daily intake level sufficient for meeting the nutrient requirements of nearly all – 97 to 98% – healthy individuals in a particular life stage and gender group, is also shown. Where there was insufficient scientific evidence to establish a DRI, we used the Dietary Recommendation (DR), which is the recommended average daily nutrient intake level based on observed or experimentally determined estimates nutrient intake by a group, or groups, of apparently healthy people assumed to be in an adequate nutritional state (IOM 2004). All fruits here studied had Mg, Cl, P, K and Ca. Sulfur was found in all fruits, except in cupuacu and passion fruit, native Brazilian fruits. Only coconut, lemon and papaya presented Na.

The micro mineral Fe was found in all fruits, Mn in 65.2% of them, and Cu and Zn in 30.4% of the analyzed fruits. A low level of Cr was found in melon, orange and papaya. The microminerals Si and Al were found in 91.30% and 39.13% of fruits, respectively.

Macro minerals are essential for a wide variety of metabolic and physiologic processes in the human body. Ca, Mg, K, Na and Cl, for example, are important for many enzymatic activities, for the composition of the skeletal system, and for ATP formation (Williams 2006).

It was observed that frozen fruits (100 g) are able to provide around 2.1% (men) and 2.8% (women) of the DRI for Mg, which acts as a cofactor for over 300 proteins. It also influences bone quality, decreasing hydroxyapatite crystal size, and thereby, preventing the larger crystals that could lead to brittle bone (Bonjour et al. 2009).

Around 0.5% (both sexes) of the DRI for Ca and P can be supplied by 100 g of frozen fruits. Calcium provides strength and hardness to bones and teeth, and mediates vascular constriction and vasodilation, muscle contraction, transmission of nerve impulses and blood clotting (Krall 2000). Phosphorus is also a constituent of bones (Bonjour et al. 2009), but when in high levels, it could lead to Ca metabolism disorders because of a drop in the plasma concentration of ionized Ca, and secondary hyperparathyroidism (Bonjour et al. 2009).

Chloride, potassium and sodium were found in small amounts, reaching only about 0.2% of the DR. These minerals present important roles in the control of cardiac output and peripheral vascular resistance, which are the main determinants of the blood pressure level (Karppanen et al. 2005). Cl and Na were believed to be readily equilibrated and achieving iso-osmolality with blood (Titze and Ritz 2009). In excess, these elements can produce hyperchloraemic acidosis, renal vasoconstriction and reduced glomerular filtration rate (Lobo 2004).

Frozen fruits (100 g) can provide about 3.5% (men) and 1.5% (women) of the DRI for Fe. Acai, apple and tangerine are rich in Fe, and 100 g of these frozen fruits can contribute to approximately 7% of the DRI for men. Red grape and coconut (100 g) can reach 22.2% of the Mn DRI. All fruits can provide more than 100% of the Cu DRI for men and women. Levels of Zn found in frozen pulps are able to supply about 2% of DRI for men and 3% for women. Microminerals such as Fe, Mn, Cu and Zn are cofactors of many enzymes and part of the active site of some oxidases and oxygenases (Halliwell and Gutteridge 2007). Iron is a component of hemoglobin, myoglobin, cytochromes, and a lot of enzymes in the muscle cells (Donabedian 2006). Manganese is a micro mineral that is found in all tissues and is required for normal amino acid, lipid, protein, and carbohydrate metabolism (Aschner and Aschner 2005). It is also a microcomponent of metalloenzymes such as arginase, glutamine synthetase, phosphoenolpyruvate decarboxylase, and Mn superoxide dismutase (Aschner and Aschner 2005). Mn is involved in immune func-

TABLE I
Level of macrominerals (mg%) in frozen fruits.

Samples	Mg	Cl	P	Ca	K	S	Na
Acai	8.47 ± 0.17^{a}	1.96 ± 0.12^{a}	3.05 ± 0.07^{a}	3.50 ± 0.13^{a}	$1.03 \pm 0.40^{a*}$	1.91 ± 0.01^{a}	nd
Acerola	8.64 ± 0.22^{a}	2.38 ± 0.19^{a}	3.25 ± 0.16^{a}	5.82 ± 0.05^{b}	1.22 ± 0.50^{b}	2.17 ± 0.09^{ab}	nd
Apple	7.74 ± 0.24^{a}	2.05 ± 0.02^{a}	2.61 ± 0.14^{a}	3.60 ± 0.50^{a}	0.97 ± 0.10^{a}	1.73 ± 0.03^{a}	nd
Black mulberry	8.21 ± 0.05^{a}	2.26 ± 0.04^{a}	3.01 ± 0.42^{a}	4.83 ± 0.02^{c}	1.35 ± 0.30^{b}	1.99 ± 0.07^{a}	nd
Cashew apple	8.22 ± 0.01^{a}	2.99 ± 0.34^{b}	2.53 ± 0.47^{c}	3.49 ± 0.05^{a}	1.43 ± 0.10^{b}	1.46 ± 0.55^{a}	nd
Coconut	9.67 ± 0.24^{a}	2.60 ± 0.01^{a}	4.43 ± 0.09^{b}	7.60 ± 0.59^{d}	2.41 ± 0.16^{b}	3.59 ± 0.21^{c}	26.95 ± 1.05^{a}
Cupuacu	8.48 ± 0.02^{a}	0.23 ± 0.07^{d}	3.13 ± 0.12^{a}	6.59 ± 0.07^{d}	1.55 ± 0.07^{b}	nd	nd
Kiwi fruit	8.91 ± 0.19^{a}	2.66 ± 0.05^{b}	3.34 ± 0.01^{a}	7.03 ± 0.03^{d}	2.07 ± 0.07^{b}	2.48 ± 0.09^{b}	nd
Lemon	8.98 ± 0.15^{a}	2.73 ± 0.02^{b}	3.47 ± 0.02^{a}	7.02 ± 0.03^{d}	2.21 ± 0.53^{b}	2.23 ± 0.03^{ab}	23.15 ± 1.44^{ab}
Mango	7.62 ± 0.05^{a}	1.89 ± 0.02^{a}	2.69 ± 0.07^{c}	3.43 ± 0.01^{a}	1.23 ± 0.16^{c}	1.79 ± 0.02^{a}	nd
Melon	11.15 ± 0.28^{b}	3.55 ± 0.84^{c}	4.17 ± 0.27^{b}	10.33 ± 0.36^{e}	2.22 ± 0.21^{b}	2.96 ± 0.86^{b}	nd
Orange	8.08 ± 0.02^{a}	2.16 ± 0.02^{a}	2.85 ± 0.02^{c}	4.45 ± 0.02^{c}	1.49 ± 0.02^{c}	1.87 ± 0.07^{a}	nd
Papaya	8.44 ± 0.49^{a}	1.82 ± 0.13^{a}	2.96 ± 0.02^{c}	5.32 ± 0.04^{c}	1.55 ± 0.26^{b}	2.01 ± 0.07^{a}	21.80 ± 1.02^{b}
Passion fruit	8.44 ± 0.23^{a}	2.36 ± 0.02^{a}	1.26 ± 0.07^{d}	5.42 ± 0.09^{c}	1.21 ± 0.16^{c}	nd	nd
Peach	11.32 ± 0.34^{b}	3.68 ± 0.06^{c}	3.91 ± 0.26^{a}	5.58 ± 0.06^{c}	1.53 ± 0.21^{c}	2.57 ± 0.05^{b}	nd
Pineapple	8.40 ± 0.33^{a}	2.30 ± 0.17^{a}	3.12 ± 0.09^{a}	4.57 ± 0.24^{c}	1.34 ± 0.52^{c}	2.01 ± 0.06^{a}	nd
Raspberry	8.40 ± 0.09^{a}	2.20 ± 0.02^{a}	3.10 ± 0.01^{a}	4.48 ± 0.25^{c}	1.52 ± 0.18^{c}	1.97 ± 0.02^{a}	nd
Red grape	8.14 ± 0.23^{a}	1.94 ± 0.01^{a}	2.81 ± 0.08^{c}	3.25 ± 0.26^{a}	0.90 ± 0.30^{a}	1.77 ± 0.06^{a}	nd
Red guava	8.61 ± 0.14^{a}	2.55 ± 0.02^{a}	3.16 ± 0.05^{a}	6.09 ± 0.09^{d}	14.4 ± 0.50^{b}	2.24 ± 0.06^{ab}	nd
Soursop	8.48 ± 0.61^{a}	2.36 ± 0.31^{a}	3.21 ± 0.10^{a}	5.72 ± 0.15^{c}	1.09 ± 0.20^{b}	2.19 ± 0.05^{ab}	nd
Strawberry	9.15 ± 0.08^{a}	2.69 ± 0.03^{b}	3.40 ± 0.04^{a}	6.57 ± 0.15^{d}	1.61 ± 0.42^{b}	2.21 ± 0.03^{ab}	nd
Surinam cherry	8.57 ± 0.14^{a}	2.12 ± 0.15^{a}	3.05 ± 0.09^{a}	4.43 ± 0.06^{c}	1.38 ± 0.07^{b}	1.87 ± 0.15^{a}	nd
Tangerine	10.66 ± 0.14^{b}	3.48 ± 0.17^{c}	2.55 ± 0.07^{c}	5.40 ± 0.80^{c}	1.49 ± 0.50^{b}	2.67 ± 0.83^{b}	nd
Men/day	*420 mg*	**2300 mg**	*700 mg*	*1000 mg*	**4700 mg**	not determinable	**1500 mg**
Women/day	*320 mg*	**2300 mg**	*700 mg*	*1000 mg*	**4700 mg**	not determinable	**1500 mg**

[a]Data are mean ± SD values of three independent experiments and different letters indicate a significant difference according to analysis of variance and Tukey's *post hoc* test ($p \leq 0.05$) for each mineral evaluated. nd: not detected. This table presents *Dietary Reference Intakes (DRI)* in italics and **Dietary Recommendations** in bold type, both for adult individuals (31-50 years old).

tion, regulation of blood sugar and cellular energy, reproduction, digestion, bone growth, and it aids in defense mechanisms against free radicals (Aschner and Aschner 2005). Copper promotes the formation of the mitochondrial heme, and the reduction of erythrocyte half-life in anemia (Conrad and Umbreit 2000). Diets low in copper are suggested as an explanation for much of the epidemiology and patho-physiology of ischemic heart disease (Klevay 2000). Zinc is essential as a catalyst for regulating the activity of over 300 specific zinc-depended enzymes (McCall et al. 2000).

Chromium controls some physiological process in human body such as blood insulin regulation and lipid profile. Excessive consumption of chromium is rare since it is poorly absorbed (Mertz 1993). In this work, pulps of melon, orange and papaya (100 g) are able to provide more than 100% of the Cr DR.

Our results show the mineral profile of 23 frozen fruits, which may help to provide the flexibility needed to achieve the optimal dietary mineral content for a healthy human diet. However, it should be taken into account that the mineral content may be influenced by growing conditions, such as soil and geographical factors (Ercisli and Ohran 2007). In addition, the bioavailability of minerals seems to be dependent on cultivar, the environment and harvest year (Bohn et al. 2008). Some compounds such as ascorbic acid can help Fe absorption; on the other hand, iron uptake could be inhibited by strong chelators such phytic acid, some polyphenols and the divalent cations Ca, Zn, Co and Mg. The rela-

TABLE II
Level of microminerals (mg%) in frozen fruits.

Samples	Fe	Mn	Cu	Zn	Cr	Si	Al
Acai	$0.51 \pm 0.28^{a*}$	0.27 ± 0.07^{a}	nd	0.20 ± 0.01a	nd	1.22 ± 0.03^{a}	nd
Acerola	0.26 ± 0.85^{b}	nd	nd	nd	nd	1.35 ± 0.07^{a}	nd
Apple	0.54 ± 1.32^{a}	0.29 ± 0.04^{ab}	1.80 ± 0.14^{a}	0.28 ± 0.05^{ab}	nd	1.12 ± 0.04^{a}	4.16 ± 0.03^{a}
Black mulberry	0.28 ± 0.57^{b}	0.31 ± 0.01^{b}	nd	nd	nd	1.28 ± 0.02^{a}	nd
Cashew apple	0.28 ± 0.64^{b}	nd	nd	nd	nd	1.54 ± 0.53^{a}	nd
Coconut	0.24 ± 0.42^{b}	0.40 ± 0.07^{b}	nd	nd	nd	1.60 ± 0.07^{a}	nd
Cupuacu	0.20 ± 0.19^{c}	0.20 ± 0.01^{a}	2.25 ± 0.78^{ab}	nd	nd	1.30 ± 0.06^{a}	nd
Kiwi fruit	0.21 ± 0.42^{b}	0.19 ± 0.02^{a}	nd	nd	nd	nd	nd
Lemon	0.27 ± 0.85^{b}	0.21 ± 0.06^{a}	2.30 ± 0.42^{b}	0.26 ± 0.04^{ab}	nd	1.37 ± 0.07^{a}	5.35 ± 0.05^{b}
Mango	0.18 ± 0.76^{c}	0.17 ± 0.06^{a}	1.85 ± 0.35^{a}	0.21 ± 0.03^{a}	nd	1.11 ± 0.01^{a}	4.17 ± 0.10^{a}
Melon	0.28 ± 0.07^{b}	0.31 ± 0.04^{b}	nd	nd	0.15 ± 0.01^{a}	1.66 ± 0.60^{a}	nd
Orange	0.28 ± 0.92^{b}	0.18 ± 0.01^{a}	nd	0.30 ± 0.08^{ab}	0.13 ± 0.02^{a}	1.22 ± 0.02^{a}	4.47 ± 0.01
Papaya	0.16 ± 0.28^{c}	nd	2.05 ± 0.07^{c}	0.22 ± 0.01^{a}	0.18 ± 0.04^{b}	1.31 ± 0.07^{a}	4.72 ± 0.30^{a}
Passion fruit	0.16 ± 0.07^{c}	0.20 ± 0.04^{a}	1.55 ± 0.05^{a}	0.30 ± 0.01^{b}	nd	1.26 ± 0.04^{a}	4.73 ± 0.07^{a}
Peach	0.34 ± 0.27^{b}	nd	nd	nd	nd	1.74 ± 0.07^{a}	nd
Pineapple	0.30 ± 0.56^{b}	0.30 ± 0.06^{b}	nd	nd	nd	1.25 ± 0.06^{a}	nd
Raspberry	0.25 ± 0.42^{b}	0.21 ± 0.05^{a}	nd	nd	nd	1.29 ± 0.07^{a}	nd
Red grape	0.18 ± 0.07^{c}	nd	3.10 ± 0.85^{c}	nd	nd	1.18 ± 0.01^{a}	4.12 ± 0.35^{a}
Red guava	0.18 ± 0.02^{c}	0.14 ± 0.02^{a}	nd	nd	nd	nd	nd
Soursop	0.18 ± 0.21^{c}	nd	nd	nd	nd	1.29 ± 0.06^{a}	4.83 ± 0.25^{a}
Strawberry	0.35 ± 0.78^{b}	0.28 ± 0.03^{a}	nd	nd	nd	1.39 ± 0.03^{a}	5.21 ± 0.35^{b}
Surinam cherry	0.14 ± 0.28^{c}	nd	nd	nd	nd	1.32 ± 0.04^{a}	nd
Tangerine	0.61 ± 0.21^{a}	nd	nd	nd	nd	3.82 ± 0.42^{b}	nd
Men/day	*8 mg*	*2.3 mg*	*0.9 mg*	*11 mg*	**35μg**	not determinable	not determinable
Women/day	*18 mg*	*1.8 mg*	*0.9 mg*	*8 mg*	**25μg**	not determinable	not determinable

[a]Data are mean $\pm$ SD values of three independent experiments and different letters indicate a significant difference according to analysis of variance and Tukey's *post hoc* test ($p \leq 0.05$) for each mineral evaluated. nd: not detected. This table presents *Dietary Reference Intakes (DRI)* in italics and **Dietary Recommendations** in bold type, both for adult individuals (31-50 years old).

tionship among all fruit constituents and between them and other elements that are present in the diet should be better studied.

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RESUMO

As frutas são ricas em minerais, sendo estes essenciais para uma grande variedade de processos metabólicos e fisiológicos no corpo humano. A utilização de frutas congeladas tem se ampliado nos últimos anos, não só na preparação de sucos, mas também como matéria-prima para iogurtes, doces, biscoitos, bolos, sorvetes e alimentos infantis. No entanto, até o momento não há dados sobre o perfil mineral de frutas congeladas. Este trabalho é o primeiro banco de dados para quantificar os níveis de minerais em 23 amostras de frutas congeladas, bastante consumidas em todo o mundo e de algumas frutas nativas da floresta amazônica, Brasil. Considerando-se as Referências de Ingestão Diárias, 100g de frutas congeladas podem fornecer 0,2-2,8% de macro e de 2,5 a 100% dos microminerais para adultos (31-50 anos). Embora as diferenças geográficas devam ser consideradas, estes dados ajudam para o plano de dietas e desenvolvimento de intervenções junto à população com o objetivo de prevenir doenças crônicas.

Palavras-chave: dieta, recomendações dietéticas, Referências de Ingestão Diária, frutas congeladas, minerais.

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