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Total antioxidant activity of yacon tubers cultivated in Brazil

Atividade antioxidante total de raízes de yacon cultivadas no Brasil

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ABSTRACT

Yacon (*Smallanthus sonchifolius*) is a tuberous root from the Andean region in the South America rich em water, fructooligosaccharides and phenolic compounds, some of which are natural antioxidants and may help prevent the deleterious action of free radicals in the body. The yacon has attracted much attention due to their potential health benefits to humans. In this study the levels of total phenolics, tannins, phenolic acids, and total antioxidant activity were measured in the peel and pulp of yacon tubers both in the fresh and flour forms. The flours of yacon presented higher concentrations of total phenolics and tannins, especially peel flour. The yacon pulp flour stood out as the main source of phenolic acids, mainly caffeic and chlorogenic acid. The total antioxidant activity assessed by DPPH (2,2-Diphenyl-1-picrylhydrazyl) and ABTS (2,2'-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)) assays was higher in the yacon peel flour. The total antioxidant activity was correlated with the total phenolic content and tannins by the DPPH and ABTS assays. These results suggest that yacon can be used as an alternative food source of phenolic compounds that help prevent degenerative processes caused by oxidative stress, especially in the flours form.

Index terms: *Smallanthus sonchifolius;* total phenolics; tannins; phenolic acids.

RESUMO

Yacon (*Smallanthus sonchifolius*) é uma raiz tuberosa da região andina na América do Sul, rica em água, frutooligossacarídeos e compostos fenólicos, alguns dos quais são antioxidantes naturais e podem auxiliar a prevenir a ação deletéria dos radicais livres no organismo. O yacon tem atraído muita atenção devido a seus potenciais benefícios de saúde para os seres humanos. Neste estudo, os níveis de fenólicos totais, taninos, ácidos fenólicos e atividade antioxidante total foram mensurados na casca e polpa de túberas de yacon ambas nas formas fresca e de farinha. As farinhas de yacon apresentaram altas concentrações de fenólicos totais e taninos, especialmente a farinha da casca. A farinha da polpa de yacon destacou-se como a principal fonte de ácidos fenólicos, principalmente caféico e ácido clorogênico. A atividade antioxidante total avaliada pelos métodos DPPH (2,2-Difenil-1-picril-hidrazil) and ABTS (2,2'-Azino-bis (3-etilbenzotiazolina-6-ácido sulfônico)) foi maior na farinha de casca de yacon. A atividade antioxidante total foi correlacionada com o conteúdo de fenólicos totais e taninos pelos métodos DPPH e ABTS. Estes resultados sugerem que yacon pode ser usado como uma fonte alimentar alternativa de compostos fenólicos que auxiliam a prevenir processos degenerativos causados pelo estresse oxidativo, especialmente na forma de farinhas.

Termos para indexação: *Smallanthus sonchifolius;* fenólicos totais; taninos; ácidos fenólicos.

INTRODUCTION

The association between diet and non-transmissible chronic diseases has been established for many years, and it has been demonstrated that certain foods can help prevent cardiovascular diseases, metabolic disorders (obesity), and cancer. Some types of food materials provide carbon and energy sources as well as bioactive components, and for this reason, they are termed functional foods. In the last decade, research has focused on such healthy foods in order to improve the quality of life of the population in general and to reduce the cost of medical treatment and the consequent burden on public health services.

Plants provide excellent sources of bioactive substances, including antioxidants, which act as free-radical scavengers or metal-chelating agents. These compounds are capable of preventing the harmful effects of oxidative stress (Bianchi; Antunes, 1999; Shahidi; Janitha; Wanasundara, 1992; Tounsi et al., 2011). Phenolic compounds are among the bioactive substances

with antioxidant function, and in yacon, the phenolic compounds are found mainly in the form of tannins, phenolic acids, and some flavonoids (Arnao, 2011; Jáuregui et al., 2007; Simonovska et al., 2003; Takenaka et al., 2003; Valentová et al., 2006).

Phenolic acids are one of the largest classes of plant antioxidants, and their antioxidant properties result from the presence of an aromatic ring, a carboxyl group, and one or more hydroxyl and/or methoxyl groups in the molecule (Degáspari; Waszczynskyj, 2004; Soares, 2002; Srinivasan et al., 2006). Such acids are abundantly found in grapes, strawberries, and citrus fruits, as well as in vegetables in general, including broccoli, water cress, carrots, aubergine, pepper, and teas (Anjo, 2004).

In an attempt to find new functional foods, a number of studies have been conducted on yacon (*Smallanthus sonchifolius*; Asteraceae), a tuber used in traditional Andean cuisine and that contains significant amounts of caffeic, chlorogenic, and ferulic acids (Simonovska et al., 2003; Takenaka et al., 2003; Yan et al., 1999). Because this plant exhibits excellent agricultural characteristics, such as being readily adaptable to altitude and to a variety of soil and weather conditions, it is currently cultivated in many parts of the world (Grau; Rea, 1997).

Yacon cultivation has been expanded to several countries such as New Zealand, Japan, and Brazil in the last decades, and the production in the Andean region and other countries have increased due to the presumed medicinal properties of both roots and leaves (Campos et al., 2012).

The yacon was introduced in Brazil in the beginning of the nineties. It can be dehydrated and/or processed to create a series of appealing convenience products (Doo et al., 2000). Moreover, new products have been developed, including breads, cakes, biscuits, and extruded snacks (Rolim et al., 2010), using yacon flour.

Water is the major component of the yacon roots (approximately 90%), which makes the roots susceptible to fast degradation and leads to a shelf life, in ambient conditions, of approximately seven days. The yacon is traditionally consumed *in natura*, but it is also found in the dehydrated form.

In this context, it is important that studies be conducted to assess whether the fresh and dehydrated products demonstrate relevant total antioxidant activity due to the presence of bioactive substances with antioxidant activity, which may be suitable for consumption by humans to help in combating reactive species that can cause harm to the organism.

Furthermore, studies have been conducted to evaluate the total content of phenolic substances such as acids and phenolic compounds in yacon, as well as its antioxidant activity, but mainly in the pulp *in natura* (Arnao, 2011; Jáuregui et al., 2007; Takenaka et al., 2003; Valentová et al., 2006). There are no reports in the literature on the composition of the yacon peel, which is commonly discarded for human consumption, such as the dehydrated forms, that can represent an important alternative source of antioxidant substances.

This paper quantifies the levels of total phenolics, tannins, phenolic acids, and total antioxidant activity in the natural pulp and peel, as well as in the flours from the pulp and peel of yacon cultivated in Brazil.

MATERIAL AND METHODS

Plant material and reagents

The yacon roots of yellow cultivar were grown in the region of Barbacena-MG (Brazil) at approximately 3200 m above sea level, at ~ 75% relative humidity and 17 ºC (average temperature). Samples were collected with 7 months of cultivation and stored at -20 ºC for further use.

The brown outer peel and pulp of fresh yacon tubers, together with the respective products, were triturated and processed at the Department of Food Science, Federal University of Lavras, MG. Standard caffeic, chlorogenic, ferulic acids, Folin & Ciocalteu's phenol reagent, 2,2-Diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) were acquired from Sigma (St. Louis, MO, USA). HPLC grade chromatographic solvents [methanol, butylated hydroxytoluene (BHT), and acetic acid] were purchased from Merck (Darmstadt, Germany). Ultra-pure water was obtained using a Milli-Q apparatus (Millipore, Bedford, MA, USA).

The peel was manually removed from clean tubers, and the pulp was cut into thick slices (1 x 1 cm). To allow for the later calculation of the concentration of phenolic acids present in the original *in natura* peel and pulp, the percentage humidity values of the fresh material were measured and found to be 79.04 and 87.52%, respectively. The plant material was subsequently dried in a forced air oven at 55 ºC, until a constant weight was achieved. Derivatives of the tuber material with the characteristics of flour were prepared by soaking the peel and pulp in a solution containing sodium hypochlorite (20 mg L^{-1}) and 0.1% sodium disulfide for 15 min, followed by dehydration (55 ºC) for either 72 h (peel) or 96 h (pulp). The dried materials were reduced to a powder using an electric multiprocessor, sieved, and stored for future analysis.

Total phenolic compounds

The total phenolic content in the hydrophilic extract was determined using the method proposed by Waterhouse (2002), using the Folin-Ciocalteu reagent. Briefly, 0.5 mL of the sample extracts was added to tubes containing 2.5 mL 10% (v/v) Folin-Ciocalteu reagent. Two milliliters of a 4% (v/v) sodium carbonate solution was then added. The tubes were agitated and incubated for 120 min in the dark. The blue color produced by the reduction of the Folin-Ciocalteu reagent by the phenolics was spectrophotometrically measured at 750 nm.

The phenolic content of the samples was calculated using the equation of the straight line obtained from the gallic acid standard curve. The results were expressed as milligrams of gallic acid equivalent per 100 grams of sample (mg GAE 100 g^{-1} wet yacon).

Tannins

For the determination of tannins, an extraction using methanol (80%) (Swain; Hillis, 1959) was performed, and the tannins were quantified by Folin-Denis' colorimeter method (Association of Official Analytical Chemists - AOAC, 1990). In natura yacon was discarded, being its pulp and peel crushed separately in a commercial multiprocessor; otherwise, pulp and peel yacon flours were directly employed in the extraction process. The readings were taken at 760 nm.

Phenolic acids

Extraction was performed according to the methodology described by Simonovska et al. (2003), with modifications. A sample (0.5 g) of plant material (peel or pulp, *in natura* or in the form of flour) was added to a solution containing 0.1% BHT (8.5 mL) and 10% acetic acid (1.5 mL), macerated, and centrifuged at 1694 g for 10 min in a Sigma (St. Louis, MO, USA) model 3K30 instrument. The supernatant was filtered through filter paper (7-cm diameter) and submitted to a clean-up process through silica gel C_{18} with the help of a pressure pump, to remove potential interferences. The filtrate was filtered through a 0.45-μm Millipore membrane and injected into the HPLC (High Performance Liquid Cromatography) system.

Chromatographic conditions

HPLC analysis was conducted using a Shimadzu (Kyoto, Japan) model 9012 chromatograph equipped with a binary pump, an automatic injector, and a photodiode array detector measuring absorbance at 330 nm. Phenolic acids were separated on a Shimadzu LC Shim-pack CLC-ODS column (250 x 4.6 mm i.d.; 5 μm) connected to a pre-column (10 x 4.0 mm, 5 μm) using a mobile phase consisting of pure methanol (solvent A) and a 2% acetic acid solution (solvent B) supplied at a flow rate of 1.1 mL min^{-1}. The gradient elution was programmed as follows: 0.0 min 10% A, 15.0 min 33% A, 30.0 min 65% A, and 40.0 min 10% A. The amounts of caffeic, chlorogenic and ferulic acids in the samples were calculated by comparison with the retention times of standard solutions analyzed under similar conditions and by co-chromatography of standard and sample solutions. Quantification was performed by constructing five-point calibration curves in the concentration range from 1.0 - 430 mg kg^{-1} in which each point represented the mean value of three experiments. Stock solutions of the phenolic acid standards (350 mg kg^{-1} for chlorogenic acid, 450 mg kg^{-1} for caffeic acid, and 50 mg kg^{-1} for ferulic acid) were prepared and diluted to the required concentration prior to the construction of the calibration curve.

Total antioxidant activity (TAA)

For the determination of the total antioxidant activity, extracts were prepared from the samples. To obtain the extract(s), 3 g of the homogenized sample was weighed, and 40 mL of 50% methyl alcohol was added to the sample. The mixture was homogenized and incubated for 1 h at room temperature. After this period, the mixture was centrifuged at 23,723 g for 17 min. The supernatant was collected, and 40 mL of 70% acetone was added to the residue.

The sample was then incubated for 1 h followed by centrifugation at 23,713 g for 17 min. The supernatant was collected and added to the first supernatant, and distilled water was added to the mixture to reach a final volume of 100 mL.

The measurement of TAA by the DPPH radical scavenging method was conducted according to the methodology proposed by Rufino et al. (2007) with adaptations. Sample extracts (0.1 mL) or standard antioxidants (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, Trolox; 0.1 mL) were added at a concentration of 0.2 mg mL^{-1} to 3.9 mL of the DPPH solution. After 30 min, readings at 515 nm were taken using a spectrophotometer, and then was calculated the free radical scavenging percentage (%FRS) for each dilution according to the following equation: % FRS = (Ac - Am) * 100 / Ac, where Ac is the absorbance of the control (0.1 mL of a solution containing 50% methanol and 70% acetone + 3.9 mL of DPPH solution) and, Am is the absorbance of

the sample. The results were expressed as a half maximal effective concentration (EC_{50}) (mg mL^{-1} of sample).

To determine TAA by the ABTS radical capturing method, the procedures proposed by Rufino et al. (2007) were adopted. Extracts (30 µL) were added to 3 mL of radical ABTS, and readings at 734 nm were taken after 6 min using a spectrophotometer. The results were expressed as Trolox equivalent antioxidant capacity (TEAC) (µMTE g^{-1} of sample). All of the chemical analyses were performed in triplicate.

Statistical analysis

This study was conducted in a completely randomized design (CRD) with three repetitions. A total of four treatments and twelve samples were used. Sisvar 5.0 software was used to analyze the data. The data were subjected to analysis of variance (ANOVA) and Tukey's test at 5% probability.

Pearson's correlation coefficient was calculated to determine the strength of the association between total antioxidant activity and the antioxidant compounds analyzed.

RESULTS AND DISCUSSION

The Table 1 shows the phenolic concentrations (total, tannins, clorogenic acid, ferulic acid and caffeic acid) in sample de yacon peel (Pe), yacon pulp (Pu), peel flour (PeF) and pulp flour (PuF).

In the Table 2 are submitted the parameters of the calibration curves constructed for the quantification of phenolic acids (chlorogenic, caffeic and ferulic) from yacon extracts by HPLC technique. The limit of detection (LOD) and the limit of quantification (LOQ) were calculated at signal-to-noise ratios of 3 and 10, respectively. We observed a larger detection limit for caffeic acid due to the concentration this acid higher in all samples studied as can be confirmed in Table 1.

The Figure 1 shows the chromatogram obtained by analytical HPLC technique used for quantification of phenolic acids (chlorogenic, caffeic and ferulic) described in Table 2.

Total phenolic compounds

The yacon peel had a higher concentration of total phenolics than the pulp, both *in natura* and as flour. The content of phenolic compounds found in the PeF (46.0 g Kg^{-1}) was higher than the content found by Simonovska et al. (2003), Valentová et al. (2006), Lachman et al. (2005) and Arnao et al. (2011) in the leaves of yacon (35.8 g Kg^{-1}, 2.44 g Kg^{-1}, 14.9 g Kg^{-1}, and 22.7 g Kg^{-1}, respectively), and by Lachman et al. (2005) and Lachman et al. (2007) in rhizomes (41.6 g Kg^{-1} and 44.95 g Kg^{-1}, respectively). The results show that the Pe may have the highest total phenolic content and greatest antioxidant potential.

Table 1: Phenolic compound levels in yacon.

Treatments **	Total phenolics (mgGAE kg^{-1})	Tannins (mg kg^{-1})	Clorogenic acid (mg kg^{-1})	Ferulic acid (mg kg^{-1})	Caffeic acid (mg kg^{-1})
			Wet matter		
Pe	2,500.0± 23.1[b]	1,621.4± 37.7[c]	9.0± 0.9[a]	2.0±0.4[a]	11.9± 1.3[a]
Pu	1,300.0± 0.0[a]	884.3± 63.8[d]	39.1± 1.3[b]	2.9±0.4[b]	27.0± 1.1[b]
PeF	46,100.0±0.6[d]	15,304.5± 72.9[a]	31.0 ± 4.1[b]	5.0±0.8[b]	56.0± 0.2[b]
PuF	16,200.0±0.4[c]	10,396.4 ± 52.1[b]	293.9±17.0[c]	30.1±1.4[c]	416.9±26.3[c]
			Dry matter***		
Pe	13,956.7± 127.0[b]	9,067.9± 210.9[c]	50.3± 5.1[a]	11.2±2.0[a]	66.7± 7.1[a]
Pu	10,686.7± 280.9[a]	7,085.4± 510.9[d]	313.0± 10.9[b]	23.5±3.2[b]	216.1± 8.9[b]
PeF	46,256.7±533.1[d]	16,651.3± 79.5[b]	36.0 ± 3.8[b]	5.3±0.8[b]	56.9± 0.3[b]
PuF	17,600.0±353.6[c]	10,884.8± 545.2[a]	319.7±18.5[c]	32.8±1.6[c]	453.6±28.6[c]
CV (%)****	1.83	3.77	9.45	8.57	10.38

* mean values of four replicates. Columns followed by same letter do not differ statistically among themselves by Tukey's test at 5% probability.
** Pe= yacon peel; Pu= yacon pulp; PeF= peel flour of yacon; PuF= pulp flour of yacon.
*** Moisture Pe= 82.12%; moisture Pu= 87.52%; moisture PeF= 4.49%; moisture PuF= 8.09%.
****CV= coefficient of variation.

Table 2: Parameters of the calibration curves constructed for the quantification of phenolic acids from yacon extracts.

Compound	Linear regression equation	Linearity (mg/kg)	R2 *	LOD** (mg kg-1)	LOQ*** (mg kg-1)
Chlorogenic acid	y = 5.94.109x -3,139.81	300.0-7.0	0.9969	3.5	4.8
Caffeic acid	y = 5.41.109x -13,865.02	430.0-10.0	0.9977	5.0	7.6
Ferulic acid	y = 7.81.109x -519.59	35.0-1.0	0.9968	0.5	1.3

* R^2=correlation coefficients; **LOD= limit of detection; ***LOQ= limit of quantification.

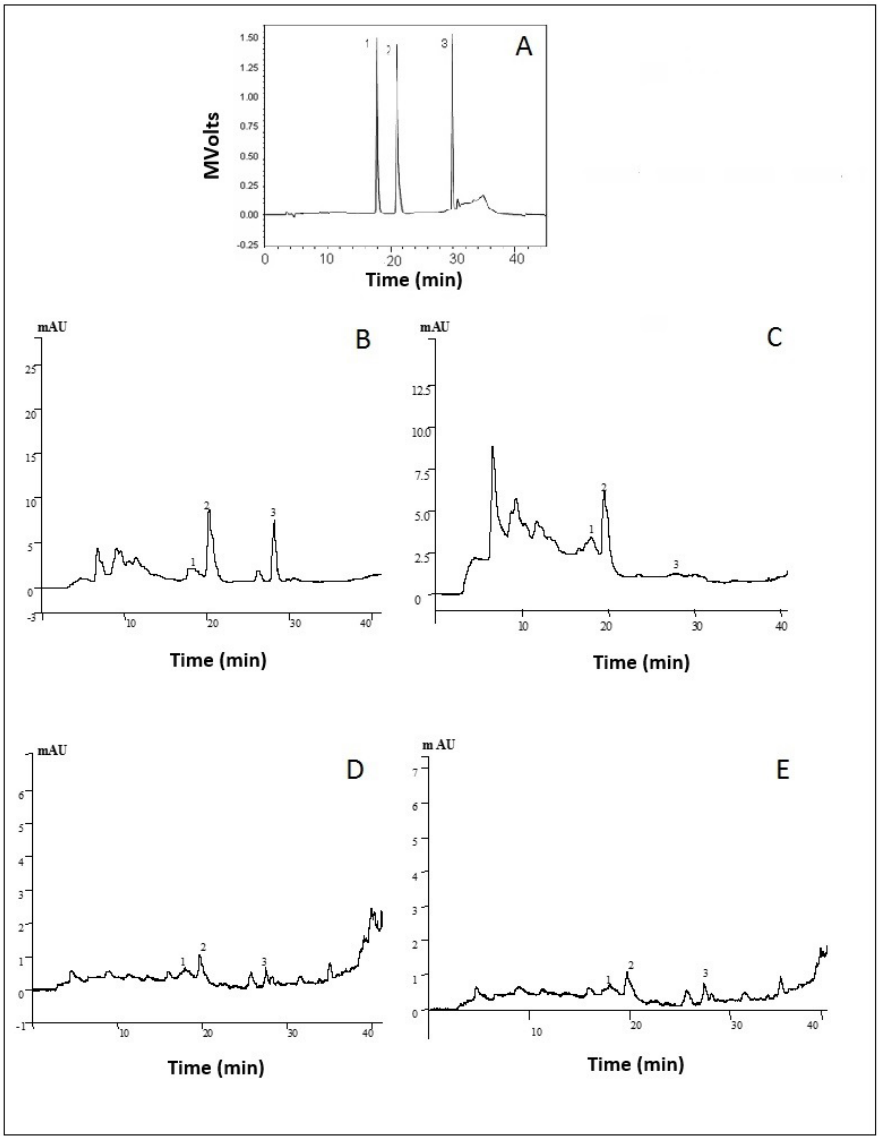

Figure 1: Chromatogram of the standard solution containing a mixture of the compounds (1A); Chromatogram of the sample of *in natura* yacon pulp (1B); Chromatogram of the sample of yacon pulp flour (1C); Chromatogram of the sample of yacon peel *in natura* (1D); Chromatogram of the sample of peel flour of yacon (1E). 1- chlorogenic acid; 2- caffeic acid and 3-ferulic acid, with spectrophotometric detection at 330 nm.

Some studies have shown that the Pu has the lowest phenolic compound content (Simonovska et al., 2003; Lachman et al., 2005; Lachman et al., 2007). This result was also observed in this study. The total phenolic content found in the PuF in this study was approximately twice that found by Simonovska et al. (2003) and by Lachman et al. (2007). Jaruégui et al. (2007) measured 676.4 mg GAE kg^{-1} of yacon pulp fresh weight, lower than the value obtained in this study, which was 1300 mg GAE kg^{-1}.

Widespread variation in the total phenolic content found in different parts of yacon has been observed in several studies. According to Muñoz et al. (2006), the agronomic characteristics, soil type, climatic and ecological conditions, the use of fertilizers and the cultivation techniques applied influence the production and the content of nutrients and bioactive compounds present in the yacon root. Furthermore, the concentrations of nutrients and bioactive compounds can be influenced by post-harvest time (Santana; Cardoso, 2008), storage form (Lachman; Fernández; Orsák, 2003) and processing methods (Milella et al., 2011). Lachman et al. (2005) found variations of 156% and 162% in the total phenolic content in rhizomes and leaves of different yacon genotypes. Milella et al. (2011) evaluated the phenolic content in the yacon biomass (tuberous roots, leaves, and rhizomes) from different countries. The phenolic content found by the authors varied from 34,940 to 68,490 mg kg^{-1}.

Tannins

In Table 1 Pu (884.3 mg kg^{-1}) and Pe (1,621.4 mg kg^{-1}) had lower concentrations of tannins (wet matter) in relation to PuF and PeF (10,396.4 mg kg^{-1} and 15,304.5 mg kg^{-1}); however, those values should be considered in light of the proportion of moisture present in the fresh products and in the flours.

The wet PuF had a lower tannin level (10,396.4 mg kg^{-1}) than PeF (15,304.5 mg kg^{-1}).

Studies have shown that tannins exhibit strong antioxidant activity that could be further explored in studies of their action in humans and in food preservation (Martinez; Moyano, 2003; Gondim et al., 2005).

Phenolic acids

The concentration of phenolic acids in the pulp of yacon tubers was significant. In a study by Jáuregui et al. (2007) evaluating the contents of phenolic compounds in fresh yacon tubers, chlorogenic, caffeic and ferulic acid concentrations of 46.38, 7.28, and 21.22 mg kg^{-1} were found. The concentrations of chlorogenic and ferulic acids were higher than those found in yacon tubers in this study (39.1 and 2.9 mg kg^{-1}, respectively) but lower for caffeic acid (27.0 mg kg^{-1} in the present case). The authors also reported that yacon is one of the plants with the highest concentrations of chlorogenic, caffeic, and ferulic acids.

The chlorogenic acid content of 39.1 mg kg^{-1} found in the pulp of fresh yacon tubers was lower than that found by Yan et al. (1999) during their investigation of the same product (48.5 mg kg^{-1}). The difference in concentrations of phenolic acids among yacon tubers reported in various works can be explained by the variability of genotypes, agronomic characteristics, soil types, climatic conditions, and use of fertilizers, as well as post-harvest time, as reported by some authors (Valentová et al., 2006; Muñoz et al., 2006).

A group of tropical fruits has been analyzed by Pontes et al. (2002) with regard to the content of chlorogenic acid in the peel, pulp, and seed. Among the evaluated pulps, quince was the richest in chlorogenic acid (261.0 mg kg^{-1} fresh weight), whereas the mango fruit (5.26 mg kg^{-1}), rose red apple (0.7 mg kg^{-1}), and persimmon (0.86 mg kg^{-1}) had the lowest concentrations. The concentration of chlorogenic acid in the pulp of fresh yacon in this study was higher than most of the fruits analyzed in previous literature. The concentration in yacon was only lower than the concentrations found in the pulp of quince, abiu, and soursop (39.0 mg kg^{-1}). The peel of fresh yacon (294.0 mg kg^{-1}) contained lower levels of chlorogenic acid compared to the peels of abiu (465.4 mg kg^{-1}), caja (435.8 mg kg^{-1}), and jackfruit (2,431.0 mg kg^{-1}), though it was larger than the values found for most of the peels of the previously analyzed fruits.

Schieber, Keller and Carle (2001) have investigated the levels of phenolic acids in apple and pear cultivars using HPLC. In the case of commercial apple pomace, chlorogenic acid and caffeic acid concentrations of 450 and 8.2 mg kg^{-1} were detected in dry matter. The residue dried under dry air at 110 ºC contained chlorogenic acid concentrations in the range 40 to 79 mg kg^{-1}. In the lyophilized pomace, concentrations of 33 to 54 mg kg^{-1} were detected for the same phenolic acid, indicating that processing can reduce the concentration of this compound. As for the pear, levels between 15 and 21 mg kg^{-1} of chlorogenic acid were found for the different fresh cultivars, smaller than those found for the pulp of fresh yacon.

In a study by Xu et al. (2009) on the peel of raw potatoes, the caffeic and chlorogenic acid concentrations ranged from 0.3 to 93.8 mg kg^{-1} and from 420.5 to

3,183.4 mg kg^{-1}, respectively, for different varieties of potatoes, thus indicating significant variations between them. The pulp and peel of fresh yacon tubers displayed a concentration of caffeic acid (27 mg kg^{-1} and 11.9 mg kg^{-1}, respectively) within the range found in the peels of the different types of raw potatoes. In relation to chlorogenic acid, both parts of yacon tubers submitted to different forms of processing contained lower concentrations than those found in the peel of raw potatoes. The peel of yacon and its respective flour showed higher levels of all the analyzed phenolic acids; however, it is noteworthy that for every root of yacon, the quantity of pulp is much larger than the amount of shell, so the pulp should be a better source of phenolic acids.

In the present study, peel and pulp flours were both prepared by drying in an oven at 55 ºC, which causes smaller losses of phenolic compounds, as has been demonstrated in the study by De Maria et al. (1998). The authors described that only small amounts of 5-CQA, an isomer of chlorogenic acid in potatoes, were destroyed during heating in an oven at 40 °C, while at temperatures of 100 °C there was a loss of approximately 24%.

The time and temperature of the oven used for drying should be evaluated in further studies to verify whether the exposure time causes damage, thereby leading to a reduction in the phenolic acids content of the samples.

The Table 3 shows the antioxidant activity (DPPH and ABTS) in sample de yacon peel (Pe), yacon pulp (Pu), peel flour of yacon (PeF) and pulp flour of yacon (PuF).

Total antioxidant activity

The total antioxidant activity assessed by the DPPH and ABTS methods was significantly higher in the peel of yacon flour and lower in the fresh pulp (Table 3). As observed in Table 4, the total antioxidant activity was highly correlated with the total phenolic content and tannins in the DPPH (-0.81 and -0.88, respectively) and ABTS radical method (0.99 and 0.97, respectively). However, a less significant correlation was observed with the phenolic acids analyzed (Table 4). In the method of DPPH the correlation with total phenolic content and tannins was negative due to the fact the results were expressed as EC_{50} that express the sample concentration required to reduce half the initial

Table 3: Antioxidant activity in yacon (wet matter).

Treatments**	DPPH EC50 (mg mL^{-1})	ABTS (µmol TE g^{-1})
Pe	3.86+002[b]	372.5±15.9[a]
Pu	5.05± 0.08[c]	274.8±39.9[a]
PeF	0.05± 0.001[a]	8,456.2±680.8[c]
PuF	2.99± 0.001[a]	2,564.1±32.7[b]
CV (%)***	14.96	10.38

* mean values of four replicates. Columns followed by same letter.
do not differ statistically among themselves by Tukey's test at 5% probability.
** Pe= yacon peel; Pu= yacon pulp; PeF= peel flour of yacon; PuF= pulp flour of yacon.
***CV= coefficient of variation.

Table 4: Association between total antioxidant activity (TAA) and antioxidant compounds analyzed using Pearson's correlation.

Variables	Pearson´s correlation (R)	
	DPPH**	ABTS***
TAA* vs. Total phenolics	-0.81	0.99
TAA vs. Tannins	-0.88	0.97
TAA vs. Chlorogenic acid	-0.53	-0.04
TAA vs. Ferulic acid	-0.59	0.03
TAA vs. Caffeic acid	-0.59	0.03

* total antioxidant activity; ** 2,2-diphenyl-1-picrylhydrazyl radical capturing method; *** 2,2'-azinobis.
(3-etilbenzotiazolina-6-ácido sulfônico) radical capturing method.

concentration of DPPH, i.e, the sample with smaller value show the greater activity antioxidant. Valentová et al. (2003) evaluated the antioxidant activity in different leaf extracts of yacon by the DPPH method. The authors found EC_{50} values equal to 0.016 and 0.024 mg mL^{-1}, which are lower than the values found in this study for the pulp and peel. The highest antioxidant activity observed by the authors in the yacon leaf extracts can be associated with the high total phenolic compound content in the extracts tested (201.6 mg $100g^{-1}$ and 365.8 mg $100g^{-1}$). Arnao et al. (2011) evaluated the total antioxidant activity of the dried leaves of yacon cultivated in different localities of Peru by the DPPH method. The authors obtained EC_{50} values between 0.051 and 0.110 mg mL^{-1}. The highest antioxidant activity obtained in yacon cultivated in Yanac was similar to the antioxidant activity obtained for peel flour (EC_{50} = 0.050 mg mL^{-1}) in the present study.

Jáuregui et al. (2007) evaluated the total antioxidant activity by the DPPH method in various vegetables produced in Peru. The efficiency of concentration (EC_{50}) ranged between 3.45 mg mL^{-1} (Camu-Camu) and 7,057.99 mg mL^{-1} (tumbo costeño). The pulp of fresh yacon presented an EC_{50} equal to 187.26 mg mL^{-1}, much higher than the value found for the yacon pulp of the present study, which is lower antioxidant activity.

Campos et al. (2012) evaluated the antioxidant capacity using the ABTS assay of thirty-five different yacon (*Smallanthus sonchifolius* Poepp. & Endl) accessions and found values in the range of 23.3 to 136 µmol de Trolox g^{-1} in the yacon pulp, which are lower than the values found in this study for the yacon pulp.

The different samples showed similar antioxidant activity behavior by DPPH and ABTS, with higher values in the yacon peel flour and less in the fresh yacon pulp. However, in the ABTS method, there was no significant difference in the total antioxidant activity of the pulp and fresh peel.

The yacon peel flour showed promising results regarding antioxidant potential .

In the Table 4 is shown the correlation between total antioxidant activity (DPPH and ABTS) and antioxidant compounds.

It can be seen, by Pearson's correlation, a greater correlation between total antioxidant activity with the total phenolics and tannin and a less significant correlation was observed with the other phenolic acids analyzed. The correlation between sets of data is a measure of how well they are related. These results support the hypothesis that an increase in total phenolic compounds will increase the antioxidant activity of extracts (Chirinos et al., 2013).

CONCLUSIONS

There are significant amounts of phenolic compounds in the yacon cultivated in Brazil, indicating that yacon can be used as a food source of phenolic compounds that help prevent degenerative processes caused by oxidative stress. Among the studied phenolic compounds, the tannins presented the best contribution to the antioxidant activity of yacon. The yacon peel had the highest antioxidant activity and may significantly contribute to increased consumption of bioactive compounds with antioxidant activity. Therefore, the use of yacon flours may be promising due to the high concentration of bioactive compounds compared to fresh yacon and may be an alternative way to increase the intake of phenolic compounds in humans. However, more studies are needed, especially *in vivo* to evaluate the effect of consumption of the products analyzed in this study.

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