Studies of chemical and enzymatic characteristics of Yacon (*Smallanthus sonchifolius*) and its flours

Estudo das carcaterísticas químicas e enzimáticas de Yacon (Smallanthus sonchifolius) e suas farinhas

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Abstract

Due to the importance of studies on yacon related to health, its *in natura* pulp, *in natura* peel, pulp flour, and peel flour were chemically analyzed in terms of its centesimal composition, specific minerals, total dietary fiber and fractions, pH, total soluble solids, total titratable acidity, tannins, oxalic acid, and nitrate. The polyphenoloxidase and peroxidase enzymatic activities were evaluated for *in natura* pulp and peel only. Yacon pulp and peel flour presented average yield of 7.94% and 10.86%, respectively. The *in natura* pulp presented a higher moisture and carboydrate content and lower lipid, protein, total dietary fiber, and ash than those of the peel flour. The same pattern was observed for pulp flour when compared to peel flour. The highest tannin, nitrate, and oxalic acid levels were found in the peel flour, 15,304.5 mg.kg^{-1}, 1,578.3 mg.kg^{-1}, and 7,925.0 mg.kg^{-1} (wet weight), respectively. The polyphenoloxidase and peroxidase enzymes presented higher enzymatic activity in the yacon peel. Based on the results obtained, it can be said that the yacon and its derivatives are important dietary carbohydrate and mineral sources and contain antinutritional substance contents lower than those harmful to health.

Keywords: *dietary fiber; antinutritional factors; enzymes.*

Resumo

Devido à importância dos estudos com yacon em relação à saúde, foram analisadas quimicamente sua polpa in natura (PY), casca in natura (CY), farinha da polpa (FPY) e casca (FCY), sendo determinados composição centesimal, minerais específicos, fibra alimentar total (FAT) e frações, pH, SST, ATT, taninos, ácido oxálico e nitrato. As atividades enzimáticas de polifenoloxidase (PFO) e peroxidase (PER) foram avaliadas para PY e CY exclusivamente. A FPY e FCY apresentaram rendimento médio de 7,94% e 10,86%, respectivamente. A PY apresentou conteúdos numericamente maiores de umidade e carboidratos e menores de lipídios, proteínas, FAT e cinzas em relação à CY. Foi observado o mesmo para a FPY quando comparada à FCY. Na FCY, foram encontrados os maiores teores de taninos, nitrato e ácido oxálico entre as amostras analisadas, sendo 15.304,5 mg.kg^{-1}, 1578,3 mg.kg^{-1}, 7.925,0 mg.kg^{-1}, respectivamente. As enzimas PFO e PER apresentaram atividades enzimáticas numericamente superiores na CY. Baseando-se nos resultados, pode-se dizer que o yacon e seus derivados são importantes fontes de carboidratos e minerais na dieta, sem riscos de toxicidade.

Palavras-chave: *fibra alimentar; fatores antinutricionais; enzimas.*

1 Introduction

The use of functional foods in their natural form or processed has been promoted around the world, among which is the yacon (*Smallanthus sonchifolius*), a tuberous root from the Andean region of South America; its global dissemination is due to the fact it can easily adapt to climate, altitude, and soil type (ASAMI et al., 1991). Functional foods are associated to health maintenance and prevention of non-transmissible chronic diseases, and therefore researchers have the challenge of unveiling characteristics of new foods and substances beneficial to health.

Yacon was introduced in Brazil in the beginning of the nineties, and as an alternative, it can be dehydrated and/or processed in a series of appealing convenience products. Juices, milk-like drinks, nectars, flours, sweets, and dehydrated chip-type slices are the most commonly described in the literature (DOO et al., 2000). Moreover, new products have been developed using yacon flour including breads, cakes, biscuits, and extruded snacks (ROLIM et al., 2010; PADILHA et al., 2010; MALDONADO; SINGH, 2008).

Yacon is rich in fructans, which include inulin and fruit-oligosaccharides (FOS) that act as soluble fibers and prebiotics benefiting the human body, as proven in many studies. When appropriate amounts are consumed, these effects can influence intestinal function, increase the frequency and weight of the feces, reduce the glucose absorption rate, decrease triacylglycerol and plasmatic cholesterol levels in hypercholesterolemic patients, reduce the risk of colon cancer, show an increase of intestinal absorption of some minerals, and promote the

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elimination of pathogenic and putrefactive bacteria by the bifidobacteria multiplication effect. Besides its reduced caloric value, Yacon has negligible cariogenicity (YOUNES et al., 1993; BRIGHENTI et al., 1995; KOK et al., 1996; AYBAR et al., 2001; GUIGOZ et al., 2002; SILVA; CÂNDIDO, 2004; GENTA et al., 2005; LOBO et al., 2007).

Besides the fructan content, yacon contains considerable phenolic acid levels, among which can be mentioned chlorogenic acid, caffeic acid, and ferulic acid, which demonstrate antioxidant activity and consequently can protect the cell membranes against free radical damage (TAKENAKA, 2003; SIMONOVSKA et al., 2003; ROCHA et al., 2007; ÖZTÜRK; TUNÇEL, 2011; DINCER et al., 2012).

Studies on conventional and nonconventional vegetables concerning nutrients and possible antinutricional factors and/or toxins are essential because these factors and toxins can affect the nutritional value of foods (GUPTA et al., 1989; PINTO et al., 2001).

Water is the major component of yacon root, about 90%, which makes it susceptible to fast degradation and guarantees a useful life, in ambient conditions, of approximately seven days. Yacon is traditionally consumed *in natura*, but it is also found in the dehydrated form, with high added value in the international market, for example Chile and in Germany, and it is also used as an ingredient in product formulations for diabetics such as yacon jellies and syrups (MOURA, 2004). The production of flours using yacon facilitates handling, increases shelf life, and requires less storage space (DOO et al., 2000).

According to a study conducted by Graefe (2004), the concentration of the prebiotics in yacon decreases during postharvest storage time due to their depolymerization. Therefore, in order to make full use of this tuberous root with its overall functionality, it should be consumed immediately after harvest or processing. An alternative to maintain the yacon adequate for consumption for a longer period of time conserving its properties is to carry out dehydration and/or drying of this raw material.

Products in the form of flours present more practicality of storage and conservation, besides being easily added to various products. Additionally, the yacon pulp flour is an ingredient with a sweet flavor and low caloric value, an option for diabetics and similar consumers.

Given the aforementioned considerations, studies to investigate whether the dehydration of products such as yacon (in terms of the pulp and peel) results in a consequent loss of concentration or even substance losses during the processing are of great importance.

Various studies have been conducted evaluating the physiological and metabolic effects of the yacon, often in the form of flour (GENTA et al., 2005; LOBO et al., 2007; 2011; PEREIRA et al., 2009; ROLIM et al., 2011; HABIB et al., 2011).

This study aimed to evaluate some characteristics such as centesimal composition, minerals, alimentary fiber and fraction content, presence of antinutrients and/or natural toxic substances in the *in natura* yacon and its flours, and some enzymatic characteristics of this vegetable *in natura*.

2 Materials and methods

Yacon roots of the 2008 harvest were obtained from a vegetable producing farm in city of Barbacena, Minas Gerais.

The yacon peel was extracted using a manual peeler separating peel and pulp. The pulp was cut into 1 cm × 3 cm pieces. The peel and the pulp were immersed in a sodium hypochlorite 20 $mg.L^{-1}$ and sodium bisulphite 0.1% solution for 15 minutes. Next, the peel and pulp were submitted to forced ventilation oven drying at 55 °C (PADILHA et al., 2009; SCHER; RIOS; NOREÑA, 2009) for 72 hours and 96 hours, respectively; the time was determined by pre-testing until they reached the desired moisture content. After drying, they were milled using a multiprocessor until ootsturning into the flour. The flour yields were obtained from four yacon root batches. The yacon roots were selected and weighed and then submitted to the elaboration of the yacon peel and pulp flour. After obtaining the flour for each batch, they were weighed and the yield percentage was calculated.

The centesimal composition of the different products was analyzed according to the AOAC method (ASSOCIATION..., 1990). The determination of total dietary fiber and fractions were performed following the enzymatic-gravimetric techniques proposed by AOAC (ASSOCIATION..., 2000) using the Sigma® – Total dietary fiber kit.

The minerals calcium, phosphorus, potassium, magnesium, sulfur, copper, manganese, zinc, and iron were determined by atomic mass spectrometry according to the method proposed by Malavolta, Vitti and Oliveira (1997).

The pH was analyzed in solutions containing the extracts in distilled water and measured using a digital pH meter (CECCHI, 2003). The same extract solutions were used for determining the total soluble solids (TSS) using a digital refractometer, and the results were expressed in °Bx. The total titratable acidity was determined by titration with NaOH 0.1N until pH 8.2 (ASSOCIATION..., 1992), and the result was expressed in % of malic acid, as proposed by Palomino and Rios (2004).

For the determination of tannins, an extraction using methanol (80%) (SWAIN; HILLIS, 1959) was performed, and they were identified by the Folin-Denis' colorimeter method (ASSOCIATION..., 1990); the readings were conducted at 760 nm.

The nitrate content was analyzed by the colorimetric method (CATALDO et al., 1975), in which a complex is formed by the nitration of salicylic acid under highly acidic conditions which is then read in spectrophotometer at 410 nm with basic solutions (pH > 12).

The oxalic acid was determined by the titrimetric method (ASSOCIATION..., 1990), the sample was extracted with hot HCl and caprylic acid, the oxalic acid precipitation occurred upon the addition of tungstophosphoric acid, sodium oxalate solution, and sulfuric acid. Next, the oxalic acid was quantified by titration with potassium permanganate.

For evaluation of the polyphenoloxidase (PPO) and peroxidase (PER) activities, the enzymatic extract was obtained according to Matsuno and Uritani (1972). In the case of PPO, a mixture of 0.5 mL of concentrated enzymatic extract, 1.8 mL of phosphate buffer 0.1 M (pH 7.0), and 0.05 mL of catecol 10 mM was incubated at 30 °C for 30 minutes. Then, 0.8 mL of perchloric acid 2N was added to stop the reaction, and the absorbance was measured at 395 nm using a UV-visible spectrophotometer (Varian®) (TEISSON, 1979). One unit of PPO activity of was defined as the increase of one unit of absorbance per minute/g of sample.

The PER enzyme activity was obtained according to the AOAC method (ASSOCIATION..., 1990) using a mixture of 3 mL enzymatic extract, 5 mL phosphate-citrate buffer (0.1 M pH 5.0), 0.5 mL hydrogen peroxide 3%, and 0.5 mL guaiacol. The mixture was subsequently incubated at 30 °C for 5 minutes. After that time, 1 mL of sodium bisulphite 30% was added to stop the reaction and the absorbance reading was taken at 470 nm.

The determination of yacon chemical and biochemical composition was carried out in four repetitions for each sample type, and the results were expressed as mean ± SD. The Tukey test was conducted at a 5% significance level to compare means.

3 Results and discussion

The average yield of the yacon pulp flour (PuF) was 7.94%, smaller than that of the yacon peel flour (PeF), 10.86%.

The high yield presented by PeF can be justified by the fact that the peel *in natura* have lower moisture content than the pulp in the same state (Table 1); therefore, the peel loses less weight in the drying process.

Viega, Oliveira and Fuke (2007) elaborated yacon pulp flour and obtained a yield of 4.57%, a value smaller than that of this study.

Fernandes (2006) used potato peels (*Solanum tuberosum L.*) for flour production and obtained an average yield of 9.94%, a value similar to that obtained for PeF (10.86%) in this study.

The centesimal composition obtained for the different yacon products is shown in Table 1.

As can be seen in Table 1, the composition of the *in natura* yacon peel (Pe) and the yacon peel flour (PeF) have levels higher than those of the pulp of *in natura* yacon (Pu) and yacon pulp flour (PuF), respectively, with the exception of digestible carbohydrates.

There was high concentration of all the components on the flours, except for moisture, compared to that of *in natura* products indicating that yacon dehydration (pulp and peel) can lead to high nutrient content in reduced volume of foods.

In the *in natura* yacon pulp, moisture content was close to the values found in the literature, which are between 81.7% and 88.7% (LAGO, 2010; SCHER; RIOS; NOREÑA, 2009; MARANGONI, 2007).

For the edible portion of the *in natura* yacon root, Palomino and Rios (2004) found the following percentages for its components (wet weight): 88.86% moisture; 0.23% protein; 0.10% lipids; 0.41% fiber; 0.30% ash, and 10.10% carbohydrates, percentages very close to those obtained in the present study, except for the fiber content, for which the authors found significantly smaller values.

Moscatto, Prudêncio-Ferreira and Hauly (2004) elaborated yacon pulp flour for cake production and found the composition of 4.37% moisture, 1.07% lipids, 8.32% protein, 3.75% ash, and 82.49% carbohydrates. An explanation for the differences between the Moscatto, Prudêncio-Ferreira and Hauly (2004) study and the present study can be the use of different drying temperature and drying time for the yacon roots.

Marangoni (2007) obtained centesimal composition values for the *in natura* yacon pulp very similar to those found in the present study. On the other hand, for the yacon flour, these authors found lower levels of centesimal composition for all components, given that the moisture content was higher in this product than that of the yacon pulp flour in the present study. Thus, it is important to point out that differences in the processing for the elaboration of flours can interfere in the final content of the nutrients.

The results found by Vasconcelos et al. (2010) when evaluating the composition of *in natura* yacon pulp and

Table 1. Chemical composition (%) of yacon and respective flours on a wet and dry basis.

Components	Moisture	Lipids	Protein	Digestible carbohydrates	Dietary fiber	Ash
			Wet matter			
Pu*	87.52 ± 0.45[a]	0.06 ± 0.01[c]	0.43 ± 0.05[c]	10.32 ± 0.40[c]	1.31 ± 0.08[d]	0.38 ± 0.04[d]
PuF	8.09 ± 1.74[c]	0.67 ± 0.19[b]	4.50 ± 1.26[b]	72.07 ± 2.23[a]	11.79 ± 0.39[b]	2.88 ± 0.13[b]
Pe	82.12 ± 1.93[b]	0.32 ± 0.06[bc]	1.09 ± 0.03[c]	5.11 ± 1.98[c]	9.68 ± 0,43[c]	1.83 ± 0.08[c]
PeF	4.49 ± 0.40[d]	1.26 ± 0.17[a]	6.06 ± 0.42[a]	42.82 ± 0.93[b]	38.56 ± 1.06[a]	6.81 ± 0.24[a]
			Dry matter			
Pu*	-	0.45 ± 0.07[c]	3.48 ± 0.46[c]	82.57 ± 0.77[a]	10.48 ± 0.33[c]	3.02 ± 0.30[c]
PuF	-	0.89 ± 0.29[c]	5.50 ± 0.39[b]	77.25 ± 1.66[b]	13,99 ± 0.66[c]	3.12 ± 0.17[c]
Pe	-	1.81 ± 0.34[a]	6.13 ± 0.52[ab]	27.94 ± 4.74[d]	53.77 ± 5.10[a]	10.36 ± 1.20[a]
PeF	-	1.32 ± 0.19[b]	6.34 ± 0.42[a]	42.93 ± 1.14[c]	42.28 ± 0.93[b]	7.14 ± 0.24[b]

Pu = yacon pulp; PuF = yacon pulp flour; Pe = yacon peel; PeF = yacon peel flour. *mean values of four replicates. Values followed by same letter in the column do not differ statistically from each other ($p < 0.05$).

respective flour indicated a higher moisture content (91.10%) and lower protein and lipid concentrations for the yacon root pulp (wet basis) compared to the values obtained in the present work. For the yacon pulp flour, these authors found lower values than those obtained in the present study for moisture (6.59%), proteins (2.61%), and lipids (0.27%). On the other hand, the total dietary fiber content in the pulp or in the yacon pulp flour was always higher than that of the present study since for the calculation of that component, the authors considered the sum of insoluble dietary fiber, soluble dietary fiber, fructooligosaccharides, and inulin; these last components, fructooligosaccharides, and inulin were determined by a specific method. According to Muñoz et al. (2006), the agronomic characteristics, soil type, climatic and ecological conditions, the use or not of fertilizers, and the cultivation techniques applied influence the production and the content of nutrients present in the yacon root.

Studies on the composition of the yacon peel *in natura* or processed are scarce.

Botelho (1998) evaluated the chemical composition of the pineapple peel (*Smooth Cayenne*) and when comparing the results obtained with those of other studies on pineapple pulp, the author verified that the peel has higher levels of lipid, protein, fiber, and ash than those of the pulp. The higher values found for some nutrients in the pineapple peel composition are similar to the results obtained in this study for yacon peel.

Fernandes (2006) produced potato peel flour for the elaboration of whole wheat bread and found the composition of 9.72% moisture, 1.61% lipids, 5.56% protein, 1.46% crude fiber, 2.22% of ash, and 79.59% carbohydrates on a wet weight basis; only the lipid and protein contents were similar to those of the present study.

The concentrations of the different minerals analyzed in the yacon and derived products are presented in the Table 2.

Most of the analyzed minerals had higher concentrations in the flours when compared to the *in natura* products due to reduced moisture. The flours, as well as other types of food concentrates tend, in general, to present higher nutrient concentrations, except for those thermally-sensitive, such as vitamin C and some of the B complex vitamins (PEREIRA, 2007).

Grau and Rea (1997) found the following amounts of minerals on a wet weight basis of yacon root pulp: 23 mg.(100 g)$^{-1}$ calcium, 0.3 mg.(100 g)$^{-1}$ iron, and 21 mg.(100 g)$^{-1}$ phorphorous, very similar levels to those obtained in this study, except for the calcium level. In the study of Hermann, Freire and Pazos (1997-1998), the value obtained for potassium was 228.2 mg.(100 g)$^{-1}$ on a wet weight basis of the yacon pulp, higher than that found in the present study. However, Valentová, Frcek and Ulrichová (2001) found the following concentrations of 0.96 copper mg.(100 g)$^{-1}$, 0.54 mg.(100 g)$^{-1}$ manganese, and 0.67 mg.(100 g)$^{-1}$ zinc in the yacon pulp. In this case, all the yacon pulp minerals had higher concentrations than those in the present study.

In the study of Gondim et al. (2005), the chemical analyses showed that fruit peels present, in general, higher nutritient levels than those of their respective edible parts, representing alternative sources of nutrients avoiding food waste.

It can be observed that PuF and PeF are considerable sources of several minerals, and some them such as phosphorous,

Table 2. Mineral concentration (mg.(100 g)$^{-1}$) in yacon and respective flours on a wet and dry basis.

Mineral	Pu*	PuF	Pe	PeF
	Wet matter			
P	23.2 ± 0.7^{d}	196.0 ± 15.2^{b}	51.5 ± 1.9^{c}	215.0 ± 5.5^{a}
K	171.7 ± 21.2^{d}	1,276.0 ± 261.0^{b}	442.8 ± 54.7^{c}	1,946.0 ± 123.8^{a}
Ca	6.3 ± 0.9^{d}	23.0 ± 4.4^{c}	50.6 ± 3.8^{b}	144.0 ± 15.2^{a}
Mg	3.7 ± 0.0^{d}	40.0 ± 0.0^{c}	49.6 ± 1.7^{b}	184.0 ± 5.5^{a}
S	9.7 ± 0.5^{d}	134.0 ± 11.4^{b}	27.6 ± 0.9^{c}	250.0 ± 12.2^{a}
Cu	0.1 ± 0.0^{b}	1.3 ± 0.5^{a}	0.2 ± 0.0^{b}	1.9 ± 0.7^{a}
Mn	0.0^{b}	0.0^{b}	0.1 ± 0.0^{a}	0.5 ± 0.0^{a}
Zn	0.1 ± 0.0^{d}	1.0 ± 0.0^{b}	0.3 ± 0.0^{c}	1.3 ± 0.0^{a}
Fe	0.3 ± 0.0^{d}	2.9 ± 0.6^{c}	9.6 ± 1.5^{b}	44.5 ± 0.8^{a}
	Dry matter			
P	186.0 ± 5.4^{c}	213.3 ± 16.5^{b}	246.0 ± 8.9^{a}	224.1 ± 5.7^{b}
K	1,376.0 ± 169.9^{b}	1,487.5 ± 86.0^{b}	2,113.0 ± 261.1^{a}	2,035.6 ± 129.8^{a}
Ca	49.9 ± 7.0^{c}	25.0 ± 4.0^{d}	241.4 ± 18.0^{a}	150.8 ± 15.8^{b}
Mg	29.7 ± 0.14^{d}	43.5 ± 0.0^{c}	236.6 ± 8.0^{a}	192.7 ± 5.7^{b}
S	78.0 ± 4.4^{c}	145.8 ± 12.4^{b}	131.8 ± 4.5^{b}	261.7 ± 12.8^{a}
Cu	0.8 ± 0.0^{c}	1.6 ± 0.4^{b}	0.9 ± 0.0^{c}	2.2 ± 0.4^{a}
Mn	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}	0.5 ± 0.0^{a}	0.5 ± 0.0^{a}
Zn	1.1 ± 0.1^{b}	1.1 ± 0.0^{b}	1.3 ± 0.0^{a}	1.4 ± 0.0^{a}
Fe	2.5 ± 0.1^{b}	3.2 ± 0.6^{b}	45.0 ± 18.6^{a}	46.6 ± 0.8^{a}

Pu = yacon pulp; PuF = yacon pulp flour; Pe = yacon peel; PeF = yacon peel flour. *mean values of four replicates. Values followed by same letter in the same lines do not differ statistically from each other ($p < 0.05$).

potassium, magnesium, copper, and iron are present at levels that can supply more than 10% of the daily needs of a healthy adult for each 100 g of the consumed product (FOOD..., 2007).

PuF and PeF were shown as important mineral sources in a range from 2.2% calcium to 556.9% iron meeting the needs of an adult man.

The levels of total dietary, soluble, and insoluble fiber are presented in Table 3.

The total dietary fiber content (TDF) of the flours in the pulp (12.85%) and in the peel (40.38%) were higher than those of the *in natura* products, Pu1.31% and Pe 9.68% (wet basis), since the dehydration process concentrates these substances.

With regard to the fractions of insoluble dietary fiber (IDF), the flours derived from the pulp (10.40%) and peel (35.28%) had higher concentrations (wet basis) than those of non-processed products. As for IDF, higher levels were found for Pe (8.49%) and PeF (35.28%) when compared to Pu (1.12%) and PuF (10.40%) on wet basis.

As to SDF, in Pe 1.19% was found and in PeF 5.10%, these values being superior those found in Pu (0.18%) and in PuF (2.42%) on wet weight.

In the study by Viega, Oliveira and Fuke (2007) on yacon pulp, the content of TDF on a wet weight basis was 14.34%, 9.68% of insoluble fiber and 4.67% of soluble fiber (SDF), and in the present study the values found for TDF, IDF, and SDF were 10.5%, 8.97%, and 1.44% on a wet weight basis, respectively. The amounts of total dietary fiber and the soluble fraction were the most different from the values found by Viega, Oliveira and Fuke (2007), possibly due to the need to combine the fructan analysis method for the determination of dietary fiber (QUEMENER; THIBAULT; COUSSEMENT, 1994).

Vasconcelos et al. (2010) obtained 2.95% and 47.42% of TDF in the pulp and yacon flour on a wet basis, respectively. These values are higher than those found in the present study, which can be justified by the fact that they considered the sum of IDF, SDF, fructooligosaccharides, and inulin for TDF. However, only considering the IDF and SDF values, they totaled 1.06% of TFD for the pulp, (wet basis) which is smaller than the value found in the present study, and 18.15% of TDF for the yacon pulp flour (wet basis); the latter was higher than that obtained in that study.

Lobo (2004) reported that the lyophilized yacon, called yacon pulp flour, had TDF content of 10.84%, IDF 7.59%, and SDF 3.25% (wet weight). Among these values, TDF and IDF were smaller than the values obtained in the present study; however, SDF was higher than that of this study.

It is important to emphasize the probable difference in maturation stage of the yacon analyzed in this study in and that used in the studies described above (LOBO, 2004; VIEGA; OLIVEIRA; FUKE, 2007) since with the ripening of that vegetable, fructans can be hydrolized by enzymatic action originating smaller molecules that possibly were not completely quantified because according to Lajolo and Menezes (2006), low molecular weight fructans are not precipitated in alcohol 78% v/v used in the SDF quantification, and thus the use of a fructan determination method is necessary (QUEMENER; THIBAULT; COUSSEMENT, 1994).

The pH, total soluble solids, and total titratable acidity results in the yacon and flours are presented in Table 4.

Vilhena, Câmara and Kakihara (2000) found a pH of 5.53 and total titratable acidity (TTA) of 1.8% for the yacon pulp, the first parameter was similar to that of the present study. According to Palomino and Rios (2004), with the yacon maturation process, the pH and the total soluble solids (TSS) increase and the TTA decreases. Therefore, the difference between the value presented here for TTA and that obtained by Vilhena, Câmara and Kakihara (2000) can be due to the degree of maturation of the roots.

Studying roots of ripe yacon, Palomino and Rios (2004) obtained 13.5 brix degree for total soluble solids, a total titratable acidity of 0.315% in malic acid, and pH of 5.78, values close to those obtained in the present study.

Palomino and Rios (2004), who also produced yacon pulp flour dried at different temperatures, obtained a total soluble solids value in the range from 24 to 27 brix degree, TTA from 0.224 to 0.228% in malic acid, and pH from 5.98 to 6.08 showing that the results of TSS and acidity were smaller than those of the present study. According to Carvalho (2000), the differences of TTA can be influenced by environmental factors such as climatic conditions, soil type, cultural practices, and physiologic maturity.

The tannin, nitrate, and oxalic acid levels found in the yacon and its flours are shown in Table 5.

Pu (884.3 $mg.kg^{-1}$) and Pe (1,621.4 $mg.kg^{-1}$) had lower concentrations of tannins in than those of PuF and PeF (10,396.4

Table 3. Levels of total dietary, soluble, and insoluble fiber of yacon and respective flours on a wet and dry basis.

Product	TDF* (%)		IDF** (%)		SDF*** (%)	
	Matéria úmida	Matéria seca	Matéria úmida	Matéria seca	Matéria úmida	Matéria seca
Pu	1.31 ± 0.08^d	10.3 ± 0.3^d	1.12 ± 0.07^d	9.0 ± 0.2^b	0.19 ± 0.02^d	1.3 ± 0.2^c
PuF	12.85 ± 0.42^b	13.98 ± 0.48^c	10.40 ± 0.24^b	11.3 ± 0.24^b	2.45 ± 0.25^b	2.64 ± 0.41^b
Pe	9.68 ± 0.43^c	45.6 ± 2.2^a	8.49 ± 0.37^c	40.0 ± 1.8^a	1.19 ± 0.53^c	5.6 ± 0.4^a
PeF	40.38 ± 1.13^a	42.2 ± 1.15^b	35.28 ± 1.03^a	36.9 ± 1.12^a	5.10 ± 0.16^a	5.3 ± 0.51^a

Pu = yacon pulp; PuF = yacon pulp flour; Pe = yacon peel; PeF = yacon peel flour. *total dietary fiber; **insoluble dietary fiber; ***soluble dietary fiber. *mean values of four replicates. Values followed by same letter in the column do not differ statistically from each other ($p < 0.05$).

mg.kg^{-1} and 15,304.5 mg.kg^{-1}) on a wet basis, respectively; however, those values should be considered due to the proportion of moisture in the fresh products and in the flours.

According to the study of Yan et al. (1999), the yacon tuberous roots contain polyphenols in the concentration of 2,030 mg.kg^{-1}, a value higher than that of tannins found for Pu and Pe, on a wet basis, but smaller than that of PuF and PeF analyzed. On the other hand, Quinteros (2000) found on average, 438.9 mg.kg^{-1} of phenols (wet basis) in the yacon root, a concentration smaller than that of tannins found for Pu in this study.

PuF had, on a wet basis, a tannin level (10,396.4 mg.kg^{-1}) smaller than that of PeF (15,304.5 mg.kg^{-1}); however, these values were higher than 1% of tannins (10,000 mg.kg^{-1}), which, according to Nozella (2001), is a considered a high value able to affect protein digestibility. In case of a diet that consists only of yacon peel and pulp flour, the level of tannin would be considerably high and could then influence protein digestibility. However, considering that this situation would be difficult to occur, the concentration of tannins in the pulp and yacon peel flours does not raise concern about protein bioavailability.

Usually, fruits contain low nitrate concentrations, which do not exceed 10 mg.kg^{-1} of whole matter, although a few exceptions exist such as bananas, strawberries, and tomatoes reaching levels above 100 mg.kg^{-1} (MÍDIO; MARTINS, 2000), whose nitrate values are close to those found for Pu (79.40 mg.kg^{-1}) and Pe (198.60 mg.kg^{-1} of whole matter); however, the yacon pulp or the peel flours had significantly higher values.

However, the levels of nitrate obtained for the pulp flour and yacon peel represent less than 50% of the maximum limits from 3,000 to 4,000 mg.kg^{-1} of whole matter permitted in Europe (BENOIT; CEUSTERMANS, 1989).

The oxalic acid was detected in higher amounts in Pe (1,915.0 mg.kg^{-1}) and PeF (7,925.0 mg.kg^{-1}) than those of Pu (850.0 mg.kg^{-1}) and PuF (3,825.0 mg.kg^{-1}). The flours had higher oxalic acid content when compared to their *in natura* products.

Nappi et al. (2006) analyzed the level of oxalic acid in multimixtures (wheat, maize flour, egg shell, and manioc leaf) and obtained the value of 510 mg. sample kg^{-1}, an amount smaller than that found in the present study in yacon peel flour (PeF). However, the manioc leaf had high concentration of oxalic acid, between 444 mg.kg^{-1} and 570 mg.kg^{-1} of whole matter (WOBETO et al., 2007), which is higher than the levels found for the yacon and derived products in the present study, except for yacon peel flour.

It is important to point out that diets with low calcium and high oxalic acid concentrations are not recommended since the formation of the calcium oxalate compound could occur, which can lead to kidney stones. However, in the occasional consumption of foods with high oxalic acid content, as long as the diet is balanced, problems have not been reported (SAVAGE et al., 2000).

The enzymatic activities of PPO and PER are presented in Table 6.

The PPO enzymatic activity was higher in the yacon peel (300.18 U.g^{-1}.min^{-1}) than in the pulp (81.51 U.g^{-1}.min^{-1}), unlike what happens in apples, in which the highest activity is present in the pulp and not in the peel, according to the study carried out by Wakayama (1995).

On the other hand, Tchoné, Barwald and Meier (2005) studied the PPO activity in the Jerusalem artichoke (*Helianthus tuberosus L.*), an important fructan source (PRAZNIK; CIEŚLIK; FILIPIAK-FLORKIEWICZ, 2002), and found higher enzymatic activity in the peel than in the pulp of that vegetable. That difference observed between peel and pulp was similar to that observed in this study with *in natura* yacon.

Table 4. pH values, total soluble solids, and total titratable acidity in the yacon and respective flours on a wet matter basis.

Products	pH	Total soluble solids (Brix degree)	Total titratable acidity (% ácido málico)
Pu	5.87 ± 0,06^{b}	15 ± 2.0^{c}	0.44 ± 0,07^{c}
Puf	4.94 ± 0,03^{d}	42.0 ± 2.0^{a}	0.91 ± 0,06^{a}
Pe	5.74 ± 0,06^{c}	15 ± 1.0^{c}	0.38 ± 0,02^{c}
PeF	6.04 ± 0,02^{a}	34 ± 2.0^{b}	0.74 ± 0,1^{b}

Pu = yacon pulp; PuF = yacon pulp flour; Pe = yacon peel; PeF = yacon peel flour. *mean values of four replicates. Columns followed by same letter do not differ statistically from one other ($p < 0.05$).

Table 5. Level of tannin, nitrate, and oxalic acid on a wet weight basis of yacon and respective flours on wet and dry basis.

Product	Tannins (mg.kg^{-1})	Nitrate (mg.kg^{-1})	Oxalic acid (mg.kg^{-1})
		Wet matter	
Pu	884.3 ± 63.8^{d}	79.4 ± 16.1^{d}	85.0 ± 5.7^{d}
FuF	10,396.4 ± 52.1^{b}	1,027.1 ± 496.3^{b}	382.5 ± 23.6^{b}
Pe	1,621.4 ± 37.7^{c}	198.6 ± 32.0^{c}	191.5 ± 5.9^{c}
PeF	15,304.5 ± 72.9^{a}	1,578.3 ± 283.0^{a}	792.5 ± 25.3^{a}
		Dry matter	
Pu	7,084.9 ± 510.9^{c}	637.8 ± 129.3^{c}	681.0 ± 46.2^{c}
FuF	11,311.0 ± 567.0^{b}	1,117.9 ± 348.3^{b}	416.2 ± 25.7^{d}
Pe	7,735.6 ± 179.8^{c}	948.1 ± 152.7^{bc}	913.6 ± 28.5^{a}
PeF	16,024.1 ± 76.6^{a}	1,648.2 ± 296.3^{a}	829.8 ± 26.5^{b}

Pu = yacon pulp; PuF = yacon pulp flour; Pe = yacon peel; PeF = yacon peel flour. *mean values of four replicates. Values followed by same letter in the column do not differ statistically from each other ($p < 0.05$).

Table 6. Average values of the polyphenoloxidase(PPO) and peroxidase (PER) enzyme activity in U.g^{-1}.min^{-1}

Product	Activity of PPO (U.g^{-1}.min^{-1})	Activity of PER (U.g^{-1}.min^{-1})
Pu	81.5 ± 7.8^{b}	53.2 ± 5.2^{b}
Pe	300.2 ± 24.9^{a}	1,560.6 ± 238.0^{a}

Pu = yacon pulp; Pe = yacon peel. *mean values of four replicates. Values followed by same letter in the column do not differ statistically from each other ($p < 0.05$).

The PER enzymatic activity was also higher in the peel when compared to that of the yacon pulp. Besides, the enzymatic activity of PER in the *in natura* yacon pulp was higher than that found by Scher, Rios and Noreña (2009) in the same product, 22.0 $U.g^{-1}.min^{-1}$.

The PPO and PER enzymes are the main responsible for the fast darkening of the *in natura* yacon during storage, cutting, or processing (LACHMAN; FERNÁNDEZ; ORSÁK, 2003). Thus, the dehydration of the different parts of the yacon becomes an interesting procedure since they are used as food products.

4 Conclusions

The peel of *in natura* yacon and the yacon flour had better results than those of yacon pulp (*in natura* and flour) in terms of lipid, protein, dietary fiber, and especially in terms of insoluble fraction content, and ash.

The flours of the yacon pulp and peel had significantly high amounts of minerals, mainly phosphorous, potassium, magnesium, copper, and iron.

The total dietary fiber, insoluble dietary fiber, and soluble dietary fiber were found in high amounts in the yacon peel (Pe and PeF), especially the insoluble dietary fiber.

The tannin, nitrate, and oxalic acid in the samples analyzed (Pu, PuF, Pe, and PeF) were present in amounts below the limits that can compromise the bioavailability of nutrients or cause intoxication when consumed by humans.

The enzymatic activity of polyphenoloxidase and peroxidase was more evident in the yacon peel than in its pulp; therefore, enzyme inactivation treatments are necessary previous to the processing of this vegetable.

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