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## Drum-drying of mango peel and characterization of different varieties<sup>1</sup>

### Secagem de cascas de manga em cilindro rotativo e caracterização de diferentes variedades

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#### HIGHLIGHTS:

*The Palmer mango showed higher nutrient concentration, besides lower moisture content and reducing sugar content in peels. The drum-drying process influenced variables related to the drying efficiency and non-enzymatic browning of mango peels. The drum-drying process did not affect nutrient concentration and the yellow color of the mango peels.*

**ABSTRACT:** Mango peel, a by-product of the mango pulp industry, is rich in nutrients but with high moisture content. Drying is indicated to stabilize the residue and use of a drum-dryer is a little studied alternative. The present study evaluated the application of this technology for mango peels, investigating the influence of process conditions. The potential of mango peels from Palmer, Haden, Keitt, and Espada Vermelha varieties was also assessed using physicochemical analyses. The results showed differences between the varieties: Palmer exhibited the lowest moisture content (73.97 g per 100 g); Keitt the highest reducing sugar content (25.06 g per 100 g d.b.); Haden the highest soluble dietary fiber content (20.85 g per 100 g d.b.); and Espada Vermelha the highest phenolic compound content (5462 mg GAE per 100 g d.b.). Palmer mango peels were dried, varying temperature (130.6/146.4 °C) and residence time (14/28 s). The independent variables influenced mass flow rate, moisture content, and color parameter  $a^*$ . The antioxidant capacity, phenolic compounds and total carotenoid content, in addition to other color parameters, were not affected. The best process conditions were determined at 138.4-146.4 °C and 14-21 s. The flakes exhibited phenolic compound contents of 3200 mg GAE per 100 g d.b., and antioxidant capacity of 360  $\mu\text{mol TE g}^{-1}$  d.b. The product can be used as an ingredient in food formulations.

**Key words:** byproduct, agro-industrial waste, antioxidant, phenolic compounds, physicochemical properties

**RESUMO:** A casca da manga, um subproduto da indústria de polpa, é rica em nutrientes, porém com alto teor de umidade. A secagem é indicada para estabilizar o resíduo e o uso do drum-dryer é uma alternativa pouco estudada. O presente estudo avaliou a aplicação da tecnologia para cascas de manga, investigando as condições de processo. O potencial das cascas das variedades Palmer, Haden, Keitt e Espada Vermelha também foi avaliado usando análises físico-químicas. Os resultados mostraram diferenças entre as variedades: a Palmer exibiu o menor teor de umidade (73,97 g por 100 g); a Keitt o maior teor de açúcar redutor (25,06 g por 100 g d.b.); a Haden o maior teor de fibra alimentar solúvel (20,85 g por 100 g d.b.) e a Espada Vermelha o maior teor de compostos fenólicos (5462 mg GAE por 100 g d.b.). As cascas da variedade Palmer foram secas variando-se a temperatura (130,6/146,4 °C) e o tempo de residência (14/28 s). As variáveis independentes influenciaram o fluxo de massa, o teor de umidade e o parâmetro de cor  $a^*$ . A capacidade antioxidante, os teores de compostos fenólicos e carotenoides totais, além dos outros parâmetros de cor, não foram afetados. As melhores condições de processo foram determinadas em 138,4-146,4 °C e 14-21 s. Os flocos apresentaram teores de compostos fenólicos de 3.200 mg GAE por 100 g d.b. e capacidade antioxidante de 360  $\mu\text{mol TE g}^{-1}$  d.b. O produto pode ser utilizado como ingrediente em formulações de alimentos.

**Palavras-chave:** subproduto, resíduos agroindustriais, antioxidante, compostos fenólicos, propriedades físico-químicas

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## INTRODUCTION

Known as the king of fruits, mango is appreciated for its taste, and Brazil is one of the largest producers, with more than 1 million tons in 2019 (FAO). Pulp production is the main industrial activity, which results in a considerable amount of residue (around 50% w/w), consisting of peels and seeds. Improper disposal of this material may have an environmental impact, but recycling is an alternative (Murray et al., 2017).

Peel is the main by-product, with high levels of fibers, pectin, phenolic and bioactive compounds (García-Amezquita et al., 2018; Gómez & Martínez, 2018). This residue is perishable due to its high moisture content, requiring rapid stabilization. Thus, drying is an effective possibility for mango peel use, inactivating enzymes and decreasing microbial growth. Drum-drying is an alternative since the technology is particularly applicable for pasty and fiber-rich products (Chia & Chong, 2015). The quality of drum-dried products depends on the process variables, mainly surface temperature and drum speed (Wiriawattana et al., 2018). Most drum-drying studies investigate cereal processing and tuber formulations (Ruttarattanamongkol et al., 2016; Wiriawattana et al., 2018), with few addressing the use of fruit processing byproducts (Chia & Chong, 2015; Galaz et al., 2017). However, this technique has yet to be reported for mango peels.

In this context, the motivation for the present study was to evaluate the use of drum-drying for mango peels, since the process is suitable for large amounts of pasty products. Moreover, adding value to this by-product, in line with circular economy concepts, would provide environmental, economic and social benefits. Thus, the aim of this study was to investigate the influence of the drum-drying process on the mass flow and quality properties of the dried mango peels obtained. In addition, the peels of four mango varieties were previously characterized in terms of physicochemical analyses, which allowed the most suitable choice for the process.

## MATERIAL AND METHODS

The study was conducted from October 2, 2018 to September 27, 2019 at the FRUTHOTEC Pilot Plant of Instituto de Tecnologia de Alimentos, Campinas, São Paulo state, Brazil (Latitude: 22° 54' 23" South, Longitude: 47° 3' 42" West, Altitude 677 m). Fruits (Palmer, Keitt, Haden, and Espada Vermelha varieties - 2018/2019 season) were purchased at a Campinas market. The Espada Vermelha variety was obtained from a producer in São Paulo state, and the others from the São Francisco Valley, Pernambuco state, Brazil. The additives used in the drum-drying process were regular Amisol 3408 corn starch (Ingredion, Brazil), and glycerol monostearate (MSG) (Labsynth, Brazil).

Fruits (approximately 10 kg for each variety) were stored under room conditions (approximately 25 °C and relative air humidity of 60%) until ripening (approximately 19 °Brix). They were cleaned under running water and manually peeled using stainless-steel knives. The peels (before drying) were analyzed for moisture content, water activity, total sugar and reducing sugar content, vitamin C, total phenolic content,

total carotenoids,  $\beta$ -carotene, total dietary fibers, insoluble and soluble dietary fibers, and antioxidant capacity (ABTS/DPPH). The choice of mango variety for subsequent drying was based on the physicochemical characterization of the peels, such as low moisture and reducing sugar content, and high nutrient concentration.

Fruits (Palmer variety) stored at room temperature were selected to produce a puree when ripened for pulp production (17-20 °Brix). After they were cleaned under running water, fruits were immersed in an active chlorine solution (150 ppm) for 10 min, and blanched in boiling water (approximately 97 °C) for 90 s. Blanching is typically carried out in the industry to facilitate peeling. Then, peels were manually removed with stainless steel knives. The blanched peels were crushed in an industrial blender (model 1560791, Skymesen, Brazil) with water (1.2 kg of water  $\text{kg}^{-1}$  of peels) at 3500 rpm for 150 s. The puree obtained was packed in a low-density polyethylene packaging (LDPE) (0.15 mm thick), containing approximately 6 kg, and stored in a freezer (-18 °C) until use. For each drying test, the previously thawed puree was homogenized in a colloid mill (model REX 2-AL, Meteor, Brazil) at a flow rate of 2000  $\text{L h}^{-1}$  for 5 min, adding the following process additives to improve the film's thermoplastic characteristics: 5% (d.b.) of regular corn starch and 1% (d.b.) of glycerol monostearate. Figure 1 shows some steps of puree preparation.

The experimental tests were carried out in a pilot drum-dryer (model D139, Richard Simon & Sons, England) with a single-cylinder (0.5  $\text{m}^2$  of surface area), heated internally via saturated steam, and an applicator cylinder (Figure 1). Based on earlier tests and a previous study with mango pulp (Tonin et al., 2018), the following process variables were fixed: pool level of 10 mm ( $\pm$  400 mL) and clearance of 0.15 mm (between the heating and applicator cylinder).

A 2<sup>2</sup> factorial experimental design with three central points based on response surface methodology was used, with process temperature and residence time as independent variables. The process temperature is the temperature of the cylinder, which is heated internally with saturated steam. The rotational speed of the cylinder determines the residence time, that is, the time that the product is in contact with the heated cylinder. The process temperature and residence time varied from 130.6 to



**Figure 1.** Steps of the experimental tests to obtain drum-dried mango peel flakes (Palmer variety): (A) peel crushing; (B) puree homogenization; (C) drum-drying of the puree; (D) flocculation of the dried film; (E) final product

146.4 °C and 14 to 28 s, respectively. The levels were established according to preliminary tests. This type of design may produce the working ranges for the variables, which are viable for drum drying because slight differences in the feeding properties usually require process condition adjustments. This option also considered the large amount of raw material involved in plant-scale tests. Each trial used approximately 12 kg of puree. Samples were taken throughout the process, from 5 min after the beginning of the tests. The drum-drying mass flow rate (MFR) was determined in quadruplicate throughout the test (Eq. 1).

$$\text{MFR} = \frac{m}{A\Delta t} \quad (1)$$

where:

- MFR - mass flow rate, kg h<sup>-1</sup> m<sup>-2</sup>;
- m - mass of product obtained during the analysis, kg;
- A - drying area, m<sup>2</sup>; and,
- Δt - sampling time interval, hour.

The dried film was flocculated (model S508, Fabbe, Brazil) using a 2.5 mm sieve (Figure 1). The product obtained after drying was analyzed (in triplicate) for moisture content, instrumental color, antioxidant capacity (DPPH/ABTS), vitamin C, total phenolic compound, total carotenoid, and β-carotene content.

The responses or dependent variables were mass flow rate and the physicochemical properties of the products obtained in each test. They were fitted to a first-order polynomial model (Eq. 2) using Statistica® software, version 8.0 (Statsoft Inc., USA). The results were statistically tested to determine the adequacy of the model using the coefficient of determination R<sup>2</sup> (> 0.80), analysis of variance by the F-test at p ≤ 0.05, and Tukey's test.

$$y = \beta_0 + \beta_1 T + \beta_2 t + \beta_{12} Tt \quad (2)$$

where:

- y - response, kg h<sup>-1</sup> m<sup>-2</sup> or mg per 100 g d.b.;
- T - coded process temperature, dimensionless;
- t - coded residence time, dimensionless; and,
- β<sub>x</sub> - regression model parameters, kg h<sup>-1</sup> m<sup>-2</sup> or mg per 100 g d.b.

The response surfaces were built from the models with significant terms. The curves obtained were compared to determine the optimal working conditions for mango peel drum-drying, aiming at the highest mass flow rate and lowest quality losses.

Water activity (Aw) was determined in a digital hygrometer (Aqualab 3 TE, Decagon Devices Inc, USA) at 25 °C, and moisture content in a vacuum oven at 70 °C for 24 hours (IAL, 2008).

Color parameters were evaluated with a colorimeter (CR400, Minolta, Japan), using the CIELAB system (D65 illuminant). Lightness L\* (black [0] to white [100]) and chromaticity parameters a\* (green [-] to red [+]) and b\* (blue [-] to yellow [+]) were measured. Hue (H\*) was determined according to Eq. 3.

$$H^* = \arctan\left(\frac{b^*}{a^*}\right) \quad (3)$$

Vitamin C content was quantified using Tillmans' titration method (IAL, 2008) based on reduction of the 6-dichlorophenolindophenol-sodium indicator (DCPIP) by ascorbic acid.

Reducing sugar content and total sugar content were determined via Munson and Walker's method (IAL, 2008).

Total phenolic compounds were obtained following Folin Ciocalteu's spectrophotometry method (Benvenuti et al., 2004). Absorbance readings were performed at 750 nm in a spectrophotometer (Cary 60 MY13110012, Agilent Technologies, Richardson, USA).

Antioxidant capacity was measured according to DPPH (2,2-diphenyl-1-picryl-hydrazyl radical) (Brand-Williams et al., 1995) and ABTS (2,2'-azino-bis [3-ethylbenzothiazoline-6-sulfonic acid] diammonium salt) methods (Rufino et al., 2007). Absorbance readings were conducted at 515 nm for the DPPH method and 734 nm for the ABTS method, using a spectrophotometer (model Cary 60 MY13110012, Agilent Technologies, USA).

Total carotenoids and β-carotene were determined (Carvalho et al., 1992). The former were quantified in a spectrophotometer (model Cary 50 UV-Vis, Agilent Technologies, USA), at the maximum absorption wavelength of β-carotene (453 nm). The detection and quantification of β-carotene were performed using high-performance liquid chromatography (HPLC) (model Infinity 1260 Quaternary LC, Agilent Technologies, USA). Dietary fibers (DF) were determined according to AOAC (2012).

## RESULTS AND DISCUSSION

Table 1 shows the physicochemical properties of the peels obtained from the mango varieties evaluated.

Moisture content (approximately 74-77%) and water activity (approximately 0.99) indicate that mango peels are an unstable commodity, requiring a quick process to prevent microbial and enzymatic degradation. The Palmer variety exhibited the lowest moisture content, showing significant differences (p ≤ 0.05) from the others. This property is relevant for drying, impacting yield.

The total sugar contents of the peels ranged from approximately 37 to 54 g per 100 g d.b., with no statistical differences (p > 0.05). Germer et al. (2018) reported total and reducing sugar contents of 87 and 23 g per 100 g d.b., respectively, for mango pulp (Tommy Atkins/Ubá varieties). In the present study, the Keitt variety had the highest reducing sugar content (25.06 g per 100 g d.b.), which was statistically different (p ≤ 0.05) from the other varieties. This property is critical for drying, since reducing sugars are responsible for non-enzymatic browning (Maillard) in addition to increasing hygroscopicity (Nunes et al., 2020).

Palmer peels showed the highest vitamin C content (430.31 mg per 100 g d.b.), differing statistically from the other varieties (p ≤ 0.05). The vitamin C content is about 7-fold higher than the value reported for mango pulp (63 mg per 100 g d.b.)

**Table 1.** Physicochemical properties of the mango peels for different varieties

| Property   | Mean value $\pm$ Standard deviation |                       |                       |                       |
|--|-------------------------------------|-----------------------|-----------------------|-----------------------|
|  | Palmer                              | Keith                 | Haden                 | Espada vermelha       |
| Water activity   | 0.985 $\pm$ 0.002 b,c               | 0.982 $\pm$ 0.002 c   | 0.989 $\pm$ 0.001 a,b | 0.992 $\pm$ 0.001 a   |
| Moisture content (g per 100 g)                                 | 73.97 $\pm$ 0.42 c                  | 75.37 $\pm$ 0.15 b    | 76.28 $\pm$ 0.13 a    | 76.51 $\pm$ 0.27 a    |
| Total sugar content (g per 100 g d.b.)                         | 36.70 $\pm$ 0.39 a                  | 50.40 $\pm$ 0.74 a    | 53.58 $\pm$ 0.67 a    | 39.43 $\pm$ 2.87 a    |
| Reducing sugar content (g per 100 g d.b.)                      | 12.47 $\pm$ 0.38 c                  | 25.06 $\pm$ 2.12 a    | 18.56 $\pm$ 2.10 b    | 9.35 $\pm$ 0.45 c     |
| Vitamin C (mg per 100 g d.b.)                                  | 430.31 $\pm$ 1.05 a                 | 156.54 $\pm$ 0.80 c   | 193.86 $\pm$ 1.41 b   | 143.47 $\pm$ 0.73 d   |
| Total phenolic compounds (mg GAE per 100 g d.b.)               | 3053.14 $\pm$ 88.90 c               | 2620.54 $\pm$ 48.48 d | 3350.04 $\pm$ 97.55 b | 5462.24 $\pm$ 67.17 a |
| Total carotenoid content (mg per 100 g d.b.)                   | 9.78 $\pm$ 1.01 b                   | 15.80 $\pm$ 0.16 b    | 12.21 $\pm$ 0.79 b    | 46.34 $\pm$ 5.85 a    |
| $\beta$ -carotene content (mg per 100 g d.b.)                  | 2.76 $\pm$ 0.13 c                   | 6.02 $\pm$ 0.41 b     | 4.59 $\pm$ 0.46 b,c   | 26.37 $\pm$ 1.46 a    |
| Total dietary fibers (TDF) (g per 100 g d.b.)                  | 35.00 $\pm$ 0.27 b                  | 32.24 $\pm$ 0.57 c    | 35.60 $\pm$ 0.21 a    | 39.43 $\pm$ 0.66 a    |
| Soluble dietary fibers (SDF) (g per 100 g d.b.)                | 19.67 $\pm$ 0.27 a,b                | 15.45 $\pm$ 0.49 c    | 20.85 $\pm$ 0.09 a    | 19.22 $\pm$ 0.51 b    |
| Insoluble dietary fibers (IDF) (g per 100 g d.b.)              | 15.33 $\pm$ 0.00 c                  | 16.79 $\pm$ 0.09 b    | 14.76 $\pm$ 0.30 c    | 20.20 $\pm$ 0.15 a    |
| SDF/TDF (%)  | 56.20                               | 47.92                 | 58.56                 | 48.74                 |
| SDF/IDF (%)  | 128.31                              | 92.01                 | 141.26                | 95.15                 |
| Antioxidant capacity ABTS ( $\mu$ mol TE g <sup>-1</sup> d.b.) | 274.94 $\pm$ 11.33 b                | 266.96 $\pm$ 5.13 b   | 301.68 $\pm$ 12.43 b  | 450.82 $\pm$ 6.33 a   |
| Antioxidant capacity DPPH ( $\mu$ mol TE g <sup>-1</sup> d.b.) | 276.36 $\pm$ 7.60 c                 | 250.14 $\pm$ 8.73 d   | 303.23 $\pm$ 8.34 b   | 554.87 $\pm$ 5.18 a   |
| Color parameter L*   | 43.47 $\pm$ 6.83 c                  | 54.89 $\pm$ 4.86 b    | 56.60 $\pm$ 8.86 b    | 65.25 $\pm$ 4.07 a    |
| Color parameter a*   | 15.00 $\pm$ 12.53 a                 | -12.00 $\pm$ 5.61 c   | -0.75 $\pm$ 12.98 b   | 20.88 $\pm$ 5.39 a    |
| Color parameter b*   | 29.18 $\pm$ 9.95 c                  | 37.92 $\pm$ 8.66 b    | 36.60 $\pm$ 11.51 b   | 53.13 $\pm$ 2.53 a    |
| Color parameter H*   | 62.26 $\pm$ 22.87 c                 | 108.04 $\pm$ 10.82 a  | 87.72 $\pm$ 24.67 b   | 68.60 $\pm$ 5.56 c    |

GAE - Gallic acid equivalent; TE - Trolox equivalent; d.b. - Dry basis; Different lowercase letters on the same line represent significant differences according to the Tukey test ( $p \leq 0.05$ )

(Yamato et al., 2020). On the other hand, the Espada Vermelha variety exhibited the highest total phenolic content (5462.24 mg GAE per 100 g d.b.) when compared to the other varieties ( $p \leq 0.05$ ). This result is almost 8-fold higher than the value found for mango pulp (694 mg GAE per 100 g d.b.) (Tonin et al., 2018). In another study, Ferrari et al. (2021) observed a total phenolic compound content of around 2700 mg GAE per 100 g d.b. for mango peel powder (Palmer variety) obtained by hot-air drying. Masibo & He (2009) reported polyphenol content between 5500 and 11000 mg GAE per 100 g d.b. for ripe mango peels. According to the authors, the two main polyphenols present in mango peel are mangiferin and quercetin 3-O-galactoside.

The Espada Vermelha peels showed significantly higher total carotenoid and  $\beta$ -carotene content ( $p \leq 0.05$ ) than that of the other varieties, with values almost four times higher than those reported for commercial mango pulp (Tonin et al., 2018).

The total dietary fiber content (TDF) of the mango peels varied between 32 and 39 g per 100 g d.b., about 2-fold higher than the value reported by Marques et al. (2010) for mango pulp (Tommy Atkins) (18.33 g per 100 g d.b.). In another study, Sánchez-Camargo et al. (2019) observed a TDF of 35.6 g per 100 g d.b. for Sugar variety peels, which is close to that obtained in the present study. The Espada Vermelha variety had the highest TDF and insoluble dietary fiber content (IDF), both significantly different ( $p \leq 0.05$ ) from the other peels, while the Haden and Palmer varieties showed the highest soluble dietary fiber (SDF) level. Dietary fibers have several technological and physical properties, such as viscosity and water holding capacity, in addition to the ability to form gels, and the rate at which they are fermented by intestinal microbes. The SDF/TDF ratios ranged from 48 to 59%, slightly higher than the well-balanced proportion recommended for physiological purposes (30-50%) (Masibo & He, 2009). The SDF/IDF ratios showed a predominance of SDF in the Palmer and Haden varieties, and a better balance in their Keitt and Espada Vermelha counterparts. With respect to the use of peels as a food ingredient, since different applications require particular characteristics, specific

ratios can be obtained by mixing different varieties.

The antioxidant capacity of mango peels varied from approximately 250 to 555  $\mu$ mol TE g<sup>-1</sup> d.b., where the Espada Vermelha variety had the highest content, which is statistically different ( $p \leq 0.05$ ) from the other samples.

In relation to color parameter a\* (green/red), Palmer and Espada Vermelha exhibited reddish peels ( $a^* > 0$ ), while those obtained from the Keitt and Haden varieties are greenish ( $a^* < 0$ ). For color parameter b\* (blue/yellow), all the varieties assessed were predominantly yellow ( $b^* > 0$ ), but Espada Vermelha obtained the highest b\* values, indicating a more intense color. Benevides et al. (2008) reported that the high parameter b\* values in mango suggested the prevalence of carotenoids when compared to other pigments. As previously mentioned, the Espada Vermelha peels stood out among all the mango varieties evaluated in the present study, in terms of carotenoid contents. The Palmer, Haden, and Espada Vermelha varieties were predominantly yellow, with a hue angle (H\*) between 0 and 90°. The Haden variety exhibited the most yellow peel, with a significantly higher value ( $p \leq 0.05$ ) than the others, while the Keitt peels were between green and yellow ( $H^* > 90^\circ$ ). With respect to the L\* parameter, the Palmer variety showed the lowest values, indicating that these samples were the darkest peels.

The physico-chemical differences between varieties might affect the quality of drum-dried mango peel. The Palmer variety was selected for the next step of the study due to some of its peel characteristics, such as low moisture content and reducing sugar content, and high nutrient concentration. In addition, Palmer is one of the most widely produced varieties in Brazil and largely used in the pulp industry (Costa et al., 2019).

Table 2 presents the coded and real independent variable levels in the experimental design, as well as the responses, which were fitted to the models: moisture content, color parameter a\*, and mass flow rate. The regressions did not result in valid models for the other responses, according to the criteria established. Table 3 and Figure 2 exhibit the mathematical models and response surfaces, respectively.

**Table 2.** Coded and real independent variable values in the experimental design for the drum-drying of mango peel puree (Palmer variety) and significant response results

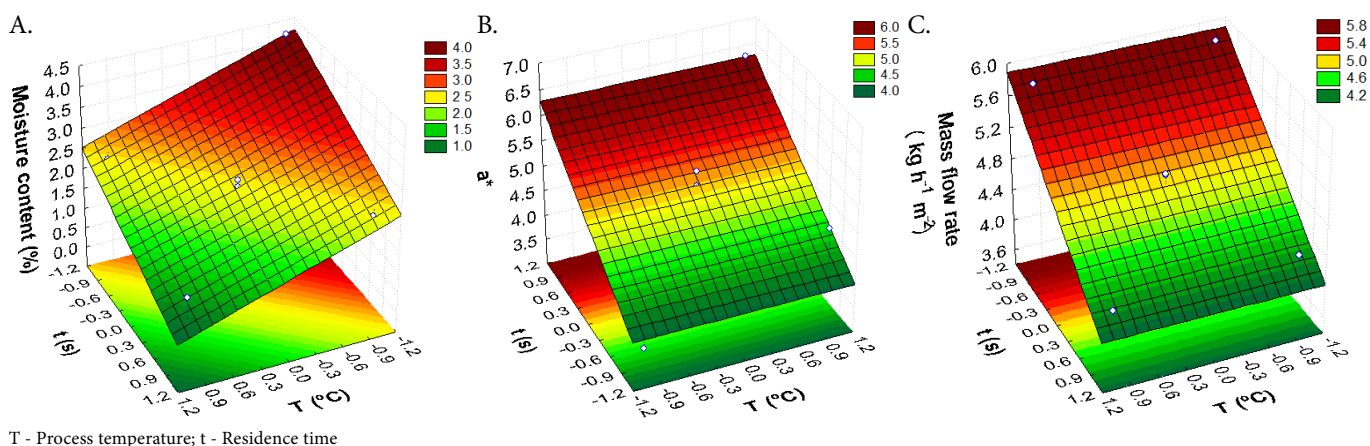
| Test | Residence time (s) | Temperature (°C) | Moisture content (%) | a*          | Mass flow rate (kg h <sup>-1</sup> m <sup>-2</sup> ) |
|------|--------------------|------------------|----------------------|-------------|--|
| 1    | 14 (-1)            | 130.6 (-1)       | 4.40 ± 0.04          | 3.53 ± 0.06 | 5.86 ± 0.07  |
| 2    | 14 (-1)            | 146.4 (1)        | 2.37 ± 0.04          | 4.96 ± 0.44 | 5.81 ± 0.08  |
| 3    | 28 (1)             | 130.6 (-1)       | 2.26 ± 0.03          | 5.85 ± 0.37 | 4.35 ± 0.13  |
| 4    | 28 (1)             | 146.4 (1)        | 1.45 ± 0.04          | 6.49 ± 0.23 | 4.24 ± 0.33  |
| 5    | 21 (0)             | 138.4 (0)        | 2.47 ± 0.04          | 5.25 ± 0.21 | 4.44 ± 0.17  |
| 6    | 21 (0)             | 138.4 (0)        | 2.31 ± 0.01          | 4.22 ± 0.29 | 5.01 ± 0.10  |
| 7    | 21 (0)             | 138.4 (0)        | 1.99 ± 0.02          | 5.53 ± 0.32 | 5.02 ± 0.11  |

Moisture content - Mean ± standard deviation (n = 3); Mass flow rate - Mean ± standard deviation (n = 4); Color parameter a\* - Mean ± standard deviation (n = 9)

**Table 3.** F values, coefficients of determination (R<sup>2</sup>), coefficients of variation (CV) and models of the significant dependent variables obtained in the drum-drying tests of mango peel puree (Palmer variety): moisture content (MC), color parameter a\*, mass flow rate (MFR)

| Dependent variable | R <sup>2</sup> | CV    | F <sub>calc</sub> | F <sub>tab</sub> | Equation                           |
|--------------------|----------------|-------|-------------------|------------------|------------------------------------|
| Moisture content   | 0.93           | 17.19 | 12.14             | 6.94             | MC = 2.464 - 0.710*T - 0.765*t (4) |
| Color parameter a* | 0.83           | 10.62 | 8.22              | 6.61             | a* = 5.119 + 0.963*t (5)           |
| Mass flow rate     | 0.88           | 6.59  | 36.17             | 6.61             | MFR = 4.961 - 0.770*t (6)          |

F<sub>calc</sub> - calculated F value; F<sub>tab</sub> - tabulated F value (p ≤ 0.05); T - Coded temperature; t - Coded residence time; \* - Significant at p ≤ 0.05 according to the F test



T - Process temperature; t - Residence time

**Figure 2.** Response surfaces obtained from the drum-drying of mango peels: (A) moisture content; (B) color parameter a\*; (C) mass flow rate

The coefficients of determination (R<sup>2</sup>) of the models varied from 0.83 to 0.93 (Table 3), which is a good fit considering that the trials were carried out on a pilot scale, and fruits have inherent variability. The type of experimental design used makes it possible to observe the influence of independent variables on the responses, as well as determine the working ranges for the drum-drying variables (Rodrigues & Iemma, 2014).

Process temperature (T) and residence time (t) showed a negative influence on the moisture content of the dried product (Eq. 4). An increase in both independent variables decreased this property. A rise in temperature reduces feed viscosity and, consequently, the entrainment flow of liquid on the drum surface, resulting in lower moisture (Wiriyawattana et al., 2018). Figure 2A shows that a combination of residence time longer than 21 s and process temperature above 138.4 °C resulted in moisture content below 2.5%. Similarly, Germer et al. (2018) reported that the use of higher temperatures (>135 °C) and longer residence times (t > 25 s) in the drum-drying of mango pulp resulted in a moisture content of around 1%.

According to Eq. 5, residence time positively affected color parameter a\* (red). The longer the residence time (> 21 s), the higher parameter a\* (> 5) (Figure 2B), indicating a more

reddish product. Similarly, in the drum-drying of pomegranate peels, Galaz et al. (2017) reported that high temperatures influenced red coloring (a\*), which can be intensified with prolonged film exposure to heat. This behavior might be related to non-enzymatic browning (Maillard) and caramelization reactions.

Residence time (t) had a negative effect on mass flow rate, according to the model (Eq. 6). The response surface (Figure 2C) demonstrated that mass flow rate (MFR) increased with shorter residence times, with no effect of process temperature. The lower the residence time (< 21 s), the higher the MFR (> 5 kg h<sup>-1</sup> m<sup>-2</sup>). The highest MFR in the present study was 5.8 kg h<sup>-1</sup> m<sup>-2</sup>, while Tonin et al. (2018) reported a higher value for drum-dried mango pulp without additives (6.9 kg h<sup>-1</sup> m<sup>-2</sup>). This difference might be due to the higher fiber content of mango peel, resulting in thicker puree with more difficult entrainment flow from the pool level to the cylinder surface.

According to the response surfaces (Figure 2), lower moisture contents are obtained with higher temperatures and longer residence times. On the other hand, lower parameter a\* and higher MFR are obtained with shorter residence times. For dried products, moisture contents lower than 5% are required to decrease the rate of degradation reactions. The development

of a reddish color (non-enzymatic browning) is undesirable in the drying process since it decreases the quality of the product. High MFR is expected in an industrial process, aiming at greater productivity. Thus, the ranges  $0.0 \leq T \leq 1.0$  and  $-1.0 \leq t \leq 0.0$ , that is,  $138.4 \leq T \leq 146.4$  °C and  $14 \leq t \leq 21$  s represent the best process conditions for the desired independent variables. In another study with drum-dried mango pulp, Germer et al. (2018) obtained the optimal area, delimited by temperatures between 120 and 135 °C and residence times varying from 10 to 25 s, considering the lowest moisture content and highest carotenoid and color retention.

Table 4 shows the responses not fitted to the models. The behavior indicates that the independent variables did not influence these properties, given the range of levels used in the experimental design.

Lightness ( $L^*$ ) varied from 60.71 to 67.58, meaning that the drum-dried mango peel flakes were lighter than the drum-dried mango powder obtained by Caparino et al. (2012) ( $L^* = 38$ ). Color parameter  $b^*$  (yellow) ranged between 42.30 and 47.8, which is lower than the values observed in drum-dried mango pulp (66.33 to 70.61) (Tonin et al., 2018). Nevertheless, Hue ( $H^*$ ) varied from 82 to 86, close to the pure yellow color (Hue = 90°) and the range reported for drum-dried mango pulp (from 83 to 86) (Germer et al., 2018).

A comparison between the contents observed in drum-dried mango (Table 4) and fresh Palmer peels (Table 1) indicates nutrient retention in the process. Vitamin C retention ranged between 14 and 18%, lower than the value reported for drum-dried mango pulp (48-75%) (Germer et al., 2018). It is important to note that the present study involved an extra process step, namely crushing the peels in an industrial blender. This additional step may have contributed to the reduction in vitamin C, due to oxidation and enzymatic degradation. Nyangena et al. (2019) found that pre-drying treatments have a strong influence on vitamin C losses. According to Table 4, the vitamin C content of the drum-dried product varied from approximately 66 to 93 mg per 100 g d.b., higher than the value reported in drum-dried mango pulp (22 mg per 100 g d.b.) (Yamato et al., 2020). On the other hand, Ferrari et al. (2021) assessed the stability of mango peel powder obtained by hot-air drying (Palmer variety), and found that the initial vitamin C content of the product was around 370 mg per 100 g d.b., while the retention of this nutrient was about 62% after 180 days of storage at 25 °C. The higher vitamin C retention than that obtained in

the present study may be related to the different pre-drying steps, drying technology, and process conditions.

The maximum total carotenoid and  $\beta$ -carotene retention were 168 and 270%, respectively. The resulting product may contain up to 16 and 8 mg per 100 g d.b. of total carotenoid and  $\beta$ -carotene content (Table 4), respectively, which is slightly higher than the results reported by Yamato et al. (2020) for drum-dried mango pulp (14 and 6 mg per 100 g d.b., respectively). Retention values above 100% may be related to the improved compound extractability due to microstructural changes in the food matrix during drying (Córdova et al., 2020).

Total phenolic compound retention varied between 93 and 105%, with their content ranging from 2841 to 3194 mg GAE per 100 g d.b. (Table 4), which is around 5-fold higher than the value reported for drum-dried mango pulp (600 mg GAE per 100 g d.b.) (Germer et al., 2018). Studying the drum drying of broccoli pulp, Córdova et al. (2020) observed maximum total phenolic compound retention of around 147.6%.

The retention of the antioxidant capacity in the present study was between 103 and 132%, considering both analysis methods. Antioxidant capacity ranged from approximately 286 to 361  $\mu\text{mol TE g}^{-1}$  d.b. (Table 4), higher than the values obtained for hot air-dried mango peel (171  $\mu\text{mol TE g}^{-1}$  d.b.) (Aziz et al., 2012), and drum-dried mango pulp (40-75  $\mu\text{mol TE g}^{-1}$  d.b.) (Germer et al., 2018). Galaz et al. (2017) also observed that the experimental temperature (100-120 °C) and process time (257-422 s) did not affect the total phenolic compound content and antioxidant capacity of the drum-dried pomegranate peels. Retentions above 100% could be attributed to the drying treatment, which, according to other studies, may enhance the extractability of different compounds (Ruttarattanamongkol et al., 2016). Que et al. (2008) reported that the increase in polyphenol content after drying might be responsible for the high antioxidant activity of hot air-dried pumpkin flour. Furthermore, the formation of phenolic compounds may be due to the availability of phenolic molecule precursors by non-enzymatic interconversion between phenolic molecules. Another explanation for the higher antioxidant activity after heating is the generation and accumulation of Maillard-type antioxidants.

Ferrari et al. (2021) evaluated the stability of mango peel powder produced by hot-air drying (Palmer variety) over 180 days. Phenolic compound content was around 2700 and 2530 mg GAE 100 per g d.b. at time zero and the end of storage, respectively, at 25 °C. In relation to antioxidant capacity,

**Table 4.** Physicochemical properties of drum-dried mango peel flakes (Palmer variety) in the different tests of the experimental design

| Test | $L^*$        | $b^*$        | Hue          | Vitamin C<br>(mg<br>per 100 g d.b.) | Total phenolic<br>compounds<br>(mg GAE<br>per 100 g d.b.) | Total carotenoids |             | Antioxidant capacity<br>( $\mu\text{mol TE g}^{-1}$ d.b.) |               |
|------|--------------|--------------|--------------|-------------------------------------|---|-------------------|-------------|---|---------------|
|      |              |              |              |                                     |   | $\beta$ -carotene | ABTS        | DPPH  |               |
| 1    | 67.58 ± 0.76 | 45.03 ± 1.09 | 85.51 ± 0.13 | 81.04 ± 2.35                        | 3070.52 ± 42.42   | 13.83 ± 0.99      | 7.36 ± 0.14 | 335.32 ± 6.25   | 297.31 ± 3.49 |
| 2    | 65.57 ± 1.30 | 44.94 ± 1.30 | 83.70 ± 0.42 | 84.65 ± 1.03                        | 3193.60 ± 59.70   | 15.35 ± 0.96      | 7.89 ± 0.43 | 359.08 ± 11.65  | 300.74 ± 8.84 |
| 3    | 63.88 ± 1.10 | 47.83 ± 1.84 | 83.04 ± 0.23 | 87.08 ± 2.05                        | 2841.72 ± 269.61  | 15.95 ± 0.98      | 7.86 ± 0.28 | 334.83 ± 25.48  | 293.61 ± 3.66 |
| 4    | 62.93 ± 0.92 | 43.80 ± 1.24 | 81.57 ± 0.13 | 85.22 ± 0.88                        | 3154.24 ± 183.03  | 15.74 ± 0.09      | 7.33 ± 0.05 | 361.67 ± 21.05  | 306.72 ± 5.59 |
| 5    | 64.37 ± 0.95 | 44.26 ± 0.91 | 83.24 ± 0.21 | 59.30 ± 1.71                        | 3096.17 ± 13.67   | 16.44 ± 0.08      | 7.59 ± 0.01 | 341.99 ± 20.10  | 305.17 ± 4.26 |
| 6    | 66.61 ± 0.62 | 47.26 ± 1.26 | 84.89 ± 0.25 | 93.38 ± 2.93                        | 2931.47 ± 67.43   | 13.53 ± 0.71      | 6.98 ± 0.15 | 309.00 ± 4.18   | 286.81 ± 1.87 |
| 7    | 60.71 ± 1.11 | 42.30 ± 1.09 | 82.55 ± 0.32 | 66.40 ± 3.95                        | 3038.87 ± 19.91   | 15.20 ± 0.26      | 7.36 ± 0.20 | 359.82 ± 9.26   | 308.66 ± 2.70 |

Vitamin C - Mean ± standard deviation (n = 4); Total phenolic compounds and antioxidant capacity - Mean ± standard deviation (n = 3); Total carotenoids and  $\beta$ -carotene - Mean ± standard deviation (n = 2); Color parameters ( $L^*$ ,  $b^*$ , Hue) - Mean ± standard deviation (n = 9); d.b. - Dry basis; GAE - Gallic acid equivalent; TE - Trolox equivalent

the initial values were close to 304 and 334  $\mu\text{mol TE g}^{-1}$  d.b. (DPPH and ABTS method, respectively). The authors found a significant reduction in antioxidant capacity at the final time (around 267 and 283  $\mu\text{mol TE g}^{-1}$  d.b. for the ABTS and DPPH methods, respectively).

In general, the drum-drying of mango peels showed high nutrient retention, despite the high process temperature (130.6 to 146.4 °C). The results may be related to the low residence time (14 to 28 s). The presence of corn starch as an additive may have protected nutrients against the heating effect due to the structure formed during gelatinization (Setyadjit & Sukasih, 2015). The drum-dried mango peel flakes can be used as a source of nutrients in snacks, cereal bars, pasta, fillings, bakery, confectionery, and meat products.

## CONCLUSIONS

1. Drum-drying is an alternative technology for the processing of mango peels.
2. Drum-drying temperature and residence time had an effect on the moisture content and red color ( $a^*$ ) of the final product, as well as mass flow rate, a relevant variable for industrial yields.
3. The independent variables did not affect properties such as antioxidant capacity, total phenolic compound, total carotenoid, and  $\beta$ -carotene contents, as well as other color parameters ( $L^*$ ,  $b^*$ , Hue).
4. The combination of temperature and residence time from 138.4 to 146.4 °C and 14 to 21 s results in lower moisture content (< 2.5%) and better color ( $a^* < 5$ ).
5. Peels obtained from different varieties displayed different physicochemical properties, demonstrating challenges for a productive process using by-products.

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## LITERATURE CITED

- AOAC - Association of Official Analytical Chemists. Official methods of analysis of the Association of Official Analytical Chemists. 19.ed. Gaithersburg: AOAC, 2012. 1018p.
- Aziz, N. A. A.; Wong, L. W.; Bhat, R.; Cheng, L. H. Evaluation of processed green and ripe mango peel and pulp flours (*Mangifera indica* var. Chokanan) in terms of chemical composition, antioxidant compounds and functional properties. *Journal of the Science of Food and Agriculture*, v.92, p.557-563, 2012. <https://doi.org/10.1002/jsfa.4606>
- Benevides, S. D.; Ramos, A. M.; Stringheta, P. C.; Castro, V. C. Quality of the fruits and pulp of Ubá mango. *Ciência e Tecnologia de Alimentos*, v.28, p.571-578, 2008. <https://doi.org/10.1590/S0101-20612008000300011>
- Benvenuti, S.; Pellati, F.; Melegari, M.; Bertelli, D. Polyphenols, anthocyanins, ascorbic acid, and radical scavenging activity of *Rubus*, *Ribes* and *Aronia*. *Journal of Food Science*, v.69, p.164-169, 2004. <https://doi.org/10.1111/j.1365-2621.2004.tb13352.x>
- Brand-Williams, W.; Cuvelier, M. E.; Berset, C. Use of a free radical method to evaluate antioxidant activity. *LWT - Food Science and Technology*, v.28, p.25-31, 1995. [https://doi.org/10.1016/S0023-6438\(95\)80008-5](https://doi.org/10.1016/S0023-6438(95)80008-5)
- Caparino, O. A.; Tang, J.; Nindo, C. I.; Sablani, S. S.; Powers, J. R.; Fellman, J. K. Effect of drying methods on the physical properties and microstructures of mango (Philippine "Carabao" var.) powder. *Journal of Food Engineering*, v.111, p.135-148, 2012. <https://doi.org/10.1016/j.jfoodeng.2012.01.010>
- Carvalho, P. R. N.; Collins, C. A.; Rodriguez-Amaya, D. B. Comparison of provitamin A determination by normal-phase gravity-flow chromatography and reversed phase high performance liquid chromatography. *Chromatographia*, v.33, p.133-137, 1992.
- Chia, S. L.; Chong, G. H. Effect of drum drying on physico-chemical characteristics of dragon fruit peel (*Hylocereus polyrhizus*). *International Journal of Food Engineering*, v.11, p.285-293, 2015. <https://doi.org/10.1515/ijfe-2014-0198>
- Córdova, C.; Vivanco, J. P.; Quintero, J.; Mahn, A. Effect of drum-drying conditions on the content of bioactive compounds of broccoli pulp. *Foods*, v.9, p.1-13, 2020. <https://doi.org/10.3390/foods9091224>
- Costa, L. O.; Lara Junior, J. M.; Costa, J. M. C. da; Afonso, M. R. A.; Rodrigues, S.; Wurlitzer, N. J. Stability and microstructure of powdered pulp of the Palmer mango obtained by the process of lyophilisation. *Revista Ciência Agronômica*, v.50, p.251-258, 2019. <https://doi.org/10.5935/1806-6690.20190029>
- Ferrari, C. C.; Morgano, M. A.; Germer, S. P. M. Evaluation of water sorption isotherm, glass transition temperature, vitamin C and color stability of mango peel powder during storage. *SN Applied Sciences*, v.3, p.1-12, 2021. <https://doi.org/10.1007/s42452-021-04251-x>
- Galaz, P.; Valdenegro, V.; Ramirez, C.; Nuñez, H.; Almonacid, S.; Simpson, R. Effect of drum drying temperature on drying kinetic and polyphenol contents in pomegranate peel. *Journal of Food Engineering*, v.208, p.19-27, 2017. <https://doi.org/10.1016/j.jfoodeng.2017.04.002>
- García-Amezquita, L. E.; Tejada-Ortigoza, V.; Campanella, O. H.; Welti-Chanes, J. Influence of drying method on the composition, physicochemical properties, and prebiotic potential of dietary fiber concentrates from fruit peels. *Journal of Food Quality*, v.3, p.1-11, 2018. <https://doi.org/10.1155/2018/9105237>
- Germer, S. P. M.; Tonin, I. P.; Aguirre, J. M.; Alvim, I. D.; Ferrari, C. C. Influence of process variables on the drum drying of mango pulp. *Drying Technology*, v.36, p.1488-1500, 2018. <https://doi.org/10.1080/07373937.2017.1410707>
- Gómez, M.; Martínez, M. M. Fruit and vegetable by-products as novel ingredients to improve the nutritional quality of baked goods. *Critical Reviews in Food Science and Nutrition*, v.58, p.2119-2135, 2018. <https://doi.org/10.1080/10408398.2017.1305946>
- IAL - Instituto Adolfo Lutz. Physicochemical methods for food analysis. São Paulo: Instituto Adolfo Lutz, 2008, 1020p.
- Marques, A.; Chicaybam, G.; Araujo, M. T.; Manhães, L. R. T.; Sabaa-Srur, A. U. O. Mango rind and pulp (*Mangifera indica* L.) cv. Tommy Atkins centesimal composition and minerals contents. *Revista Brasileira de Fruticultura*, v.32, p.1206-1210, 2010. <https://doi.org/10.1590/S0100-29452010005000117>

- Masibo, M.; He, Q. Mango bioactive compounds and related nutraceutical properties - A review. *Food Reviews International*, v.25, p.346-370, 2009. <https://doi.org/10.1080/87559120903153524>
- Murray, A.; Skene, K.; Haynes, K. The circular economy: an interdisciplinary exploration of the concept and application in a global context. *Journal of Business Ethics*, v.140, p.369-380, 2017. <https://doi.org/10.1007/s10551-015-2693-2>
- Nunes, L. P.; Ferrari, C. C.; Ito, D.; Souza, E. de C. G.; Germer, S. P. M. Drum drying process of jaboticaba pulp using corn starch as an additive. *Brazilian Journal of Food Technology*, v.23, p.1-13, 2020. <https://doi.org/10.1590/1981-6723.16619>
- Nyangena, I. O.; Owino, W. O.; Imathiu, S.; Ambuko, J. Effect of pretreatments prior to drying on antioxidant properties of dried mango slices. *Scientific African*, v.6, p.1-9, 2019. <https://doi.org/10.1016/j.sciaf.2019.e00148>
- Que, F.; Mao, L.; Fang, X.; Wu, T. Comparison of hot air-drying and freeze-drying on the physicochemical properties and antioxidant activities of pumpkin (*Cucurbita moschata* Duch.) flours. *International Journal of Food Science and Technology*, v.43, p.1195-1201, 2008. <https://doi.org/10.1111/j.1365-2621.2007.01590.x>
- Rodrigues, M. I.; Iemma, A. F. Experiment design and process optimization. New York: CRC Press, 2014. 336p.
- Rufino, M. do S. M.; Alves, R. E.; Brito, E. S. de; Moraes, S. M. de; Sampaio, C. de G.; Pérez-Jiménez, J.; Saura-Calixto, F. G. Scientific methodology: determination of total antioxidant activity in fruits by the capture of free radical ABTS•+. *Forteleza: Comunicado Técnico Embrapa Agroindústria Tropical*, 2007. 4p.
- Ruttarattanamongkol, K.; Chittrakorn, S.; Weerawatanakor, M.; Dangpium, N. Effect of drying conditions on properties, pigments and antioxidant activity retentions of pretreated orange and purple-fleshed sweet potato flours. *Journal of Food Science and Technology*, v.53, p.1811-1822, 2016. <https://doi.org/10.1007%2Fs13197-015-2086-7>
- Sánchez-Camargo, A. P.; Gutiérrez, L. P.; Vargas, S. M.; Martínez-Correa, H. A.; Parada-Afonso, F.; Narváez-Cuenca, C. E. Valorisation of mango peel: proximate composition, supercritical fluid extraction of carotenoids, and application as an antioxidant additive for an edible oil. *Journal of Supercritical Fluids*, v.152, p.1-9, 2019. <https://doi.org/10.1016/j.supflu.2019.104574>
- Setyadjit, E.; Sukasih, E. Effect of addition of filler on the production of shallot (*Allium cepa* var. *ascalonicum* L.) powder with drum dryer. *Procedia Food Science*, v.3, p.396-408, 2015. <https://doi.org/10.1016/j.profoo.2015.01.044>
- Tonin, I. P.; Ferrari, C. C.; Silva, M. G. da; Berto, M. I.; Oliveira, K. L. de; Silva, V. M. da; Germer, S. P. M. Performance of different process additives on the properties of mango powder obtained by drum drying. *Drying Technology*, v.36, p.355-365, 2018. <https://doi.org/10.1080/07373937.2017.1334000>
- Wiriyawattana, P.; Suwonsichon, S.; Suwonsichon, T. Effects of drum drying on physical and antioxidant properties of riceberry flour. *Agriculture and Natural Resources*, v.52, p.445-450, 2018. <https://doi.org/10.1016/j.anres.2018.11.008>
- Yamato, M. A.; Silva, V. M. da; Souza, E. de C. G.; Ferrari, C. C.; Germer, S.P. M. Stability of mango flakes obtained by drum drying with different additives. *Drying Technology*, v.38, p.361-375, 2020. <https://doi.org/10.1080/07373937.2019.1571505>