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Influence of drying temperature on the chemical constituents of jaboticaba (*Plinia Jaboticaba* (Vell.) Berg) skin

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ABSTRACT. Jaboticaba is a fruit native to Brazil. Its skin represents up to 43% of the fruit and contains high levels of fiber, minerals and phenolic compounds. The use of the skin waste adds value to the fruit. However, one of the drawbacks of skin storage is the high water content, which requires drying processes to preserve the skin without leading to the loss of nutrients and antioxidants. The influence of different drying temperatures on the levels of nutrients and antioxidants was investigated. Jaboticaba (*Plinia jaboticaba* (Vell.) Berg, genotype Sabará) skins were lyophilized or dried at three temperatures (30, 45, and 60ºC, using food dryers). The skins were then ground, stored (protected from light) and subjected to analysis of proximate composition, vitamin C, phytate, polyphenols, anthocyanins and antioxidant activity. The drying process had little effect on the proximate composition of the flour, presenting significant difference only for crude protein, fiber and non-nitrogenous extract. The greatest preservation of chemical constituents occurs in the lyophilized jaboticaba skins. Among the drying temperatures tested, however, the skins dried at 45 and 60°C had more highly preserved nutritional substances and antioxidants.

Keywords: *Plinia jaboticaba*, nutrients, bioactive compound.

Influência da temperatura de secagem nos constituintes químicos de cascas de jabuticaba (*Plinia Jaboticaba* (Vell.) Berg)

RESUMO. A jabuticaba é um fruto nativo do Brasil. Sua casca representa até 43% do fruto e contém altos níveis de fibras, minerais e compostos fenólicos, que são substâncias antioxidantes. O aproveitamento deste resíduo agregará valor ao fruto jabuticaba. Entretanto, um dos inconvenientes para o armazenamento das cascas é seu elevado teor de água, necessitando, portanto, de processos de secagem que viabilizem a sua conservação sem levar a perdas da qualidade nutritiva e antioxidante. Neste trabalho, estudou-se a influência de diferentes temperaturas de secagem sobre os teores dos nutrientes e compostos antioxidantes. As cascas de jabuticaba, *Plinia jaboticaba* (Vell.) Berg genótipo Sabará, foram secas por liofilização e em três temperaturas (30, 45 e 60ºC) em secadores de alimentos. Em seguida, foram moídas e armazenadas em frascos hermeticamente fechados, protegidos da luz e analisadas quanto à composição centesimal, vitamina C, fitato, polifenóis, antocianinas e atividade antioxidante. Verificou-se que o processo de secagem pouco afetou a composição centesimal das farinhas, havendo diferença significativa apenas para a proteína bruta, fibras alimentares e extrato não nitrogenado. Observou-se que as cascas liofilizadas apresentaram os teores mais elevados para todos os compostos bioativos. Entre as temperaturas testadas, no entanto, as peles secas a 45 e 60°C apresentaram alta conservação das substâncias nutritivas e antioxidantes.

Palavras-chave: *Plinia jaboticaba*, nutrientes, composto bioativo.

Introduction

Fruits and vegetables are important sources of vitamins, minerals, fibers and phenolic compounds and contribute to the prevention of various diseases, such as cancer, gastrointestinal diseases, and premature aging caused by free radicals.

For fruit, most of the substances of interest are found in the skins. However, despite all the rich substances found in fruit skins, they are often discarded. Hunger and food waste are some of the serious problems facing Brazil, and thus, this waste of fruit skins is a great loss (GONDIM et al., 2005).

Jaboticaba is a fruit native to Brazil, found from the states of Pará until to the Rio Grande do Sul, but the states of São Paulo, Rio de Janeiro, Minas Gerais and Espirito Santo show the highest production (MATTOS, 1983). In 2008 were marketed 1,849,735 kg of jaboticaba in the Companhia de Entrepostos e Armazéns Gerais de São Paulo (Ceagesp), being 95.6% originated from the state of

São Paulo, especially from the municipalities of Casa Branca and Avai. The months of September and October concentrate approximately 60% of annual production and marketing (SASSO et al., 2010).

The skin represents up to 43% of the jaboticaba fruit and contains the following components (in g 100 g^{-1} dry matter - DM): 1.16 crude protein; 0.57 lipids; 4.39 ash; 6.80 soluble fiber; 26.43 insoluble fiber; and 11.99 polyphenols (LIMA et al., 2008). Lima et al. (2008) also analyzed the minerals in lyophilized skins, and concluded that the skins can be considered an alternative source of minerals, including iron (2.59 mg 100 g^{-1} DM), potassium (1,180.00 mg 100 g^{-1} DM), magnesium (90.00 mg 100 g^{-1} DM) and manganese (1.27 mg 100 g^{-1} DM).

However, one of the drawbacks of skin storage is the high water content, which requires drying processes that allow their preservation without leading to a loss of nutritional quality and antioxidants. There are many advantages of using drying processes, including the ease of product storage; the stability of the aromatic compounds at room temperature for long periods; the protection against enzymatic degradation and oxidation; the reduction of skin weight; the reduction of the energy required for storage due to the lack of refrigeration needs; and product availability during any season of the year (PARK et al., 2001). One drying process that causes less damage to the chemical constituents is lyophilization. However, lyophilization is a relatively expensive process. Thus, the search for other forms of drying with the least possible harm caused to the constituents is relevant. Therefore, this work aimed to study the influence of different drying temperatures on the chemical constituents of jaboticaba skin.

Material and methods

Sampling

The ripe jaboticaba fruit (*Plinia jaboticaba* (Vell.) Berg, genotype Sabará) were manually picked by the morning in October, 2009 on the farm São José do Ismeril located in the municipal district of Coqueiral (Minas Gerais, Minas Gerais State, Brazil; located at 21° 11' 22" S latitude and 45° 26' 26" W longitude, with an altitude of 867 meters). The local climate is classified by Köppen as Cwa-type (a mild and rainy summer, with a moderate temperature; average annual temperature below 21°C). The average annual precipitation and relative humidity are 1,500 mm and 70%, respectively (EMATER, 2002).

Fruit were selected, washed with tap water and sanitized by immersion in a solution of sodium hypochlorite (200 mg kg^{-1}) for 10 minutes. Fruit were then squeezed manually with the use of gloves, and the skins were weighed and separated into fractions of 1.6 kg, with five replicates for each form of dehydration.

Dehydration of jaboticaba skins and the production of flour

The jaboticaba skins were either lyophilized (lyophilizer, pressure used 1.0 millibar, temperature used -50°C, model Modulyo D-115; Thermo Electron Corporation) or dehydrated using food dryers, in which the skins were placed in metal baskets with a fine mesh at three temperatures (30, 45, and 60°C) with an air-drying velocity of 1.0 m s^{-1}.

The weight loss readings of each sample were taken at regular intervals of 120 minutes until a constant weight was reached. For the weight loss readings, the samples were taken from the dryer, weighed and quickly returned to the dryer. The samples for lyophilization were frozen at -18°C and were then lyophilized in the dark to a constant weight.

After dehydration, the jaboticaba skins were ground in a knife mill (TE 631 Tecnal) for 3 minutes, and the resulting flour was then placed in sealed bottles, which were protected from light and stored at room temperature until analysis.

Analysis

The proximate composition of the flour of the jaboticaba skins and moisture content of the jaboticaba skins were performed according to the methods described by AOAC (2005). The vitamin C content was determined by the colorimetric method described by Strohecker and Henningg (1967) using ascorbic acid as a standard. Phytate was extracted and then quantified according to the methods described by Latta and Eskin (1980) and Frühbeck et al. (1995) using sodium phytate as a standard. Polyphenols were extracted from the flour with 50% methanol and quantified according to the methods described by AOAC (2005) using tannic acid as a standard.

Anthocyanins were extracted using a method proposed by Lees and Francis (1972), with modifications made by Lima et al. (2011).

The antioxidant activity was determined using an ABTS method, proposed by Re et al. (1999), with modifications made by Rufino et al. (2007). Trolox was used as the standard, and comparison tests were performed using BHT, quercetin and rutin.

The chemical constituents and the antioxidant activity of the skins that were obtained by the different drying processes were subjected to a completely randomized design with four treatments and five replications using the computer program SISVAR (version 4.6; build 61). When the difference was statistically significant by analysis of variance,

Tukey's test at 5% probability was used for the comparison of means (FERREIRA, 2003). The results were also treated in the computer program Octave 3.4.3 (EATON, 2011), and the principal component analysis (PCA) was performed.

Results and discussion

The drying kinetic curves of jaboticaba skins at three temperatures are illustrated in Figure 1. Jaboticaba skins showed a high moisture content (83.4 g 100 g^{-1}).

The drying curves in were similar, with decreasing rates for the conditions studied and no constant rate periods. Gouveia et al. (2003) also reported an absence of a constant rate period in caja fruit.

Moreover, the kinetics was strongly influenced by temperature, with higher temperatures significantly reducing the time required to dry the jaboticaba skins. The moisture loss was more rapid at the beginning of the drying process until reaching approximately 20% of moisture content. At 30°C, stabilization of the moisture content occurred after approximately 64 hours, and at 45 and 60°C, stabilization occurred after approximately 34 and 32 hours, respectively (Figure 1).

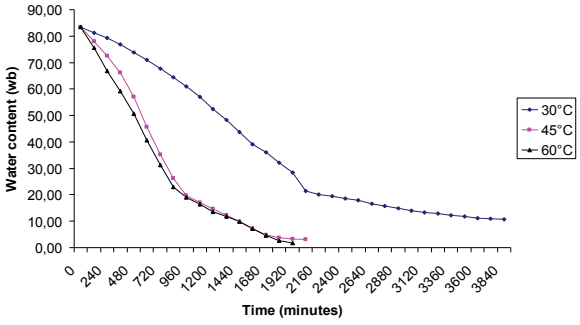

Figure 1. Kinetics of drying jaboticaba skins at three temperatures with an air velocity of 1.0 m s^{-1}.

Gouveia et al. (2003) also found similar results, and reported that the time required to dry caja at a low temperature (50°C; 38 hours and 30 minutes) was significantly longer than when the fruit was dried at a high temperature (80°C; 9 hours and 30 minutes).

The average moisture contents of the jaboticaba skin flour obtained from the treatments at 30, 45 and 60°C and by lyophilization were 10.36 ± 0.50, 1.66 ± 0.36, 0,38 ± 0.22 and 9.30 ± 0.39, respectively.

The results of the proximate composition of jaboticaba skins dried at 30, 45 and 60°C and by lyophilization are listed in Table 1. The drying process had little effect on the proximate composition of the flour. With respect to protein, the highest content was found for the skins dried at 30°C with a protein content of 6.58 g 100 g^{-1} DM, which was not significantly different from the lyophilized jaboticaba skins. These levels were higher than observed by Lima et al. (2008), who found 1.16 g 100 g^{-1} in the lyophilized skins. Borges et al. (2006) also verified significant variations in protein levels of pumpkin seeds dried at different temperatures, with a protein level of 30.80 g 100 g^{-1} DM at 60 and 28.70 g 100 g^{-1} DM at 70°C.

The levels of lipids and ash showed no significant difference. The ether extract content was 0.60 g 100 g^{-1} DM for the lyophilized skins, which was similar to that reported by Lima et al. (2008), who registered an ether extract content of 0.57 g 100 g^{-1} for lyophilized skins. In this study, the average ash content of 3.09 g 100 g^{-1} DM was lower than reported by Lima et al. (2008), who observed an ash content of 4.39 g 100 g^{-1} DM. This difference is own of jaboticaba crops, which are influenced by many factors.

The highest level of soluble fiber was found in the skins dried at 30°C, which was not significantly different from the level found in the skins dried at 45°C or the lyophilized skins (Table 1). The lowest level of soluble fiber was verified for the skins dried at 60°C. Higher temperatures may have promoted reactions that changed the structure of the fibers, which would make difficult the extraction of these fibers (CHO et al., 1997). Borges et al. (2006) also reported a decrease in fiber for jackfruit seed flour dried at 60 and 70°C.

Table 1. Proximate composition (in g 100 g^{-1} dry matter) of jaboticaba skins subjected to four drying processes.

				Dietary fiber		
Drying	Crude protein	Lipids	Ash	Soluble	Insoluble	NNE*
30°C	6.58 ± 0.23 a	0.58 ± 0.0 4	3.41 ± 0.16	8.73 ± 0.89 a	30.81 ± 0.91 a	49.89 ± 0.76 c
45°C	6.06 ± 0.15b	0.62 ± 0.08	3.05 ± 0.17	8.26 ± 0.69 ab	29.54 ± 2.03 a	52.47 ± 2.48 bc
60°C	5.95 ± 0.10 b	0.56 ± 0.05	3.30 ± 0.33	7.43 ± 0.12 b	26.46 ± 1.07 b	54.65 ± 0.72 ab
Lyophilization	6.39 ± 0.17 a	0.60 ± 0.00	3.09 ± 0.12	8.43 ± 0.58 ab	29.50 ± 1.54 a	56.30 ± 1.44 a
CV (%)	2.71	9.28	7.26	7.73	4.95	2.86

Moisture of the flour of jaboticaba skins dried at 30, 45 and 60°C and lyophilized: 10.36 ± 0.50, 1.66 ± 0.36, 0.38 ± 0.22 and 9.30 ± 0.39, respectively. Data represent the means of 5 replicates ± standard deviation. Values followed by the same letters in the column are not significantly different by Tukey's test at 5% probability. *NNE: non-nitrogenous extract.

Several studies have demonstrated the benefits of soluble fiber in reducing cholesterol and blood glucose levels in humans, and therefore, the jaboticaba skins flour (JSF) is a good alternative as a source of dietary fiber, since it overcomes oats (1.5 g of soluble fiber 100 g^{-1} DM), which is considered a food rich in soluble fiber (CHAWLA; PATIL, 2010)

With regard to the insoluble fiber content, the treatments at 30 and 45°C and lyophilization showed the highest levels.

The non-nitrogenous extract (NNE) or the fraction of carbohydrates that was obtained consists mainly of digestible carbohydrates not included in the fiber fraction. The highest level of NNE was found in lyophilized skins with a level of 56.30 g 100 g^{-1} DM, and this level was not significantly different from the NNE level for the treatment at 60°C. The lowest level of NNE was observed for the treatment at 30°C, and this level was not significantly different from the NNE level for the treatment at 45°C.

According to previous studies, freeze-drying maintains most of the biochemical properties of plant tissues (SILVA et al, 2011) which justifies the higher amount of preserved sugar. Studying jackfruit seed flour, Borges et al. (2006) reported a higher amount of carbohydrates with increasing temperature, which was similar to reported in the present study. They also registered carbohydrate levels of 58.38 g 100 g^{-1} DM for seeds dried at 60°C and 61.94 g 100 g^{-1} DM for seeds dried at 70°C. The lowest level of NNE in jaboticaba skins dried at 30°C may be due to the increased drying time, which led the skins to retain water for a longer period, which results in the fermentation of soluble carbohydrates.

The levels of vitamin C, phytate, polyphenols and anthocyanins are presented in Table 2. The lyophilized skins had the highest level of vitamin C, followed by the skins treated at 45 and 60°C, which were not statistically different to each other, and the lowest level of vitamin C was found in the skins dried at 30°C.

The degradation of vitamin C in the skins dried at 45, and 60°C may be explained by the sensitivity of vitamin C to certain factors, such as heat, oxygen and light, and the lowest level of vitamin C, which was found in the skins dried at 30°C, may be due to the increased exposure of skins to oxygen and light due to the longer period of drying at this temperature. The lyophilized skins showed the highest levels of vitamin C, which may have been due to less exposure to all the factors that would cause the degradation vitamin C.

For lyophilized jaboticaba skins, Lima et al. (2011) reported a vitamin C content of 298.23 mg 100 g^{-1} DM, which was approximately 40% less than the amount found in the present study.

The lyophilized jaboticaba skins and skins dried at 30°C had the highest levels of phytate followed by the skins dried at 45°C. The lowest level of phytate was found for the treatment at 60°C, with a level of 0.66 g 100 g^{-1} DM. This decrease in phytate with increasing temperature may have occurred during drying due to phytase activity. According to Bartnik and Szafranska (1987), phytase is an enzyme that is abundantly present in nature (in plants, fungi, bacteria, and yeast). This enzyme has high activity in foods, such as wheat, barley, wheat bran and rice, but it is dormant in dry cereal. This enzyme is activated when moisture is increased with its optimal activity at 55°C. Thus, the high moisture of the jaboticaba skins and the temperatures close to the optimal activity of phytase may have contributed to the degradation of phytate. The higher levels of phytate in the lyophilized skins may have been due to the lack of exposure to heat.

Jaboticaba skins dried at 45 and 60°C had the lowest levels of polyphenols. The lyophilized skin exhibited the highest levels of polyphenols, and treatment at 30°C presented intermediate polyphenol levels, which differed from the other treatments. The lyophilized skins may have had the highest polyphenol levels due to less exposure to environmental factors, such as light and oxygen.

In the skins of two grape varieties, Soares et al. (2008) found polyphenol contents ranging from 0.22 to 1.24 g 100 g^{-1} DM. These levels represented only 2 to 13%, respectively, of the polyphenols from the lyophilized jaboticaba skins in this study. Therefore, these data suggest that jaboticaba skins are a good source of polyphenols, which are substances that contribute to the prevention of various diseases, such as cancer and premature aging caused by free radicals.

Table 2. Levels of vitamin C (mg 100 g^{-1}), phytate (g 100 g^{-1}), polyphenols (g 100 g^{-1}) and anthocyanins (mg g^{-1}) in the dry matter of jaboticaba skins subjected to four drying processes.

Drying	Vitamin C	Phytate	Polyphenols	Anthocyanin
30°C	319.79 ± 4.89 c	0.87 ± 0.01 a	8.61 ± 0.09 b	4.04 ± 0.04 d
45°C	342.27 ± 6.07 b	0.77 ± 0.01 b	8.05 ± 0.12 c	6.46 ± 0.06 b
60°C	344.43 ± 0.74 b	0.66 ± 0.01 c	8.19 ± 0.06 c	5.88 ± 0.05 c
Lyophilization	509.67 ± 2.23 a	0.86 ± 0.01 a	9.79 ± 0.12 a	11.16 ± 0.08 a
CV (%)	1.10	1.23	1.15	0.87

Moisture of the flour of jaboticaba skins dried at 30, 45 and 60°C and lyophilized: 10.36 ± 0.50, 1.66 ± 0.36, 0.38 ± 0.22 and 9.30 ± 0.39, respectively. Data are the means of 5 replicates ± standard deviation. Values followed by the same letters in the column are not significantly different by Tukey's test at 5% probability.

Lyophilized jaboticaba skins had the highest anthocyanin content with a value of 11.16 mg g^{-1} DM, which was different from the other treatments. During lyophilization, jaboticaba skins were protected from light and were dehydrated at low temperature, which may explain this result. The anthocyanin content was lower than found by Lima et al. (2011) who reported a value of 20.57 mg g^{-1} DM in lyophilized jaboticaba skins. This difference may have been due to harvesting different crops.

The lowest content of anthocyanins was observed in the jaboticaba skins dried at 30°C, followed by skins dried at 60 and 45°C. The greater degradation of anthocyanins at 30°C may be due to the increased drying time (64 hours) in a dryer with air circulation and no protection from light. Peixoto Sobrinho et al. (2010) found an inverse relationship between the drying temperature and flavonoid concentrations in *Bauhinia cheilantha* leaf samples, with an increase in temperature leading to a reduction of flavonoids.

In PCA, components 1 and 2 accounted for 70.40% of the total variance of the analysis performed in the flour made from jaboticaba skins. It was noted from the graphs of scores (Figure 2) and weights (Figure 3) that the lyophilized skins showed a better preservation of the studied bioactive compounds (except for phytate) and consequently a higher antioxidant activity. With the exclusion of data from the lyophilized skins, it was possible to observe that the temperature at which the constituents were better conserved was 45ºC, except for protein, fiber, lipids and phytate that were best kept at 30ºC and ashes at 60ºC.

Table 3 lists the average antioxidant activity of the jaboticaba skins under four different drying conditions. The lyophilized skins had higher antioxidant activity than the skins treated with the other forms of drying. There was no significant difference in antioxidant activity among the skins dried at 30, 45, and 60°C.

The lyophilized skins had 47% of the antioxidant activity of BHT, 65% of the activity of rutin and only 30% of the activity of quercetin. Lima et al. (2011) found similar results for the lyophilized jaboticaba skins. They reported that the skins had 60% of the activity of rutin and only 9% of the activity of quercetin, which was lower than the percentage verified in the present study.

Lima et al. (2011) also studied the JSF of the Sabará variety, analyzed the relationship among the antioxidant assays and the polyphenols and concluded that polyphenol contents were better associated with ABTS method and that the antioxidant activity is related to the content of polyphenols.

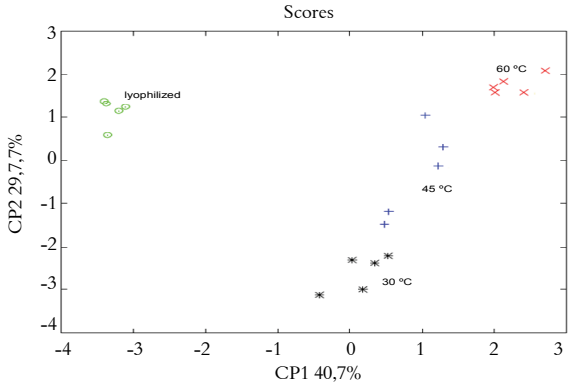

Figure 2. Graphical representation of the jaboticaba skins flour scores in different drying temperatures in relation to the axes defined by the principal components (PC1 and PC2).

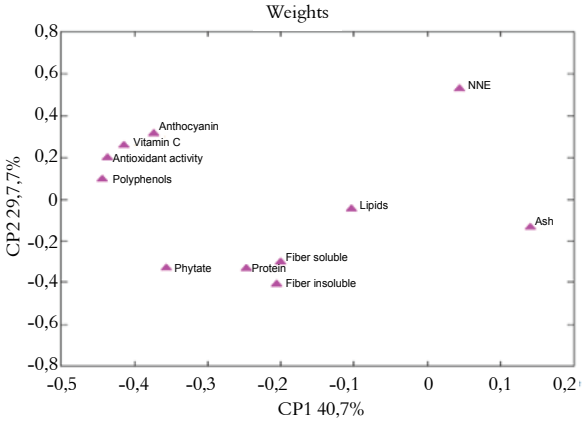

Figure 3. Graphical representation of the weights for the analyses performed in the jaboticaba skins flour in relation to the axes defined by the principal components (PC1 and PC2).

Table 3. Antioxidant activity, determined using an ABTS method, of the jaboticaba skins subjected to four drying processes and three standards, BHT, quercetin and rutin.

Drying	μmol Trolox L^{-1} g^{-1}
30°C	335.15 ± 16.02 b
45°C	327.98 ± 8.85 b
60°C	328.56 ± 5.86 b
Lyophilization	661.21 ± 12.14 a
CV (%)	2.75
BHT	1418.14 ± 17.42
Quercetin	2156.44 ± 28.37
Rutin	1017.82 ± 3.66

Moisture of the flour of jaboticaba skins dried at 30, 45 and 60°C and lyophilized: 10.36 ± 0.50, 1.66 ± 0.36, 0.38 ± 0.22 and 9.30 ± 0.39, respectively. Data are the means of 5 replicates ± standard deviation. Values followed by the same letters in the column are not significantly different by Tukey's test at 5% probability.

Therefore, the degradation of polyphenolic compounds during the different drying processes explains the lower antioxidant activity recorded for the three temperatures (30, 45, and 60°C).

Conclusion

The highest preservation of chemical constituents takes place in lyophilized jaboticaba skins. Among the drying temperatures tested, however, the skins dried at 45ºC had more highly preserved nutritional substances and antioxidants. Therefore, this drying temperature for jaboticaba skins represent a viable second option.

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