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Production and quality of pineapple juice with mint powder by foam-mat drying

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Abstract

The paper aimed to produce dried pineapple with mint juice using the foam-mat drying and assess the final product's quality 2% (m/m) of Super Liga Neutra and Emustab were added to the pineapple with mint juice to form the foam. The ingredients were mixed in a domestic mixer for fifteen minutes. After this, the mixture was spread on trays forming a 1.0 cm layer, which was dried at 60, 70, and 80 °C. The experimental data of the pineapple's drying kinetic with mint juice allowed to trace drying curves according to the following adjusted to data models: Two-terms exponential model, Henderson and Pabis, and Page. The final product was assessed as pH, titratable acidity, water content, total solids, soluble solids, ascorbic acid, solubility, and color (L*, a* e b*). The Page model was the one that best fit the experimental data of the pineapple with mint juice drying at all temperatures, presenting the highest coefficient of determination (R^2). This model explained in a satisfactory form the drying of the pineapple juice with mint. The research highlighted that as increasing the drying temperature, the acidity and the water content reduced, and, at the same time, the soluble solids rate increased. The samples that had been dried at 70 °C displayed higher stability of the ascorbic acid content and lower darkening.

Keywords: *Ananas comosus,* foam-mat, additives, dehydration, mathematical models

Introduction

Brazil is the third world fruit producer and is responsible for 35% of world production: just China and India produce more fruit than Brazil. At the same time, Brazil is the second world pineapple (*Ananas comosus*) producer. Pineapple is a high-commercial and economic value fruit, with a double consumption attitude: *in natura* or processed (Anuário Brasileiro de Fruticultura, 2018).

The pineapple fruit pulp (*Ananas comosus*) is its pseudofruit, mainly consumed as juice, pulp, sweets, and jams. The fruit has high energetic and nutritional values due to its high simple carbohydrates concentration, calcium, phosphorus, magnesium, sodium, copper and iodine, and vitamins C (ascorbic acid), B3 (niacin), B1 (thiamine), and B2 (riboflavin) (Ogawa et al., 2017).

From the medical point of view, pineapple consumption is of the highest importance due to the presence of bromelain, a proteolytic enzyme, with pharmacological properties as an anti-inflammatory, inhibition of the platelets aggregation, and chemoprophylaxis of cancer, and is widely used in the food industry as a natural meat tenderer (Chobotava et al., 2010). Besides this proteolytic enzyme, the fruit bark fiber reduces gastrointestinal transit time and improves the growth of intestinal probiotics (Alves et al., 2011).

As its high humidity (85% of the fruit is water), the pineapple is highly perishable and susceptible to enzymatic and bacterial activities. For this reason, its shelf life is short, and it is not accepted, either by the final consumers and the industry, due to its external features, causing losses at the post-harvest stage. An alternative to reduce these losses is the application of conservation methods to preserve the sensitive and nutritional features of the fruit (Miranda et al., 2015). Among these conservation methods, drying stands out.

Most consumers appreciate juices with flavors

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similar to those of natural fruits. Consumers prefer mixed pineapple juices, added with mint leaves as flavoring agents, which improve the consumers' acceptability, reduce the acid taste, and add freshness to the beverage, mostly during warm days (Dias et al., 2012; Nayyar & Sharma 2019).

The juice market is growing and growing due to the research for powdered natural products, easy to prepare (Franco et al., 2016). Drying has been commonly used to prepare these products: it is relatively easy, has a low cost, easy to carry, reduces storage costs, as is waiving the cold chain (refrigeration) (Carvalho et al., 2017).

One of the most used techniques for the production of powder juices is foam-mat drying. Foam-mat drying mixes a fruit pulp or juice with a stabilizing agent or a foamy agent to produce a stable foam. The foam is spread on a tray, submitted to drying temperatures between 50 to 80 °C, obtaining a dry product that is later minced to produce the powder (Abbasi & Azizpour, 2016). The system has low operational costs, lower drying time due to the vast contact area exposed to the warm air, which eases the humidity removal. The final product is porous and can be easily rehydrated (Tavares et al., 2020).

The paper aimed to produce dried pineapple with mint juice using the foam-mat drying at different temperatures and assess the final product's quality.

Material and Methods

Raw Material

This work was developed in the Agroindustry laboratory of the Agriculture Science Campus (CCA) of the Univasf/PE. The raw material were: pineapple fruit, mint leaves, and the additives Emustab® and Super Liga Neutra® (compounds based on sugar and the thickeners guar gum and carboxymethylcellulose). All products were bought at the local commerce of Petrolina (PE) (Brazil).

Preparation of juice and foam for drying

The pineapple and mint leaves were initially sanitized in a 50 ppm chlorine solution to prepare the juice. After this, the pineapple was peeled and cut into cubes. The juice was prepared in a domestic mixer: 800 grams of pineapple cubes and ten mint leaves. The liquid juice was not sweetened so that the consumer could sweeten the rehydrated dusted product according to its preference.

Preliminary tests defined the additives' dosage to elaborate the foam: 2% (w/w) of each additive (Super Liga Neutra and Emustab) were incorporated and homogenized to the pineapple juice. After this, the ingredients were mixed and air incorporated in a domestic blender for 15 minutes to form a 0.56 $g.100g^{-1}$ density foam. This density standard was chosen according to the study of Bates (1964). The author claimed that foams are deemed stable mechanically and thermally when neither the drainage nor the collapse is observed. This event occurs at densities below 0.5 g/cm^3.

The foam was spread on stainless steel trays, forming a foam layer with 1.0 cm thickness, measured by a digital caliper. Foams were dehydrated in an air circulation stove at 60, 70 and 80°C temperatures.

Drying process assessment

Drying kinetics were determined by weighing the trays with the samples until the weight stabilization at regular intervals. As with the experimental data, the humidity rate was calculated (Equation 1).

$$RX=\frac{X - X_e}{X_0 - X_e} \quad (1)$$

Where: RX= humidity rate (adimensional); X= humidity, dry basis; Xe= equilibrium humidity, dry basis; Xo= initial humidity, dry basis.

The semi-theoretical models (Table 1) of two-terms exponential, Henderson and Pabis, and Page adjusted the data to the drying curves. The models were adjusted to the drying kinetic curves, and the *software* Sigma Plot 11.0 elaborated the graphics.

The coefficient of determination (R2) and the root mean square deviation (equation 2) assessed the model best fitted to the experimental data.

$$DQM=\frac{\sqrt{\Sigma(RX_{pred} - RX_{exp})^2}}{n} \quad (2)$$

Where: RMSD- root mean square deviation; RX_{pred}- humidity ratio predicted by the model; RX_{exp}- experimental humidity ratio; n- observations number.

Table 1. Mathematical models applied to the drying kinetic data.

Model	Equation	Reference
Two-terms exponential	RX = a.exp(-k . t) + (1 -a).exp(-k . a . t)	Togrul & Pehlivan (2003)
Henderson and Pabis	$RX = a.exp(-k. t^n)$	Henderson & Pabis (1961)
Page	$RX = exp(-k.t^n)$	Page (1949)

Where, RX- humidity ratio; a and n- equation parameters; t- time (minutes); k- drying constant (min^{-1}).

Quality assessment of the powder juice

After drying, the samples were assessed as pH, soluble solids, titratable acidity, ascorbic acid (Vitamin C), water content (humidity), total solids, color (L*, a*, and b*), and solubility.

The pH was determined by potentiometry, using a digital pH-meter, calibrated with buffer solutions at pH 4.0 and 7.0. An Abbe bench refractometer determined the soluble solids rate (°Brix), and data were corrected at 20°C. Water content (%) and total solids (%) were determined by direct drying in a stove at 105 ± 1 °C until reaching a constant weight. The titratable acidity was expressed as citric acid by acid-base volumetry, using the alkaline 0.1 mol. L^{-1} solution of NaOH as a titrating agent, and the 1% alcoholic solution of phenolphthalein as an indicator. All the analyses were performed according to the Adolfo Lutz methods (IAL, 2008).

The ascorbic acid was determined by oxid-reduction volumetry, using the 2,6 dichlorophenol indophenol at 0.02% solution as a titrating agent, and the oxalic acid solution at 1%, according to Williams (1984), and its modifications by Benassi & Antunes (1988).

The color was assessed by a digital colorimeter (Minolta CR 10), using the CIELab system (Lozano et al., 1978). The results were expressed as L* (luminosity), a* (red intensity (+) and green (-), and b* (blue intensity (-) and yellow (+)).

Powder solubility was determined as described by Goula & Adamopoulos (2005), by adding two grams of juice powder in 50 mL of distilled water and later continuous shaking by a magnetic shaker to verify the time required until the total dissolving of the material.

Statistical analysis of the experimental data

The experimental data obtained by analyzing the quality assessment parameters were submitted to the analysis of variance (ANOVA) in a completely randomized experimental design (DIC). The mean values were compared by the Tukey's test at 5% probability, by the software Sisvar 5.3 (Ferreira, 2014).

Results and Discussion

Figure 1 displays the pineapple juice with mint in the foam-mat drying curves at the temperatures of 60, 70, and 80°C. The average yield of the obtained powder product was about 18% at all the studied temperatures.

Temperature increase reduces the drying temperature, as displayed by the drying time, which was 600 minutes at 80°C, 720 minutes at 70°C, and 1080 minutes at 60°C. The comparison between the highest temperature (80°C) and the lowest temperature (60°C) drying times displayed a 45% reduction.

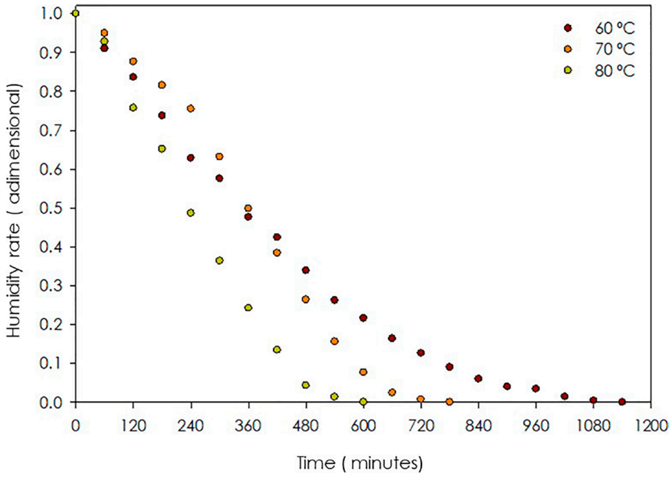

Figure 1. Drying curves of pineapple juice with mint powder at the temperatures of 60, 70 and 80 °C.

Baptestini et al. (2015) described a similar behavior as studying the soursop foam-mat drying at different temperatures. As the soursop foams were dried at 40 °C, the drying time was 1035 min. As increasing the temperature to 80 °C, the time deccreased to 225 min, which was 4.6 times lower.

Table 2 displays the estimated values of the two-terms exponential model's parameters, Henderson and Pabis, and Page models for the studied temperatures, for the layer thickness of 1.0 cm, and the coefficient of determination (R^2) and the root mean square deviation (RMSD).

The values associated with the coefficient of determination (R^2) increase as the model fits the data. As observing table 2, it is possible to observe. All models displayed high R^2 values, all over 0.9, and RMSD lower than 0.1.

Table 2. Parameters, coefficient of determination (R^2), and root mean square deviation (RMSD) of the models adjusted to the pineapple juice's drying curves with mint, as to the different analyzed temperatures.

Model	T (°C)	Parameters		R²	RMSD
		A	K		
Two-terms exponential	60	1.9395	0.0036	0.9936	0.0272
	70	1.9886	0.0056	0.9872	0.0443
	80	2.1278	0.0061	0.9847	0.0483
		A	K		
Henderson and Pabis	60	1.0935	0.0026	0.9735	0.0554
	70	1.0973	0.0039	0.9612	0.0771
	80	1.1188	0.0041	0.9413	0.0944
		K	N		
Page	60	0.0002	1.4325	0.9967	0.0196
	70	0.0001	1.5706	0.9936	0.0313
	80	$4.5293.10^{-5}$	1.7698	0.9949	0.0277

Where: a and n- equation parameters, and k- drying constant (min^{-1}).

The Page model displayed the highest adjusted coefficient of determination, and the lowest root mean square deviation at all studied drying temperatures.

The "k" parameters of all mathematical models but Page one increased as elevating the air temperature. As Alexandre et al. (2013) studied the drying kinetics of the enriched pineapple residual, the authors discovered that the "k" parameter of the Henderson and Pabis and Page models increased with the temperature, as analyzing temperatures between 40 and 60°C.

The "n" parameter displayed a tendency to increase the values as increasing the temperature (Table 3). The observed values agree with Leite et al. (2017). The authors studied the kinetics of pineapple bark drying and observed an increase of the "n" values in the Page model as increasing the drying temperature (Table 2).

The "a" parameter of the two-terms exponential and Henderson and Pabis models increased as increasing temperature. Filho et al. (2016) observed the opposite, using the Henderson and Pabis model to adjust the mangoes cv's foam-mat drying curves. Haden at the temperatures of 50, 60, and 70°C with three layers of thickness.

As the two-terms exponential model refers to, the present work observed an increase of the "a" and "k" parameters, increasing the drying temperature. This observation partially corroborates with Guimarães et al. (2017), as the authors assessed the kinetics of foam layer drying of the 'Keitt' mango. The authors described an increase of the "k" parameter as the temperature increased. The "a" parameter, on the other hand, did not display any tendency as the temperature increased.

Figure 2 displays the pineapple juice with mint in the foam-mat drying curves at the temperatures of 60, 70, and 80°C adjusted by the Page mathematical model.

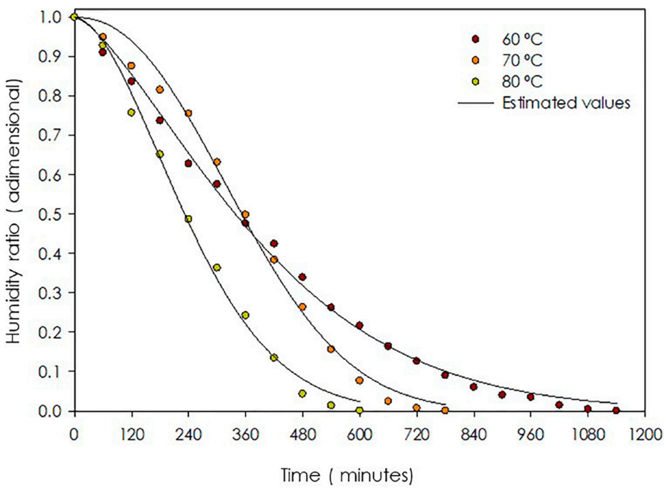

Figure 2. Drying kinetics for the 1.0 cm thickness at different temperatures, adjusted by the Page model.

Guimarães et al. (2017) assessed the foam layer drying kinetics of 'Keitt' mango. The authors fitted the data to the Page, Henderson and Pabis, Logarithmic, and two-terms exponential models, and observed that the Page model best fitted the experimental data of the drying curves.

The result described by Guimarães et al. (2017) agrees with Khanlari et al. (2014), who assessed the drying kinetics of the tomato pulp, and concluded that the Page model best fitted the drying data, as presenting the highest R^2 adjusted for the tomato pulp drying in different conditions.

Table 3 displays the mean values and the respective standard deviations of the pineapple powders' physicochemical parameters with mint obtained by foam-mat drying at 60, 70, and 80°C.

The dusted pineapple juice's pH values with mint obtained at different temperatures displayed significant differences (Table 3). The rise of the drying temperature caused an increase in the pH values. According to Araújo et al. (2015), this suggests precipitation and oxidation of the organic acids, which corroborates with reducing the titratable acidity as the drying temperature increased.

Water content decreased as the temperature increased—the higher the drying temperature, the lower the final product's water content. The opposite occurred with the total solids, which means a concentration of the solids occurred (Table 3). Nunes et al. (2017) studied the influence of the drying temperature on pineapple residuals' physico-chemical properties at the same temperatures of the present study. The authors observed the same water content decreasing reduction according to the increase of the used temperature.

Coradi et al. (2016) claimed that decreasing the water content is due to the temperature difference between the product and the drying air. As increasing the drying temperature, there is a higher heat transference, and there is a higher water loss in the product, which decreases the water content.

Independently from the drying temperature, the elaborated product is in agreement with the resolution of the collegiate board (*Resolução da Diretoria Colegiada*, RDC) number 272 of Thursday, September 22, 2005, of the national agency of Sanitary surveillance (*Agência Nacional de Vigilância Sanitária*: ANVISA), establishing a maximum 25% water content in dry or dehydrated fruit products (Brasil, 2005).

As the soluble solids rate (°Brix), the drying temperature increase caused an increase in these components, mainly water-soluble sugars. According to

Baptestini et al. (2018), the increase of drying temperature promotes the nutrients' concentration, as it removes a higher amount of water from the product, resulting in lower water content. The opposite happens with the soluble solids that increase (Table 3).

Table 3. Physico-chemical properties of the pineapple with mint juice dehydrated at 60, 70, and 80°C.

Parameter	**Drying temperature (°C)**		
	60	70	80
pH	3.35± 0.01 b	3.93± 0.01a	3.87± 0.01a
Titratable acidity (g of citric acid.100g^{-1})	3.85± 0.02a	3.61± 0.02 b	2.77± 0.02c
Water content (%b.u.)	6.41± 0.08a	4.99± 0.08 b	3.74± 0.08c
Total solids (%)	93.59± 0.08c	95.01± 0.08 b	96.25± 0.08a
Soluble solids (°Brix)	24.67± 0.06 b	30.67± 0.06a	30.67± 0.06a
Ascorbic acid (mg.100g^{-1})	15.53± 0.26c	32.04± 0.26a	29.16± 0.26 b
Solubility (%) (s^{-1})	52.33± 0.69a	36.67± 0.69 b	34.33± 0.69 b
L*	66.28± 0.42 b	69.93± 0.42a	64.89± 0.42 b
a*	5.56± 0.15 b	5.72± 0.15 b	7.47± 0.15a
b*	30.25± 0.32 b	33.29± 0.32a	34.45± 0.32a

Means followed by the same do not differ significantly according to Tukey's test at 5% probability.

The ascorbic acid (Vitamin C) is one of the most sensitive vitamins to heating end oxygen exposition. For these reasons, it can be partially or totally destroyed by the drying process. On the other side, dehydration at higher temperatures may help inactivate the enzyme ascorbate oxidase, promoting the degradation of the ascorbic acid (Maharaj & Sankat, 1996).

The lowest vitamin C content was observed at 60°C, probably due to the more extended exposition and low ascorbate oxidase inactivation efficiency. Simultaneously, the dehydrating the juice at 80°C, there could have been an excessive high-temperature exposition, indicating the partial loss of the compound. The sample dried at 70°C displayed a higher constituent concentration due to the intermediate temperature and time.

Silva et al. (2008) studied the tamarind pulp's foam-mat drying at 50, 60, 70 e 80 °C. The authors observed that the exposition at the highest temperature (80°C) reduced the drying time and produced higher ascorbic acid stability in the final product.

The powder juice dehydrated at the 60°C temperature displayed the most rapid solubility (Table 3). Pelegrine & Gasparetto (2005) and Pereda et al. (2005) claim that solubility depends on the juice's proteins. An excessive heat exposition causes denaturation of the proteins' sulfhydryl (-SH) groups, increases the formation of hydrophobic groups on the proteins' surface, affecting the juice's solubility.

As it refers to the color, table 3 highlights that the juice dehydrated at 70°C displayed a higher luminosity (L*). As to the (a *) value, the drying temperature increase increased the red intensity (+a*). Karin & Chee-Wai (1999) also observed the same behavior as studying the star fruit pulp's foam-mat dehydration at the 80°C and 90°C temperatures.

The same authors claimed that the darkening might be non-enzymatic, or sugars' caramelization during the drying process. The mean yellow intensity values (b*) also increased as the drying temperature was increasing. The 60°C values differed significantly from the 70 and 80°C values, which statistically equal each other.

Quek et al. (2007) observed the same behavior as they studied the influence of air temperature (145, 155, 165, and 175 °C) on watermelon pulp drying. The authors observed that the yellow intensity (b*) also increased as increasing the drying temperature.

Conclusions

The Page model was the one that best fitted to foam-mat drying of pineapple juice with mint at the different studied temperatures.

As increasing the drying temperature, acidity and the water content reduced, and, at the same time, the soluble solids rate increased.

The samples dried at 70 °C displayed higher stability of the ascorbic acid and a lower darkening.

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