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Foam-mat drying technology applied for the development of cashew juice powder: effect on physicochemical properties and principal component analysis

Secagem em camada de espuma aplicada para o desenvolvimento de suco de caju em pó: efeito nas propriedades físico-químicas e análise de componentes principais

J. M. Fernandes[1]; C. V. B. Grisi[2,*]; P. S. Souza[3]; E. C. Monção[1], A. M. T. de M. Cordeiro[1] ; A. L. de Souza[1,3]

[1]*Postgraduate Program in Food Science and Technology, University Federal of Paraiba, 58051-900, João Pessoa-PB, Brazil*
[2]*Postgraduate Program in Chemistry Engineering, University Federal of Paraiba, 58051-900, João Pessoa-PB, Brazil*
[3]*Postgraduate Program in Chemistry, University Federal of Paraiba, 58051-900, João Pessoa-PB, Brazil*

**crisgrisi.gere@gmail.com*
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Foam-mat drying technology has gained attention due to its ability to process sensitive fruits and produce products with desired properties while retaining their volatiles that otherwise would be lost during the drying of non-foamed materials. The objective of the study was to obtain cashew juice by drying foam-mat and evaluate the effect of adding different concentrations of ovalbumin (2%, 3% and 6%) on the physicochemical properties through the analysis of principal components. Treatments with 2% and 3% OVA showed hydrophilic characteristics that favored rehydration in aqueous mixtures. The treatment with 2% OVA showed superior results in water absorption (0.32 gH_2O/g), hygroscopicity (36.52%) and lower pH (4.33). The high solubility in water (9.23%) observed in the treatment with 3% OVA. The treatment with 6% OVA showed greater oil absorption (3.23 gOil/g) characterized as more hydrophobic and can be recommended for flavoring cake mixes. Therefore, the results indicated that foam-mat drying using ovalbumin as a foaming agent has potential as a new technology to be implemented in the juice powder industry.
Keywords: *Anacardium occidentale* L., foam-mat drying technology, powdered juice.

A tecnologia de secagem por camada de espuma tem ganhado atenção devido a sua capacidade de processar frutas sensíveis, e produzir produtos com as propriedades desejadas, retendo seus voláteis que, de outra forma, seriam perdidos durante a secagem de materiais sem espuma. O objetivo do estudo foi obter o suco de caju por secagem em camada de espuma e avaliar o efeito da adição de diferentes concentrações de ovoalbumina (2%, 3% e 6%) nas propriedades físico-químicas através da análise de componentes principais. Os tratamentos com 2% e 3% OVA apresentaram características hidrofílicas que favoreceram a reidratação em misturas aquosas. O tratamento com 2% OVA apresentou resultados superiores de absorção de água (0,32 gH2O/g), higroscopicidade (36,52%) e menor pH (4,33). A alta solubilidade em água (9,23%) observada no tratamento com 3% OVA. O tratamento com 6% OVA apresentou uma maior absorção de óleo (3,23 gÓleo/g) caracterizado como mais hidrofóbico, podendo ser recomendado para saborizar mistura de bolo. Portanto, os resultados indicaram que a secagem por camada de espuma utilizando ovalbumina como agente espumante tem potencial como uma nova tecnologia a ser implementada na indústria de suco em pó.
Palavras-chave: *Anacardium occidentale* L., tecnologia de secagem por camada de espuma, suco em pó.

1. INTRODUÇÃO

The pseudo fruit of the cashew tree (*Anacardium occidentale* L.) is popularly known as cashew, a food distributed around the world that has therapeutic and medicinal properties [1]. As it is a seasonal fruit with a high percentage of water in its composition, cashew is very perishable, and production waste can reach 85%, representing around one million tons [2]. The shelf life of fruit can be extended through treatments such as refrigeration, freezing, minimal processing, drying, among others.

Cashew is a source of bioactive compounds that contain a high content of vitamin C, phenolics, especially the flavonoids myricetin and quercetin, in addition to gallic acid, tocopherols and phenolic acids, compounds with recognized antioxidant action and proven antimicrobial properties [3, 4]. It is a fruit used in the production of various products, such as juice, ice cream, jellies, hamburgers, sweets, cakes, cereal bars, among others [2]. However, due to its high perishability and astringency, it is underused in the food industry [1].

In this context, drying food is an alternative that allows for the concentration and conservation of bioactive compounds from minimally processed fruits [5, 6]. Among the various existing drying methods, the foam-mat drying process has been widely recommended for liquid or semi-liquid foods, as pulp or fruit juice. The main advantage of this method is that it possibility fast drying at low temperatures, around 50 to 80 °C, due to the use of emulsifying and/or stabilizing agents. The formation of a stable foam through the incorporation of air makes it possible to accelerate the drying process [7]. Foams are thermodynamically unstable systems that have a three-dimensional structure made up of gaseous cells surrounded by a continuous liquid film. This structure originates from the grouping of bubbles generated when a gas is dispersed in a liquid that contains foaming agents. On the other hand, the efficiency of the process is also related to the large contact area that facilitates the removal of moisture present in a thin and porous foam layer. The result of drying is a powder with greater rehydration capacity, less deterioration and longer shelf life [8, 9].

Proteins, gums, glycerol monostearate, propylene glycerol monostearate, carboxymethylcellulose, and trichlorophosphate are examples of emulsifiers and stabilizers used in the foam-mat drying technology. Egg white is the most used raw material among proteins, as it has globular proteins, such as ovalbumin (54%), ovotransferrin (12%), ovomucoid (11%), ovomucin (3.5%), and lysozyme (3.5%) [10, 11]. Egg white proteins are endogenous, natural, have low cost, high nutritional value, and good functional properties, such as emulsifier and gelling agent. [12-14]. The use of ovalbumin as an emulsifier, together with the foam layer drying process, was reported in the production of mixed “jambolão” and “acerola” pulp, obtaining promising results [15].

According to our best knowledge, the use of the foam-mat drying technology for the development of powdered cashew juice using ovalbumin as an emulsifying agent has not been found in the literature. Given the above, this study aimed to evaluate the effect of different levels of ovalbumin on the physicochemical characteristics of powdered cashew juice obtained by foam-mat drying.

2. MATERIAL AND METHODS

2.1 Material

Cashews were selected based on uniformity of size, stage of maturity (based on skin color and firmness) and absence of physical damage. Cashew and egg albumin were purchased in the local market in the city of João Pessoa – PB.

2.2 Preparation of powdered cashew juice

Cashews were washed with tap water and left submerged with chlorine (100 mg/L of free chlorine), then rinsed and frozen at -18 °C. To obtain the juice, they were first thawed at refrigeration temperature for 12 h and manually macerated. The foam was produced according to the method by Dehghannya et al. (2018) [16], with adaptations (ovalbumin concentration and tray thickness). The process of obtaining powdered cashew juice started by mixing cashew pulp and ovalbumin at different concentrations (2, 3 and 6%). The mixture was aerated in a domestic mixer (planetary mixer dimensions 16 x 12 x 12 cm, Compact Inspirart Arno KM32) for 10 min at maximum speed (500 W). The foam formed was spread on aluminum plates (15x1.5 cm) with a layer thickness of 1.5 cm. Then, drying was carried out in an oven with air circulation at 60 °C

for 4 h consecutive, until constant weight [17]. The dehydrated material was removed from the plates with the aid of a spatula, manually macerated for 10 min and packaged in polyethylene pots with a lid and wrapped in aluminum foil. The pots were stored under refrigeration at 4 °C until analysis was performed.

2.3 Foam expansion and stability

The foam expansion was quantified from Equation 1 [18].

$$E_x\ (\%)\ =\ \frac{1/\rho foam\ -\ 1/\rho pulp}{1/\rho pulp} \times 100 \quad (1)$$

Where, ρ_{pulp} - density of the pulp (g/mL), ρ_{foam} - foam density (g/mL)

Pulp and foam densities were determined from mass over volume (g/mL). The sample was added to a 50 mL beaker and the mass was quantified at room temperature (25 °C) [19]. Equation 2 was used to calculate the pulp and foam densities.

$$\rho\ =\ \frac{ms}{Ve} \quad (2)$$

Where, ρ – density, m_s – mass, V_e – volume

The foam stability was determined according to the methodology of Franco et al. (2015) [18]. A system composed of a 100 mL beaker with a glass funnel and filter was set up. After preparing the system, 7 g of foam was added to the funnel and then left to rest until the first drop of foam flows. The foam stability (E%) was calculated by Equation 3.

$$E_S\ (\%) = \left(\frac{V_{foam}}{V_{0foam}}\right) x\ 100 \quad (3)$$

Where, E_S - foam stability (%); V_{foam} - final foam volume; V_{0faom} - initial foam volume.

2.4 Yield

The yield of the powdered cashew juice drying process was determined by Equation 4.

$$R(\%)\ =\ \frac{A}{B} \times 100 \quad (4)$$

Where, A - mass of powdered cashew juice found after drying (g), B - mass of total solids present in the sample before drying (g)

2.5 Moisture content, water activity, hydrogenionic potencial and total soluble solids

Moisture was measured by the gravimetric method by heating the sample (5 g) in a circulation oven at 105 °C for 24 h. The water activity was verified by direct reading in an Aqualab equipment (DEW POINT 4 TEV) at 25 °C. The pH was directly recorded using a pH meter (Digimed DM-22) at 25 °C [20]. The levels of total soluble solids were verified with a refractometer. A drop of pulp and PCJ suspended in water was inserted into the refractometer (TECNAL) to measure °Brix levels at 25 °C.

2.6 Physicochemical characterization of powdered cashew juice

2.6.1 Bulk, tapped and true density

Bulk density was determined according to the method described by Caparino et al. (2012) [21]. A total of 1 g of the sample was added to a 5 mL graduated cylinder, without compaction. The total volume occupied by the sample was used to calculate the bulk density through Equation 5.

$$\rho_b = \frac{m_s}{V_t} \tag{5}$$

Where, ρb - bulk density (g/mL); m_s - solid mass (g); V_t - total volume (mL).

The tapped density of the powder was performed according to the method of Tonon (2013) [22]. A total of 1 g of the sample was placed in a 5 mL graduated measuring cylinder and applying 50 strokes to the measuring cylinder with the powder sample on the bench surface at a height of 10 cm. Then, the volume occupied by the sample after compaction was used to calculate the tapped density according to Equation 6.

$$\rho_{ta} = \frac{m_s}{V_c} \tag{6}$$

Where, ρ_{ta} - tapped density (g/mL); m_s - solid mass (g); V_c - Volume of solid after compaction (mL).

The true density was determined by the liquid displacement method using soybean oil as immersion fluid as described by Pragati et al. (2014) [23]. A total of 1g of the sample was weighed in a 10 mL graduated cylinder, where the soybean oil contained in a 25 mL burette was added to complete the total volume of the cylinder, and the amount of oil left in the burette was read. The true density was calculated by Equation 7.

$$\rho_{tr} = \frac{m_s}{10 - V_g} \tag{7}$$

Where, ρ_{tr} - true density (g/mL); m_s - solid mass (g); V_g- Oil spent volume (mL)

2.6.2 Porosity

The porosity (ε) was calculated using the apparent density and the real density, according to Equation 8 [24].

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_{tr}}\right) x\ 100 \tag{8}$$

Where, Ɛ – porosity; ρ_b – bulk density (g/mL); ρ_{tr} – true density (g/mL).

2.6.3 Carr Index and Hausner Factor

The Carr Index (compressibility index) and Hausner factor are simple methods to indirectly assess powder flow properties by comparing the bulk density (ρa) and the tapped density (ρc). The compressibility index was calculated by Equation 9 according to the methodology of Asokapandian et al. (2016) [25].

$$CI = \frac{\rho_{ta} - \rho_b}{\rho_{ta}} \times 100 \quad (9)$$

Where, CI – Carr Index; ρta – tapped density (g/mL); ρb – bulk density (g/mL).

The Hausner factor (FH) was calculated by Equation 10 according to the methodology of Asokapandian et al. (2016) [25].

$$FH = \frac{\rho_{ta}}{\rho_b} \quad (10)$$

Where, FH – Hausner factor; ρta – tapped density (g/mL); ρb – bulk density (g/mL).

2.6.4 Water and oil absorption capacity

To determine the water and oil absorption capacity. Initially, 10 mL of distilled water or oil was added to 1 g of the sample in centrifuge tubes. The suspensions were homogenized for 3 min and then left to rest for 30 min. Afterwards, the tubes were closed and centrifuged for 10 min at 2.500 rpm. The sediment in the centrifuge tube, after separation from the supernatant, was weighed and the water and oil absorption capacity were calculated according to Equations 11 and 12, respectively [26]:

$$Water\ absorption\ capacity = \frac{Hydrated\ sediment\ mass}{dry\ mass} \quad (11)$$

$$Oil\ absorption\ capacity = \frac{Minsoluble\ sediment\ roast}{dry\ mass} \quad (12)$$

2.6.5 Solubility

To determine solubility, a total of 1 g of the sample was added in 100 mL of distilled water at 25 °C and it was stirred constantly for 1 min. After shaking, the samples were filtered on filter paper and the retained material was dried in an oven at 105 °C for 24 h. The solubility was calculated by Equation 13 [27].

$$SOL = \lfloor \frac{m_2 - m_1}{m_s} \rfloor x100 \quad (13)$$

Where, SOL - solubility; m_1 - filter mass; m_2 - sample mass remaining in the filter after oven; m_s - initial mass of the analyzed sample.

2.6.6 Hygroscopicity

To determine Hygroscopicity, a total of 1 g of the sample was filled into glass capsules, then placed in an airtight container containing saturated NaCl solution at 25 °C (relative humidity 75%) for 7 days. After this period, the samples were weighed, and the amount of water absorbed was used to calculate hygroscopicity according to Equation 14 [28].

$$\%\ H = \frac{m_a}{mi} \times 100 \quad (14)$$

Where, H – hygroscopicity (%); m_a - absorbed water mass (g); m_i - initial mass of the sample (g).

2.6.7 Infrared spectroscopy

Analyzes were performed using a FTIR spectrophotometer (Shimadzu, IR model Prestige-2), using the ATR technique in the range of 4000 to 600 cm^{-1}, resolution of 4 cm^{-1} and 40 scans.

2.7 Statistical analysis

The results were expressed as the mean of the triplicates ± standard deviation (n=3). The results of the characterization of the powders were evaluated through analysis of variance (ANOVA) and Tukey test to identify the existence of significant differences with 95% confidence ($p < 0.05$), using an *Assistat* 7.7 *software*.

PCA was used for the parameters of the physicochemical analyses. General variation and identification of variables with greater discriminatory power were evaluated. Samples were checked in triplicate for each PCJ formulation. Analyzes were handled using the PAST 4.03 software.

3. RESULTS AND DISCUSSION

3.1 Density, expansion and stability of foam

Foam density and stability are parameters that directly influence moisture migration during the drying process. The mechanically and thermodynamically stable foam results in high evaporation rates with faster drying, and consequently improves the quality of the product obtained [8, 29].

The foam density values ranged from 0.08 to 0.10 g/mL. The results showed a decrease in foam density with decreasing OVA, indicating greater foaming efficiency in foam with 2 and 3% OVA, due to greater stability and quick drying. Generally, foam density is used to obtain information about beating properties. According to Franco et al. (2015) [18] foams that have low density are more stable, due to the volume of air trapped inside the foam during the aeration step and, consequently, exhibiting rapid drying, even at low temperatures.

The prepared foam presented a good volumetric expansion above 100%, that is, the percentage of OVA interfered in the expansion of the foams, presenting an excellent foaming agent. According to Sangamithra et al. (2015) [30], during the aeration step, ovalbumin rapidly absorbs at the air-liquid interface from intermolecular interactions, forming a cohesive viscoelastic film. Therefore, the type of material to be dried and the concentration of foaming agent determined the expansion percentage of each foam.

The prepared foams showed a stability of 100%, verified at room temperature (25 °C). However, there were no changes in the structure of the foams or phase separation in the analyzed period of 24 h. The foams proved to be stable during this period, thus facilitating the drying process and the quality of the final product. Foams that resist collapse for more than 1 h are considered thermally and mechanically stable and maintain their porous structure during the drying process, showing a product with good rehydration [8, 19].

The yield values of the PCJ drying process with (2, 3 and 6%) of OVA were 11.19, 13.25 and 13.64%, respectively. The results showed that the increase in the concentration of ovalbumin in the process caused a higher yield. However, comparing the treatments with 3% and 6% OVA, no significant differences were observed.

3.2 Water activity, Moisture content, pH and Total soluble solids

Table 1 shows the values of the physicochemical characterization of the PCJ, regarding the parameters of water activity, moisture content, pH and total soluble solids.

Water activity is an important parameter in the development of new products. The indication of the amount of water available in a food serves to control the development of microorganisms,

the occurrence of chemical and enzymatic reactions that can change the composition of food [31]. The water activity of PCJs decreased with increasing OVA concentration, ranging from 0.25 to 0.35. This result indicates that the foaming agent in high concentration acted efficiently in the evaporation of free water from the product, increasing the stability of the product and, consequently, increasing its shelf life.

Table 1 – Water activity, moisture content, pH and total soluble solids of PCJ.

Parameters	PCJ 2% OVA	PCJ 3% OVA	PCJ 6% OVA
Water activity	0.35 ± 0.01^{a}	0.25 ± 0.01^{b}	0.25 ± 0.01^{b}
Moisture content (%)	4.70 ± 2.97^{a}	4.70 ± 0.10^{a}	5.69 ± 1.14^{a}
pH	4.33 ± 0.06^{c}	5.23 ± 0.03^{b}	5.77 ± 0.02^{a}
Total soluble solids (°brix)	49.33 ± 0.37^{b}	51.00 ± 0.16^{b}	70.67 ± 0.12^{a}

Values are represented as mean ± standard deviation. Different letters on the same line indicate significant differences ($p<0.05$). PCJ (powdered cashew juice); OVA (ovalbumin).

Moisture content is one of the parameters used to determine powder stability. Powders with low moisture content have less adherence and greater surface area for rehydration [32, 33]. PCJ moisture values ranged from 4.70 to 5.69%, bringing a significant reduction when comparing the pulp's initial moisture (89.16%). The moisture content of PCJ samples is within the standard established by Brazilian legislation, which recommends that dried or dehydrated fruit products must have a moisture content below 25% [34]. Sousa et al. (2016) [35] when drying cashew juice with maltodrextrin per spouted bed found 2.39% moisture. The moisture content of the powder is influenced by several factors in the drying process and ends up affecting the stability and shelf life of the product [36].

The pH values of the PCJ ranged from 4.33 to 5.77, where a trend of pH break was observed after foam drying, since the foam pH ranged from 5.20 to 6.20. Therefore, it was observed a direct relationship between the concentration of OVA and the increase in the pH of the PCJ, which can be explained by the pH of the OVA used as a foaming agent being around 7.0. However, the formulation with the lowest concentration of OVA (2%) had the pH closest to the pulp (4.10). Therefore, the low concentrations of OVA may have caused the denaturation of these proteins, undid the molecular interactions, and left only the primary structure of the pulp due to its acidic character. Similar behavior was reported by Abbasi and Azizpour (2016) [8], Fernandes et al. (2014) [17], Shaari et al. (2018) [37], and Rocha et al. (2014) [38]. They related the presence of OVA in the drying process to the increase in the pH value of the powders.

The values of total soluble solids of the PCJ ranged from 49.33 to 70.67 °Brix, showing that there was a significant difference between treatments. However, treatments with lower concentrations (2% and 3%) of OVA did not differ. Comparing the results of this PCJ parameter with cashew pulp (12.9 °Brix), it is possible to see that the drying process helped in the concentration of soluble solids in more than 5 times the value of the pulp, especially in the lowest concentrations of OVA (2% and 3%).

3.3 Physical characterization of powdered cashew juice

Table 2 shows the values of the physical characterization of the PCJ, regarding the parameters of density, Carr and Hausner index and porosity. All parameters determined showed a statistically significant difference ($p < 0.05$) as the variation in OVA concentration.

The bulk density of powders is analyzed for influencing the packaging, transport, marketing, rehydration and appearance of powders. In addition, density can be related to moisture content, particle size and shape [16, 36]. PCJ bulk density values ranged from 0.11 to 0.16 g/mL. The results showed that the concentration of OVA influenced the results of this parameter, providing a direct relationship with the increase in the concentration of OVA. The air incorporation process during foam formation may have influenced the apparent density values of the PCJs. This can be

attributed to the reduction in surface tension that leads to increased air intake into the foam structure [8, 18]. In addition, these powders with high bulk density sink faster in water when compared to powders that have low bulk density [16, 18].

Table 2: Physical characterization of powdered cashew juice.

Parameters	PCJ 2% OVA	PCJ 3% OVA	PCJ 6% OVA
Bulk density (g/mL)	0.11 ± 0.01^{c}	0.14 ± 0.01^{b}	0.16 ± 0.01^{a}
Tapped density (g/mL)	0.92 ± 0.06^{a}	0.72 ± 0.02^{b}	0.42 ± 0.01^{c}
True density (g/mL)	0.52 ± 0.04^{b}	0.54 ± 0.03^{b}	0.98 ± 0.10^{a}
Carr Index (%)	88.07 ± 0.12^{a}	79.51 ± 0.85^{b}	61.08 ± 1.87^{c}
Hausner Index	8.33 ± 0.08^{a}	5.26 ± 0.23^{b}	2.62 ± 0.18^{c}
Porosity	0.79 ± 0.01^{a}	0.74 ± 0.01^{b}	0.83 ± 0.01^{a}

Values are represented as mean ± standard deviation. Different letters on the same line indicate significant differences ($p<0.05$). PCJ (powdered cashew juice); OVA (ovalbumin).

The values of tapped density found in PCJ ranged from 0.42 to 0.92 g/mL. The results showed that the treatment with 2% OVA presented higher tapped density results than the treatments with higher concentration of OVA. Therefore, the treatment with 2% OVA showed larger particles and larger spaces between the particles, possibly hindering the flowability of the powders.

The true density of particles is considered an important parameter as it interferes with stability and drying efficiency. True density values ranged from 0.52 to 0.98 g/mL. The true density of PCJ increased significantly in the treatment with the highest concentration of OVA (6%), indicating that it is a product with smaller particles and quantity of air, and making a powder with less agglomeration.

The fluidity of the powdered product is related to the Carr index and the Hausner Factor. Thus, powders with good fluidity according to the Carr Index (<20%) are considered of good quality and are more accepted [29, 39]. The PCJs presented a Carr index ranging from 61.08 to 88.07% and a Hausner factor from 2.62 to 8.33. A decreasing trend was observed in the Carr index and in the Hausner Factor with increasing ovalbumin concentration. Therefore, powders with smaller and uniform particles present fewer empty spaces between the particles and greater contact surface with the environment, resulting in a product with high apparent density, low Carr index and Hausner Factor [40], behavior that was not observed in the developed PCJ. All formulations showed low fluidity as they had a Carr index >20%.

PCJ porosity values ranged from 0.74 to 0.83. PCJs with 3% OVA had a lower porosity value, indicating that it is a powder with less space between its particles when compared to other treatments (with 2% and 6% OVA). Therefore, the treatment with 3% OVA contains a low volume of oxygen between the particles, which can stabilize the degradation processes by oxidation. It is noteworthy that it is possible to associate this condition of the particles with the drying process in a foam layer, as it supports the conservation of bioactive present in the fruit.

Table 3 shows the results of water and oil absorption capacity, solubility and hygroscopicity in PCJ treatments.

Table 3: Physical characterization of powdered cashew juice

Parameters	PCJ 2% OVA	PCJ 3% OVA	PCJ 6% OVA
Water absorption (g H_2O/g)	0.32 ± 0.11^{a}	0.12 ± 0.06^{b}	0.10 ± 0.09^{b}
Oil absorption (g Oil/g)	1.50 ± 0.10^{b}	1.89 ± 0.08^{b}	3.23 ± 0.30^{a}
Solubility in water (%)	8.48 ± 0.27^{b}	9.23 ± 0.04^{a}	6.64 ± 0.24^{c}
Hygroscopicity (%)	36.52 ± 0.27^{a}	29.53 ± 0.49^{b}	28.56 ± 1.87^{b}

Values are represented as mean ± standard deviation. Different letters on the same line indicate significant differences ($p<0.05$). PCJ (powdered cashew juice); OVA (ovalbumin).

The water absorption index is directly related to the rehydration capacity of the powder. An ideal powder features complete and rapid rehydration, in addition to sinking quickly into water

[16, 36]. The results showed that PCJ with 2% OVA had the highest water absorption rate (0.32 gH_2O/g) when compared to treatments with 3% and 6% OVA (0.12 and 0.10 gH_2O/g). Therefore, these results indicate that the lower concentration of OVA provides powder with rapid rehydration, facilitating the homogenization process when added to aqueous mixtures, compared to other treatments.

The PCJ's oil absorption index ranged from 1.50 to 3.23 g Oil/g. The results showed an inverse behavior to the water absorption capacity. The higher the concentration of OVA in the treatments showed a higher oil absorption capacity. Therefore, it is possible to state that OVA at concentrations of 6% has the ability to bind molecules of a hydrophobic character and may associate its chemical structure that has a disulfide bond and four free sulfhydryl groups within the molecules in a hydrophobic core [41]. The OVA used is not pure, it contains other proteins such as: ovotransferrin (12%), ovomucoid (11%), ovomucin (3.5%), lysozyme (3.5%) and several other proteins, which may also have contributed to this hydrophobic character [10, 11].

The solubility index evaluates the behavior of the powdered product in aqueous solution, that is, its ability to remain homogeneous together with water. PCJ solubility values ranged from 6.64 to 9.23%. The low solubility of PCJs in the treatment with 6% OVA when compared to other treatments of lower concentration (2% and 3%) may be related to its chemical composition and the hydrophobic character of the protein structure, as was perceived for the oil absorption parameter. The high solubilization of the formulation with 3% of OVA in relation to other treatments may be related to the greater expansion of the foams of the studied treatments, favoring the increase in the penetration of water in the powder and the increase in its solubility.

Hygroscopicity is the ability of a powder to absorb water from the environment with a relative humidity higher than the equilibrium moisture content of the powder, and is strongly linked to physical, chemical and microbiological stability [37, 42]. The hygroscopicity values of the samples ranged from 28.56 to 36.52%. Powders with 2% OVA showed higher hygroscopicity values when compared to treatments with higher concentration (3% and 6%). According to the classification proposed by Yinka et al. (2024) [43], the PCJ obtained in this study are extremely hygroscopic. This property was also noticed during the storage of PCJ, which over time, even with controlled temperature and humidity, agglomerations occurred in the powder particles.

3.4 Principal Component Analysis (PCA)

Principal component analysis was used to indicate possible differences and similarities between PCJ treatments, caused by the incorporation of ovalbumin. The PCA allowed us to evaluate the influence of the OVA variability of the treatments based on the investigated physicochemical parameters and identifying those with greater discriminatory power. The load factor for the physicochemical parameters of the PCA is shown in Table 4.

Table 4: Load factor for the physicochemical parameters of each PCA of the PCJ.

Variables	PC1	PC2
Bulk density	*-0.34468*	-0.13171
Tapped density	0.34961	*0.04794*
True density	*-0.3342*	0.22048
Carr index	0.34968	*-0.04572*
Hausner index	0.33837	*0.19046*
Porosity	*-0.20918*	0.58927
Water absorption	*0.28482*	0.42775
Oil absorption	*-0.34755*	0.09285
Water solubility	0.28339	*-0.43191*
Hygroscopicity	*0.29074*	0.40988

Values in italics are the load factors. They are related to the correlations between the variables.

Figure 1 showed in general that PC1 represents 81.47% of the data variation and the second, PC2 represents 18.53%. The first component was represented by tapped density, Carr index,

Hausner index and water solubility, being the most significant variables, as they explained the general variability of the data in a greater percentage. The second component was represented by bulk density, true density, porosity, water absorption, oil absorption and hygroscopicity. It was verified that the PCA graph showed the formation of three different groups, among the PCJ (2%, 3% and 6% OVA). Thus, it may indicate a differentiation in the physicochemical parameters of the formulations between the PCJ added with different concentrations of OVA.

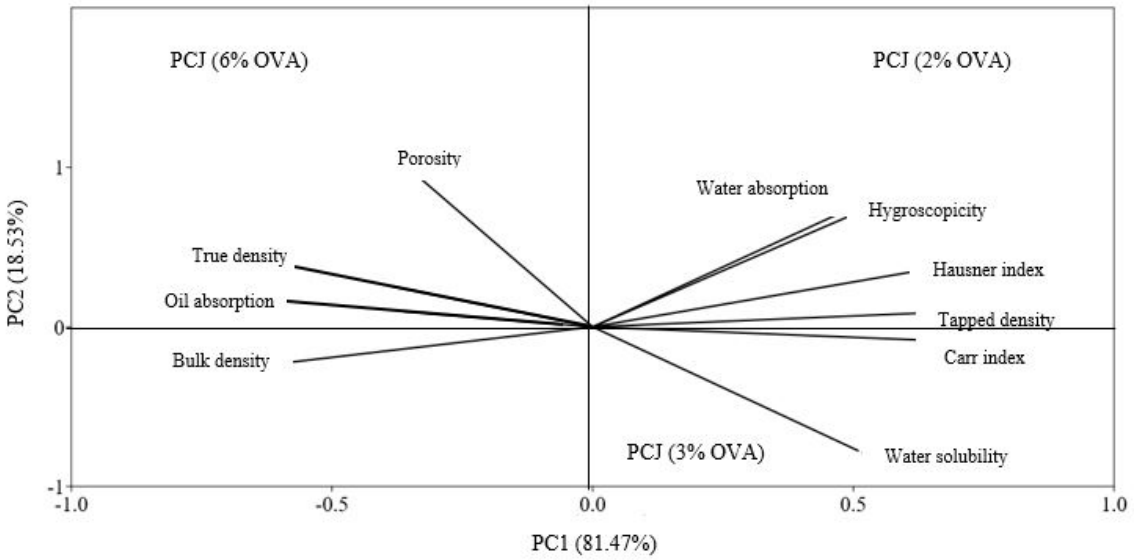

Figure 1: Principal Component graph for the physicochemical variables of the PCJ

The rehydration of powders is related to several factors such as water absorption capacity, porosity, redistribution and solubility in the matrix in the aqueous medium, and several physical and chemical changes may occur, such as the moisture content, weight, texture and porosity of the powder. Therefore, these parameters are very important to be analyzed to define the applications of powders [16, 37]. In view of the PCA results, the treatments with 2% and 3% of OVA had a more hydrophilic character, where these low concentrations of OVA studied had a greater impact on the parameters of hygroscopicity, water absorption and water solubility, favoring the application of these treatments in the food sector that needs good rehydration, such as soluble powdered juices. Then, these PCJs (2% and 3% OVA) with high solubility are preferable for instant beverages, allowing for quick dissolution and improved consumer convenience [44]. Meanwhile, the treatment with 6% of OVA presented a more hydrophobic character, highlighting the greater results of oil absorption. The treatment with 6% of OVA can be recommended for cake mixes, which have lipid compounds in their composition, in order to assist in their homogenization process. Furthermore, PCJ (6% OVA) showed high oil absorption capacity compared the others samples, then it is ideal for baked products, enhancing texture and flavor [45].

3.5 Spectroscopy in the infrared region

Infrared spectroscopy was used to identify the characteristic bands of chemical groups present in the developed PCS. The FTIR spectra are shown in Figure 2.

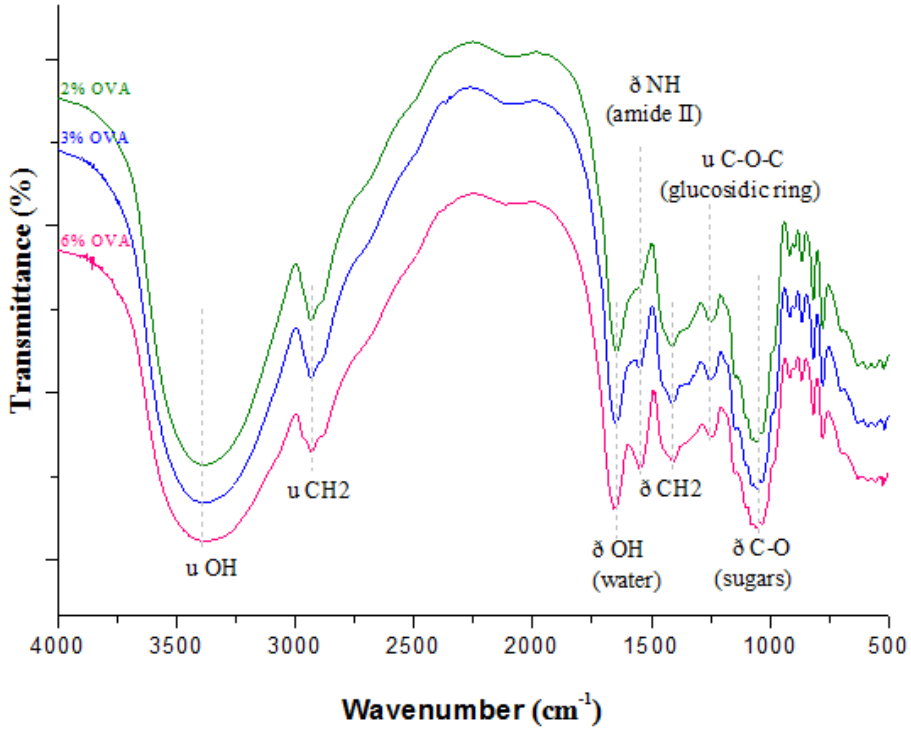

Figure 2: Infrared spectra of the PCJ.

The wide bands in the region from 3374 to 3381 cm^{-1} were attributed to the vibrational stretching of the OH group, which can be associated with the hydroxyl of the phenolic compounds present in cashew. A similar result was observed by Silva et al. (2020) [46] when analyzing lyophilized and natural cashew juice. The bands in the region from 2924 to 2928 cm^{-1} were attributed to the stretching of CH_2 bonds also present in cashew bioactive compounds [46, 47].

The bands in the region from 1647 to 1657 cm^{-1} were attributed to angular deformation of the OH group, being attributed to water remaining in the powder. The bands in the region from 1547 to 1551 cm^{-1} were caused by the angular deformation of the NH group (amide II), which may be present in ovalbumin. The bands in the region from 1406 to 1408 cm^{-1} were caused by the CH_2 angular deformation of the glucosidic ring [48]. The band in the 1242 cm^{-1} region is characteristic of the stretching of the C-O-C group of the glucosidic ring. This aromatic ring can be attributed to the phenolic compounds found in powdered cashew juice. According to Zhang and Tsao (2016) [49], phenolic compounds were defined as substances that have at least one aromatic ring. The bands in the region from 1053 to 1057 cm^{-1} were attributed to angular deformation of the C-O group, characteristic of the absorption of sugars such as fructose and glucose present in cashew [46, 47].

Infrared spectroscopy is a technique that allows non-destructive evaluation, with relative speed and ease, while being eco-friendly and in situ, to assess samples for potential adulteration or unwanted variations in the process of obtaining the product analysed. Adulteration of powdered juices usually involves the addition of cheaper substances such as maltodextrin, starches or dextrins, simple sugars such as glucose or excess sucrose, and undeclared artificial flavour or colour [50]. In this study, ovalbumin can be considered as adulteration in juices. Ovalbumin from the powder drying process can be seen as an undesirable product by the consumer.

4. CONCLUSION

The present work fully achieved its objective of developing powdered cashew juice through the foam-mat drying technology. The treatments with 2% and 3% of ova resulted in a powdered cashew juice with greater hygroscopicity, water absorption, and solubility, favoring rehydration

and homogenization in aqueous mixtures. On the other hand, the treatment with 6% ova showed better absorption in oil and possibly better solubilization in lipid products and can be recommended with cake mix flavors. In addition, PCI showed a significant reduction in water and moisture activity when compared to cashew pulp, which favored greater stability in terms of the development of microorganisms and oxidative reactions.

Therefore, foam-mat drying is a promising method for the juice industry, which can contribute to a decrease in moisture through low temperatures, shorter process time and low cost when compared to other drying methods, such as spray dried. Additional research on bioactive compounds, bio-accessibility of active compounds, their health effects and sensory analyzes of powdered cashew juices will be carried out to reaffirm the claims of this study.

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6. REFERÊNCIAS BIBLIOGRÁFICAS

1. Talasila U, Shaik KB. Quality, spoilage and preservation of cashew apple juice: A review. J Food Sci Technol. 2015 Jan;52(1):54-62. doi: 10.1007/s13197-013-0931-0
2. Sharma P, Gaur V, Sirohi R, Larroche C, Kim S, Pandey A. Valorization of cashew nut processing residues for industrial applications. Ind Crops Prod. 2020 Sep;152:112-550. doi: 10.1016/j.indcrop.2020.112550
3. Adegunwa MO, Kayode BI, Kayode RMO, Akeem SA, Adebowale AA, Bakare HA. Characterization of wheat flour enriched with cashew apple (*Anacardium occidentale* L.) fiber for cake production J Food Meas Charact. 2020 Mar;14(4):1998-2009. doi: 10.1007/S11694-020-00446-9/TABLES/6
4. Das I, Arora A. Post-harvest processing technology for cashew apple – A review. J Food Eng. 2017 Feb;194:87-98. doi: 10.1016/J.JFOODENG.2016.09.011
5. Fonteles T, Leite A, Silva A, Carneiro A, Miguel E, Cavada B, et al. Ultrasound processing to enhance drying of cashew apple bagasse puree: Influence on antioxidant properties and in vitro bioaccessibility of bioactive compounds. Ultrason Sonochem. 2016 Jul;31:237-49. doi: 10.1016/j.ultsonch.2016.01.003
6. Sogi DS, Siddiq M, Dolan KD. Total phenolics, carotenoids and antioxidant properties of Tommy Atkin mango cubes as affected by drying techniques. LWT - Food Sci Technol. 2015 Jun;62(1):564-8. doi: 10.1016/j.lwt.2014.04.015
7. Tan SL, Sulaiman R. Color and rehydration characteristics of natural red colorant of foam mat dried *Hibiscus sabdariffa* L. powder. Int J Fruit Sci. 2019 Apr;20:89-105. doi: 10.1080/15538362.2019.1605557
8. Abbasi E, Azizpour M. Evaluation of physicochemical properties of foam mat dried sour cherry powder. LWT - Food Sci Technol. 2016 May;68(2):105-10. doi: 10.1016/j.lwt.2015.12.004
9. Carvalho TIM, Nogueira TYK, Mauro MA, Gómez-Alonso S, Gomes E, Da Silva R, et al. Dehydration of jambolan (*Syzygium cumini* L.) juice during foam mat drying: Quantitative and qualitative changes of the phenolic compounds. Food Res Int. 2017 Dec;102:32-42. doi: 10.1016/j.foodres.2017.09.068
10. Elqars E, Guennoun M, Ouarhach A, Sqalli Houssini N, Elhafdi M, Essadki A, et al. Expired chicken egg-white extract's adsorption behavior as a corrosion inhibitor for carbon steel in 1M HCl. J Chem. 2021;2021:3416092. doi: 10.1155/2021/3416092
11. Vashishth P, Bairagi H, Narang R, Shukla SK, Olasunkanmi LO, Ebenso EE, et al. Experimental investigation of sustainable corrosion inhibitor albumin on low-carbon steel in 1N HCl and 1N H_2SO_4. Results Surf Interfaces. 2023;13:100155. doi: 10.1016/j.rsurfi.2023.100155
12. Hao Y, Wang F, Huang W, Tang X, Zou D, Li Z, et al. Sucrose substitution by polyols in sponge cake and their effects on the foaming and thermal properties of egg protein. Food Hydrocolloids. 2016 Jun;57:153-59. doi: 10.1016/j.foodhyd.2016.01.006
13. MA Y, Zhao Y, Jiang Y, Chi Y. Effect of dry heating on the aggregation behaviour and aggregate morphologies of ovalbumin. Food Chem. 2019 Jul;285:296-304. doi: 10.1016/j.foodchem.2019.01.170
14. Sheng L, Wang Y, Chen J, Wang Q, Ma M. Influence of high-intensity ultrasound on foaming and

structural properties of egg white. Food Res Int. 2018 Jun;108:604-10. doi: 10.1016/j.foodres.2018.04.007
15. Matos JDP, Figueirêdo RMF, Queiroz AJM, Moraes MS, Silva SN, Silva LPFR. Foam mat drying kinetics of jambolan and acerola mixed pulp. Rev Bras Eng Agric Amb. 2022 Jul;26(7):502-12. doi: 10.1590/1807-1929/agriambi.v26n7p502-512
16. Dehghannya J, Pourahmad M, Ghanbarzadeh B, Ghaffari H. Heat and mass transfer modeling during foam-mat drying of lime juice as affected by different ovalbumin concentrations. J Food Eng. 2018 Dec;238:164-77. doi: 10.1016/j.jfoodeng.2018.06.014
17. Fernandes RVB, Queiroz F, Botrel DA, Souza VR, Lima CF. Study of the addition of albumin and the drying temperature on the characteristics of powdered tomato pulp. Semina: Ciencias Agrarias. 2014 May;35(3):1267-78. doi: 10.5433/1679-0359.2014v35n3p1267
18. Franco T, Perussello C, Ellendersen L, Masson M. Foam mat drying of yacon juice: Experimental analysis and computer simulation. J Food Eng. 2015 Aug;158:48-57. doi: 10.1016/j.jfoodeng.2015.02.030
19. Bag SK, Srivastav PP, Mishra HN. Optimization of process parameters for foaming of bael (*Aegle marmelos* L.) fruit pulp. Food Bioproc Technol. 2011 Nov;4(8):1450-8. doi: 10.1007/s11947-009-0243-6
20. Association of Official Analytical Chemists (AOAC). Official Methods of Analysis of AOAC Internacional. 20ª ed. Maryland (US): AOAC; 2016.
21. Caparino O, Tang J, Nindo C, Sablani S, Powers J, Fellman J. Effect of drying methods on the physical properties and microstructures of mango (*Philippine "Carabao*" var.) powder. J Food Eng. 2012 Jul;111(1):135-48. doi: 10.1016/j.jfoodeng.2012.01.010
22. Tonon RV. Application of spray drying to obtain functional products with high added value from açaí. Soc Incl. 2013 Oct;6(2):70-6. doi: 10.1080/07373937.2020.1832513
23. Pragati S, Genitha I, Ravish K. Comparative study of ripe and unripe banana flour during storage. Jf Food Process Technol. 2014 Oct;5(11):1-6. doi: 10.4172/2157-7110.1000384
24. Zaman A, Uddin S, Mehboob N, Ali A. Structural investigation and improvement of microwave dielectric properties in Ca (HfxTi1-x)O_3 ceramics. Phys Scr. 2020;96(2):025701. doi: 10.1088/1402-4896/abce74
25. Asokapandian S, Venkatachalam S, Swamy G, Kuppusamy K. Optimization of foaming properties and foam mat drying of muskmelon using soy protein. J Food Process Eng. 2016 Nov;39(6):692-701. doi: 10.1111/jfpe.12261
26. Mudau M, Ramashia SE, Mashau ME, Silungwe H. Physicochemical characteristics of bread partially substituted with finger millet (*Eleusine corocana*) flour. Braz J Food Technol. 2021;24:e2020123. doi: 10.1590/1981-6723.12320
27. Surasani VKR, Singh A, Gupta A, Sharma S. Functionality and cooking characteristics of pasta supplemented with protein isolate from pangas processing waste. LWT-Food Sci Technol. 2019;111:443-8. doi: 10.1016/j.lwt.2019.05.014
28. Smagin AV, Sadovnikova NB, Belyaeva EA. Hygroscopicity of gel-forming composite materials: thermodynamic assessment and technological significance. J Compos Sci. 2022;6(9):269. doi: 10.3390/jcs6090269
29. Salahi MR, Mohebbi M, Taghizadeh M. Foam-mat drying of cantaloupe (*Cucumis melo*): Optimization of foaming parameters and investigating drying characteristics. J Food Process Preserv. 2015 Dec;39(6):1798-808. doi: 10.1111/jfpp.12414
30. Sangamithra A, Venkatachalam S, Jonh S, Kuppuswamy K. Foam mat drying of food materials: A review. J Food Process Preserv. 2015 Dec;39(6):3165-74. doi: 10.1111/jfpp.12421
31. Cól C, Tischer B, Hickmann Flôres S, Rech R. Foam-mat drying of bacaba (*Oenocarpus bacaba*): Process characterization, physicochemical properties, and antioxidant activity. Food Bioprod Process. 2021 Mar;126:23-31. doi: 10.1016/j.fbp.2020.12.004
32. Breda CA, Justi PN, Sanjinez-argandona EJ. Dehydration effect foam mat in the retention of vitamin c in caja mango pulp. Braz J Food Nutrit. 2013 Apr/Jun;4(2):189-93.
33. Franco T, Ellendersen L, Fattori D, Granato D, Masson M. Influence of the addition of ovalbumin and emulsifier on the physical properties and stability of yacon (*Smallanthus sonchifolius*) juice foams prepared for foam mat drying process. Food Bioproc Technol. 2015 Jul;8(10):2012-26. doi: 10.1007/s11947-015-1553-5
    a. Brasil. Agência Nacional de Vigilância Sanitária. Resolução RDC nº 263, de 22 de setembro de 2005. Aprova o regulamento técnico para produtos de cereais, amido, farinha e farelo. Brasília (DF): Diário Oficial da União; 2005. Available from: https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2005/rdc0263_22_09_2005.html

34. Sousa S, de Morais B, Ribeiro L, da Costa J. Stability of cashew apple juice in powder dehydrated in spouted bed. Rev Bras Eng Agric Amb. 2016 Jul;20(7):678-82. doi: 10.1590/1807-1929/agriambi.v20n7p678-682
35. Nishad J, Selvan C, Mir S, Bosco S. Effect of spray drying on physical properties of sugarcane juice powder (*Saccharum officinarum* L.). J Food Sci Technol. 2017 Mar;54(3):687-97. doi: 10.1007/s13197-017-2507-x
36. Shaari N, Sulaiman R, Rahman R, Bakar J. Production of pineapple fruit (*Ananas comosus*) powder using foam mat drying: Effect of whipping time and egg albumen concentration. J Food Process Preserv. 2018 Feb;42(2):1-10. doi: 10.1111/jfpp.13467
37. Rocha É, Sousa S, Costa J, Rodrigues S, Afonso M, Costa J. Obtaining atomized cashew juice by controlling drying conditions. Braz J Agric Environml Eng. 2014 Jun;18(6):646-51. doi: 10.1590/S1415-436620140006000012
38. Santhalakshmy S, Don Bosco S, Francis S, Sabeena M. Effect of inlet temperature on physicochemical properties of spray-dried jamun fruit juice powder. Powder Technol. 2015 Apr;274:37-43. doi: 10.1016/j.powtec.2015.01.016
39. Seerangurayar T, Manickavasagan A, Al-Ismaili A, Al-Mulla Y. Effect of carrier agents on flowability and microstructural properties of foam-mat freez e dried date powder. J Food Eng. 2017 Dec;215:33-43. doi: 10.1016/j.jfoodeng.2017.07.016
40. Yanping L. Different drying methods' effects on the nutritional components and flavor of fruits. J Food Drug Saf Res. 2024;1(2):6-11 doi: 10.70767/jfdsr.v1i2.227
41. Franco T, Perussello C, Ellendersen L, Masson M. Effects of foam mat drying on physicochemical and microstructural properties of yacon juice powder. LWT - Food Sci Technol. 2016 Mar;66:503-13. doi: 10.1016/j.lwt.2015.11.009
42. Yinka S, Jitendra P, Chyngyz E. Three-dimensional characterization of potatoes under different drying methods: Quality optimization for hybrid drying approach. Foods. 2024;13(22):3633. doi: 10.3390/foods13223633
43. Małgorzata C, Mariola K Anna I, Hanna K. Development of drying and roasting processes for the production of plant-based pro-healthy snacks in the light of nutritional trends and sustainable techniques. Trends Food Sci Technol. 2024 Jul;149:104553. doi: 10.1016/j.tifs.2024.104553
44. Nnadikwe J, Chigozie I. Elevating sustainability in design: advancing state-of-the-art food drying methods to optimize efficiency, preserve nutritional value, and minimize waste in contemporary food production. 2024;105(1):120. doi: 10.3390/proceedings2024105120
45. Silva A, Santos D, Sousa T, Silva F, Egea M. "Cerrado" cashew (*Anacardium othonianum* Rizz.) juice improves metabolic parameters in women: A pilot study. J Funct Foods. 2020 Jun;69: 103950. doi: 10.1016/j.jff.2020.103950
46. Zhang C, Ada Khoo S, Chen X, Quek S. Microencapsulation of fermented noni juice via micro-fluidic-jet spray drying: Evaluation of powder properties gand functionalities. Powder Technol. 2020 Feb;361:995-1005. doi: 10.1016/j.powtec.2019.10.098
47. Tan S, Zhong C, Langrish T. Encapsulation of caffeine in spray-dried micro-eggs for controlled release: The effect of spray-drying (cooking) temperature. Food Hydrocoll. 2020 Nov;108:105979. doi: 10.1016/j.foodhyd.2020.105979
48. Zhang H, Tsao R. Dietary polyphenols, oxidative stress and antioxidant and anti-inflammatory effects. Curr Opinion Food Sci. 2016 Apr;8:33-42. doi: 10.1016/j.cofs.2016.02.002
49. Galvin-King P, Haughey SA, Elliott CT. Garlic adulteration detection using NIR and FTIR spectroscopy and chemometrics. J Food Compos Anal. 2021;96:103790. doi: 10.1016/j.jfca.2021.103790