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Foam mat drying of Tommy Atkins mango: Effects of air temperature and concentrations of soy lecithin and carboxymethylcellulose on phenolic composition, mangiferin, and antioxidant capacity

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ABSTRACT

In this study, foam mat drying was applied to Tommy Atkins mango. Using a multifactorial design, the effect of soy lecithin (L) and carboxymethylcellulose (CMC) used as foam stabilizers (0–1.50 g/100 g), as well as temperature (T) (53–87 °C), on phenolic content and antioxidant capacity of mango were evaluated. Mango pulp contains antioxidant, such as mangiferin, that can be utilized in foods to enhance their functional properties. Our results indicated that L and T had negative effects ($p < 0.05$) on the phenolic content and antioxidant capacity, whereas CMC had a positive effect ($p < 0.05$). Increasing the total amount of phenolic compounds present in dried mango contributed to the higher antioxidant capacity after the drying process. This study concluded that a drying T of 80 °C, and a concentration of 0.30 g/100 g of CMC and L are optimal for increased retention of phenolic compounds and antioxidant capacity.

1. Introduction

Mango (*Mangifera indica*) is an important tropical fruit that is extensively consumed in many countries because of its sweet taste, exotic flavor, and succulence. This fruit is considered to be a health food due to the presence of bioactive compounds, such as phenols, carotenoids, and vitamin C (Cheema & Sommerhalter, 2014). These bioactive compounds are widely used as functional food ingredients because of their potential health benefits. For example, the bioactive compounds present in mangoes have been reported to lower blood cholesterol, regulate blood glucose levels, and display anticarcinogenic effects (Ajila & Prasada Rao, 2013). Thus, mangoes are a good source of beneficial phytochemicals, and devising appropriate processing techniques that enable the retention of the bioactive compounds from fresh-cut mangoes is critical for their ability to provide health-promoting effects (Sogi, Siddiq, & Dolan, 2015).

The beneficial effects of mangoes have been attributed to polyphenols. In mango, one of the most prominent polyphenols identified was mangiferin. This polyphenol is an antioxidant with strong radical scavenging activity that also has the ability to chelate metals and displays multiple pharmaceutical properties. Other phenolics, such as quercetin and gallic acid, are also present in mango leaves, and they have been reported to exhibit anti-inflammatory, anticarcinogenic, and gene regulation effects along with other biological properties (Fernández-Ponce, Casas, Mantell, & Martínez de La Ossa, 2015).

Mangiferin is widely known as an ingredient of natural remedies in many parts of the world, with the natural Cuban medicine Vimang being the best-known example. Vimang is extracted from mango stem bark, and has been shown to have antioxidant, anti-inflammatory, and antiviral effects. Although mangiferin is present in all mangoes, the concentration of mangiferin varies significantly depending on the mango cultivars (Hewavitharana, Tan, Shimada, Shaw, & Flanagan, 2013). Furthermore, Luo et al. (2012) described that mangiferin is found primarily in the shell, with concentrations ranging from 0.04 to 7.34 mg/g from a Chinese mango. However, because of mangiferin's biological activity, the concentration of

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mangiferin in the edible parts of the fruit has attracted the attention of many researchers.

While being a good source of bioactive compounds, fresh mangoes are susceptible to decomposition because of their high water content and nutrients. The mango is a seasonal fruit, and its industrialization has grown in recent years as a way to reduce losses during the harvest period. The mango is also widely popular internationally, and its processing is of high importance to decrease excess crop losses (Henrique, Silvério, Neto, & Pasquini, 2013), specially in Brazil, which is a producer and exporter of this fruit (Ribeiro, Lima, Trindade, Neto, & Ristow, 2014).

Drying can help preserve the nutrients, biologically active compounds, and antioxidant properties of the fruit (Sogi et al., 2015). Additionally, dried products provide greater total value, generate higher revenues, and provide new jobs to the country. In particular, dehydration is a processing method that leads to obtaining stable products and offers new products to consumers (Martínez et al., 2012).

In the foam mat drying process, a liquid is converted into a stable foam by adding gas and foaming agents. The food is dried by the application of hot air, resulting in a dried powder. Due to the porous structure of the foam and the large surface area, the mass transfer rates are increased compared to the solid food, which leads to a shorter period of dehydration and a product with higher quality. As a result of the low drying times, the nutrients can be preserved, and the browning rates are considerably lower. Therefore, the use of appropriate drying conditions is of fundamental importance to the quality of the final product (Franco, Perussello, Ellendersen, & Masson, 2015).

The objective of this work was to investigate the effect of different experimental parameters for foam mat drying of mango, such as drying T and concentrations of the foam stabilizers L and CMC, on the concentrations of phenolic compounds, including the glycosylated xanthone mangiferin, and antioxidant capacity of the dried mango obtained.

2. Materials and methods

2.1. Samples and reagents

Tommy Atkins mangoes with green-purple peel, firm texture, and light yellow flesh were selected in a Brazilian supermarket. Fruits were washed and peeled manually. The pulp was generated using a blender (Metvisa®), refined by sieving, and potassium metabisulfite (200 mg/kg) was added. A pulp sample (200 g) was lyophilized (control) using a lyophilizer L108 (Liotop®) at −54 °C. The foam mat drying technique was employed in 16 different conditions, varying the concentrations of the foaming agents carboxymethylcellulose (CMC) and soy lecithin (L), as well as the drying temperature (T). The mango pulp was transformed into a foam using a mixer (G. Paniz®), the foam was spread on trays that were then taken to an oven with forced ventilation, and it was dried to obtain a porous film. The drying was terminated based on the final water activity (Aw) near 0.4. Aw was measured by a digital water meter (Etec®). The dried mango was packaged in polyethylene bags and stored at −80 °C until analysis.

The extraction solvents were of analytical grade. Water was purified in a NANOpure® DIamond™ system (Barnsted Inc. Dubuque, IO). The chromatographic solvents (methanol and acetonitrile) were purchased from Fluka (Madrid, Spain). ABTS (2,2-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid)) diammonium salt), Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), and phenolic standards were purchased from Sigma-Aldrich (Madrid, Spain).

2.2. Experimental design

A multifactorial design was used to determine the effect of the different concentrations of L, and CMC, as well as the different T, on the concentration of mango phenolic compounds and antioxidant capacity, using a 2^3 full-factorial central composite rotational design (CCRD) with six axial points ($\alpha = 1.68$), and two replicates at the center point, totaling 16 experiments (Rodrigues & Iemma, 2009), as described in Table 1. The results were analyzed using the software program Statistica 8.0 (Statsoft Inc. 2325, Tulsa, OK, USA). The factors and interactions had a significant influence on responses when $p < 0.05$ for a confidence level of 0.95. A Pareto diagram was used to represent the effect of factors where the sign indicated a positive or negative effect caused by the experimental variable. Moreover, a response surface plot and empirical correlations were estimated to predict the most favorable conditions for retention of polyphenols and the antioxidant capacity of the samples.

Table 1
Coded and real (between parenthesis) variable values for each experimental condition of the Central Composite Rotable Design (CCRD) 2^3 and drying time, phenolic content and antioxidant capacity obtained.

Treatment	CMC (g/100 g)	L (g/100 g)	T (°C)	Drying time (min.)	Phenolic content[a] (mg/ 100 g)*	Mangiferin (mg/100 g)	Antioxidant capacity (mmol TE/100 g)*
1	−1 (0.30)	−1 (0.30)	−1 (60)	375	81.79	0.19	653.92
2	1 (0.75)	−1 (0.30)	−1 (60)	370	93.90	0.30	689.33
3	−1 (0.30)	1 (1.20)	−1 (60)	360	87.47	0.26	606.32
4	1 (1.20)	1 (1.20)	−1 (60)	340	76.85	0.28	640.95
5	−1 (0.30)	−1 (0.30)	1 (80)	140	116.93	0.33	772.95
6	1 (1.20)	−1 (0.30)	1 (80)	200	103.28	0.31	630.79
7	−1 (0.30)	1 (1.20)	1 (80)	180	48.30	0.38	175.37
8	1 (1.20)	1 (1.20)	1 (80)	210	65.09	0.04	432.89
9	−1.68 (0)	0 (0.75)	0 (70)	245	95.32	0.38	503.58
10	1.68 (1.50)	0 (0.75)	0 (70)	220	103.04	0.25	520.59
11	0 (0.75)	−1.68 (0)	0 (70)	285	91.01	0.27	825.24
12	0 (0.75)	1.68 (1.50)	0 (70)	245	90.02	0.22	565.62
13	0 (0.75)	0 (0.75)	−1.68 (53)	380	101.43	0.40	386.05
14	0 (0.75)	0 (0.75)	1.68 (70)	120	59.79	0.26	318.69
15	0 (0.75)	0 (0.75)	0 (70)	265	77.20	0.16	352.68
16	0 (0.75)	0 (0.75)	0 (70)	285	75.23	0.10	353.38

[a] Sum of all individual phenolic compounds.
* Values on dry basis.

2.3. Extraction of phenolic compounds

The control and dried mango (0.5 g) were extracted with 10 mL of 80% methanol containing 0.1% of concentrated hydrochloric acid (v/v). The mixture was sonicated for 15 min. The remaining residue was subjected to two further extractions with 5 mL of solvent and 5 min sonication, and the supernatants were combined, filtered using Whatman filter paper No. 1, and dried under vacuum to obtain the extract. The residue was dissolved in 1500 μL 0.01% formic acid in water (solvent A) and filtered through a 0.45-μm nylon filter. The extracts that were obtained were used for the determination of individual phenolic compounds by UHPLC-DAD, and antioxidant activity was measured by ABTS assay.

2.4. Analysis of phenolic compounds by UHPLC-DAD

Analyses were carried out in an Agilent 1260 chromatograph (Agilent Technologies, Palo Alto, CA, USA) equipped with a diode-array detector, which was set to scan from 200 to 770 nm, and a C18 Eclipse Plus 120 column (1.8 μm, 50 × 2.1 mm). The solvents were 0.01% formic acid in water (solvent A), and acetonitrile (solvent B) at the following gradient: 0–5 min, 5% B linear; 5–20 min 50% B linear; 20–25 min, 100% A linear, washing and re-equilibration of the column. The flow-rate was 1.0 mL/min, and the temperature of the column was set at 25 °C.

Phenolic compounds were identified by their retention time, and UV–vis spectroscopic characteristics using those of standards. The quantification was carried out by external calibration from the areas of the chromatographic peaks obtained by DAD detection at 280 nm. The corresponding calibration curves were made up of the following standards: gallic acid, protocatechuic acid, vanillin acid, chlorogenic acid, mangiferin, caffeic acid and *p*-coumaric acid.

Each extract was injected two times to quantify each compound, and the results are expressed as mg phenolic compound/100 g of dry matter. Total phenolic compounds were estimated by totaling the sum of each individual phenolic compound identified by UHPLC-DAD.

2.5. ABTS/persulphate assay

The ABTS radical cation was produced by the oxidation of 7 mM ABTS with potassium persulphate (2.45 mM) in water. The mixture was allowed to stand in the dark at room temperature for 16 h before use, and the ABTS radical cation solution was subsequently diluted with phosphate buffered saline (PBS) at pH 7.4 to give an absorbance of 0.7 ± 0.02 at 734 nm. The phenolic extracts (50 μL) were mixed with 2 mL of the ABTS radical cation diluted solution, vortexed for 10 s, and the absorbance measured at 734 nm after 5 min and 30 s of reaction at 30 °C.

Different dilutions of each extract were assayed, and the results were obtained by interpolating the absorbance on a calibration curve obtained with Trolox (30–1000 μM). Three independent experiments were performed for each of the assayed extracts, and the results are expressed as Trolox-equivalent antioxidant capacity (TEAC; mmols of Trolox with the same antioxidant capacity as 100 g of the studied extract).

3. Results and discussion

3.1. Drying of mango

Table 1 shows the drying time, total phenolic compounds and antioxidant capacity measured by the ABTS assay in the dried mango for each condition studied in the experimental design. The drying time was different for the different concentrations of stabilizers and the different temperatures. Mango pulp was dehydrated for 120–380 min. The drying time of mango pulp increased when the temperature decreased, but in all conditions the foam mat drying time was minimal. This finding may be observed because moisture migration is high in a foam during the drying process. The rate of moisture removal in the foamed mango pulp was very high because the water present in the foamed pulp was in the form of thin films, making it easy for the water to vaporize. These drying results are consistent with the results reported by Thuwapanichayanan, Prachayawarakorn, and Soponronnarit (2008) for bananas. The foam mat dried product had desired properties, such as the ability to rehydrate, a consistent density, and the retention of volatiles that would be lost during the drying of non-foamed materials. This may be due to its lower time of exposure to high temperature of processing. Drying was completed under each condition until the sample reached the Aw value of approximately 0.4. The low water activity in the final product can minimize the growth of microorganisms, and thus is related to the stability of the product. The dried samples were subsequently used to evaluate the content of phenolic compounds and antioxidant capacity.

3.2. Phenolic contents and antioxidant activity

Fig. 1 depicts the results from the chromatograms that were recorded at 280 nm with the profile of the lyophilized mango pulp (control), and Table 2 shows the concentrations of phenolic compounds determined by UHPLC. A total of 21 phenolic compounds were identified and quantified in lyophilized mango and foam mat dried mango. The phenolic compounds identified can be classified in three groups: benzoic acids (gallic, protocatechuic, p-hydroxybenzoic and vanillic acids), hydroxycinnamoyl derivatives (*p*-coumaric, *m*-coumaric, chlorogenic and caffeic acids), and mangiferin, a C-glucoside-xanthone. The sum of the compounds from the group of benzoic acid has its highest value in the lyophilized mango pulp (44.28 mg/100 g), followed by the hydroxycinnamoyl derivatives group (20.07 mg/100 g), and the glycosylated xanthone mangiferin represented 0.22 mg/100 g. The order of phenolic compounds in lyophilized Tommy Atkins mango pulp from the most abundant to the lowest was derivatives *p*-hydroxybenzoic (19.08 mg/100 g), gallic (18.52 mg/100 g), caffeic (7.76 mg/100 g), derivatives of coumaric (6.56 mg/100 g), chlorogenic (5.53 mg/100 g), protocatechuic (3.32 mg/100 g), and vanillic (1.34 mg/100 g) acids, and the xanthone mangiferin (0.22 mg/100 g).

The results displayed in Table 1 show that there was large variation in the amount of the total phenolics content of dried mango (46.18–116.93 mg/100 g) for mango pulp dried using the different

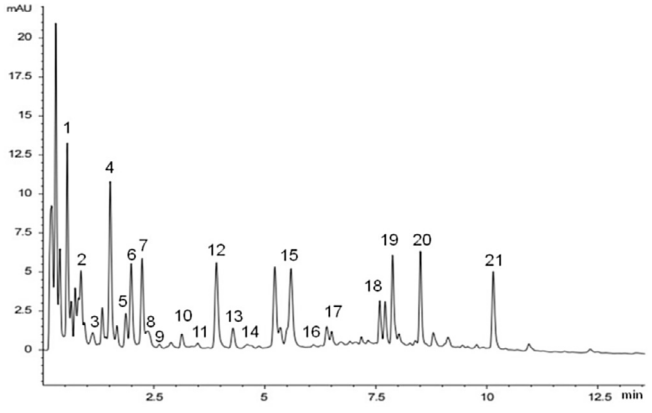

Fig. 1. Chromatographic profile of the phenolic compounds identified in lyophilized mango pulp.

Table 2
Phenolic content in mango pulp (control) and foam mat dried mango, expressed as mg/100 g on dry basis.

Phenolic compounds	D1p-hydroxybenzoic acid (1)	D2p-hydroxybenzoic acid (4)	p-hydroxybenzoic acid (8)	D3p-hydroxybenzoic acid (21)	Gallic acid (2)	D1gallic (3)	D2gallic (5)	D3gallic (6)	D4gallic (10)	D5gallic (14)	Ethyl gallate (16)
Control	6.39	7.22	1.49	3.98	5.14	1.26	2.48	6.20	2.29	0.93	0.22
Treatment											
1	13.01	11.53	2.79	5.37	10.68	1.54	4.73	7.99	2.88	1.83	0.67
2	13.98	12.34	2.86	5.45	11.67	2.44	4.83	8.99	3.66	1.84	0.66
3	12.52	11.98	2.66	5.51	9.93	1.77	4.16	9.16	3.13	1.71	0.36
4	10.87	10.04	2.46	4.35	5.31	1.78	3.12	6.54	4.14	1.45	0.31
5	14.89	14.77	3.61	6.47	21.09	6.17	5.41	9.59	4.28	2.36	0.77
6	13.15	12.83	2.92	5.95	10.89	4.71	4.68	9.02	3.98	2.03	0.35
7	5.24	5.09	1.19	2.18	1.85	3.66	0.98	2.42	0.50	0.60	0.23
8	8.79	8.49	2.09	4.75	5.56	2.39	2.99	6.20	4.49	1.32	0.50
9	10.74	10.41	2.17	5.49	8.92	3.18	3.50	7.76	3.70	1.40	0.30
10	13.36	12.61	2.74	6.27	16.09	2.69	4.70	9.67	3.63	1.82	0.51
11	11.81	11.06	2.15	5.29	14.07	1.89	4.34	8.91	2.10	1.43	0.30
12	11.45	11.37	2.34	5.52	8.90	3.79	3.57	8.76	5.13	1.66	0.36
13	15.67	13.12	3.37	5.85	12.82	1.96	4.99	7.08	3.41	1.92	0.70
14	7.59	6.94	2.02	2.69	6.70	4.29	2.22	2.55	2.24	1.14	0.20
15	10.56	9.62	2.61	4.29	10.53	3.1	3.44	4.75	4.73	1.50	0.30
16	6.37	5.60	1.58	2.42	1.88	1.59	1.05	1.95	1.14	0.69	0.29

Phenolic compounds	Protocatechuic acid (7)	DVanillic acid (9)	Vanillic acid (11)	Dp-Coumaric acid (12)	p-Coumaric acid (17)	m-Coumaric acid (19)	DCaffeic acid (20)	Caffeic acid (13)	Chlorogenic acid(15)	Mangiferin (18)
Control	3.15	0.49	0.79	3.24	0.54	2.20	5.59	1.72	5.25	0.22
Treatment										
1	4.21	0.69	1.17	1.85	0.84	1.37	4.45	1.42	2.49	0.19
2	4.62	0.79	1.09	2.86	0.76	2.16	7.04	1.55	4.01	0.30
3	4.81	0.75	1.20	2.67	0.86	1.90	6.10	1.59	4.44	0.26
4	5.12	0.67	1.18	3.10	0.82	2.12	6.69	1.59	4.91	0.28
5	5.53	0.77	1.12	2.85	0.93	2.15	7.08	1.82	4.94	0.33
6	6.98	0.79	1.59	3.53	1.04	2.41	7.13	2.31	6.68	0.31
7	0.96	0.18	0.20	3.94	0.27	3.10	9.62	0.31	5.40	0.38
8	8.21	1.08	1.19	0.54	1.31	0.38	0.99	2.94	0.84	0.04
9	4.89	0.77	0.81	5.53	0.86	3.85	10.27	1.76	8.63	0.38
10	5.64	0.77	0.90	3.46	0.95	2.38	6.58	1.95	6.07	0.25
11	4.61	0.64	0.72	3.59	0.76	2.75	7.00	1.65	5.67	0.27
12	5.80	0.81	1.12	3.15	1.00	2.14	5.79	2.05	5.09	0.22
13	4.41	0.63	0.83	3.95	0.68	2.96	9.59	1.40	5.69	0.40
14	2.82	0.42	0.49	2.62	0.50	1.89	6.09	0.97	5.15	0.26
15	5.91	0.72	1.03	1.94	0.91	1.31	3.97	2.07	3.69	0.16
16	1.61	0.24	0.29	4.40	0.24	2.73	4.42	0.51	6.81	0.37

Table 3
Regression coefficients for phenolic content and antioxidant capacity of foam mat dried mango.

Variable with statistically significant effect	Regression coefficient	Standard error	t(1)	*p* value
Phenolic content				
Mean	76,89	0,98	78,30	0,008
Lecithin (L) x temperature (L)	−11,93	0,98	−24,25	0,026
Lecithin (L)	−8,78	0,75	−23,29	0,027
Temperature (L)	−5,59	0,75	−14,84	0,042
Carboxymethylcellulose (Q)	6,54	0,91	14,29	0,044
Antioxidant capacity				
Mean	348,55	0,34	999,01	0,0006
Lecithin (L) × temperature (L)	−87,43	0,35	−499,64	0,0012
Carboxymethylcellulose (L) × Lecithin (L)	49,86	0,35	284,92	0,0022
Carboxymethylcellulose (L) × temperature (L)	5,66	0,35	32,37	0,0196
Carboxymethylcellulose (L)	15,68	0,26	117,03	0,0054
Carboxymethylcellulose (Q)	66,86	0,32	410,69	0,0015
Lecithin (L)	−97,29	0,26	−726,11	0,0008
Lecithin (Q)	131,82	0,32	410,69	0,0015
Temperature (L)	−50,69	0,26	−378,30	0,0016
Temperature (Q)	10,28	0,32	63,14	0,0100

conditions. Lower total phenolic values were observed using the seventh and fourteenth drying conditions (48.30 mg/100 g and 59.79 mg/100 g, respectively) compared with mango pulp that was freshly lyophilized (60.79 mg/100 g), but all other conditions that were evaluated resulted in higher total phenolic contents compared to the control.

It is has been reported that phenolic acids primarily exist in bound structures esterified to oligosaccharides or polysaccharides and form bridges between the polymer, in free or bound form, which would affect their behavior during processing, and eventually their bioavailability for absorption and subsequent physiological effects (Abdel-Aal & Rabalski, 2013). In the present study, the increased amount of the total phenolic content in the dried samples, relative to the control sample, was possibly due to the thermal processing because it most likely facilitates the extraction of the phenolic compounds that are linked to the food matrix. This thermal process causes a number of physical and chemical changes in foods, such as starch gelatinization, protein denaturation, component interactions, and disruption of plant cell wall polymers. Consequently, cell wall phenolic compounds or bond phenolics can be released, thus causing free phenolic compounds to increase in the samples (Ragaee, Seetharaman, & Abdel-Aal, 2014). This suggests that the various food processing methods may alter the total phenol content and/or phenolic composition, and may positively or negatively affect the content of phenolic compounds, which will possibly impact their bioactive properties and health benefits (Ragaee et al., 2014). Consistent with our findings, Hamrouni-Sellami et al. (2013) reported a range of values of the total phenolic contents depending on the plant material, which indicates that the drying process may result in different levels of phenol content depending on the type of phenolic compounds present and their location in the cell. In agreement, Mueller-Harvey (2001) reported that the thermal processing may release more bound phenolic acids from the breakdown of cellular constituents. Similarly, Choi, Lee, Chun, Lee, and Lee (2006) and Jeong et al. (2004) reported that heat treatment might disrupt the cell wall and liberate phenolic compounds from the insoluble portion of the plant. In contrast, Dorta, Lobo, and Gonzalez (2012) observed in mangoes that oven-drying with forced air resulted in degradation of phenolic compounds, which caused a lower antioxidant activity. One possibility for this discrepancy is that the thermal process and oxidative degradation of phenolic compounds was caused by long drying time. In our study, the chromatographic analysis showed that the foam mat drying process applied using the different conditions exhibited a different quantitative phenolic profile. However, the quality profile did not differ notably among the samples as a function of the foam drying process.

Table 3 depicts the results of the statistical analysis of the CCRD used to verify the effects of the L and CMC concentrations, and T on the total phenolic compounds and antioxidant capacity of the foam mat dried samples that were analyzed, showing the regression coefficient, the standard error, and the values of t and p. A value $p < 0.05$ was used indicate a significant effect of the variable on total phenolic content and antioxidant capacity. Only variables with $p < 0.05$ are shown in Table 3, which were those that had a significant effect on the total phenolic content, i.e., mean, interaction of L (linear effect) and T (linear effect), L (linear effect), T (linear effect) and C (quadratic effect). Fig. 2A shows Pareto diagrams that were generated from the statistical analysis on the effects of the different processing variables on the total phenolic concentration of foam mat dried mango pulp. The effects with values located to the right of the dashed line were those significant at 5% level of significance. These parameters were included in the model shown in Eq. (1), were Y is the total phenolic content (mg/100 g), x_1 is the variable L concentration, x_2 is the variable drying T, and x_3 is the variable CMC concentration.

$$Y = 76.89 - 11.93x_1x_2 - 8.78x_1 - 5.60x_2 + 6.55x_3^2 \quad (1)$$

The results from the analysis of variance (ANOVA) for the model shown in Eq. (1) are summarized in Table 4, along with the coefficient of determination (R^2), F calculated, and F tabulated. According to the ANOVA, the Fisher's F-value for the phenolic content calculated (88.98) was higher than the F tabulated value ($F_{4;\ 11;\ 0.05} = 3.86$), which allowed us to accept the codified model. However the R^2 that was obtained (0.657) only made it possible for the model to explain 65.72% of the observed variation in the total phenolic content. According to the results obtained with the statistical analysis, the total phenolic content of foam mat dried mango is inversely proportional to the amount of L and T, and the effect is additive between these variable. However, the total phenolic content increased with increasing concentrations of CMC. Furthermore, these results indicate that high concentrations of total phenolic compounds can be obtained from foam mat dried mango pulp with small levels of L and T. In addition, due to the quadratic effect of CMC, high total phenolic contents were obtained when CMC concentrations were the lowest or the highest used in this study, but the intermediary concentrations decreased the total phenolic content.

The results obtained for the total phenolic compounds indicated that the foam mat drying process for mango pulp is an efficient

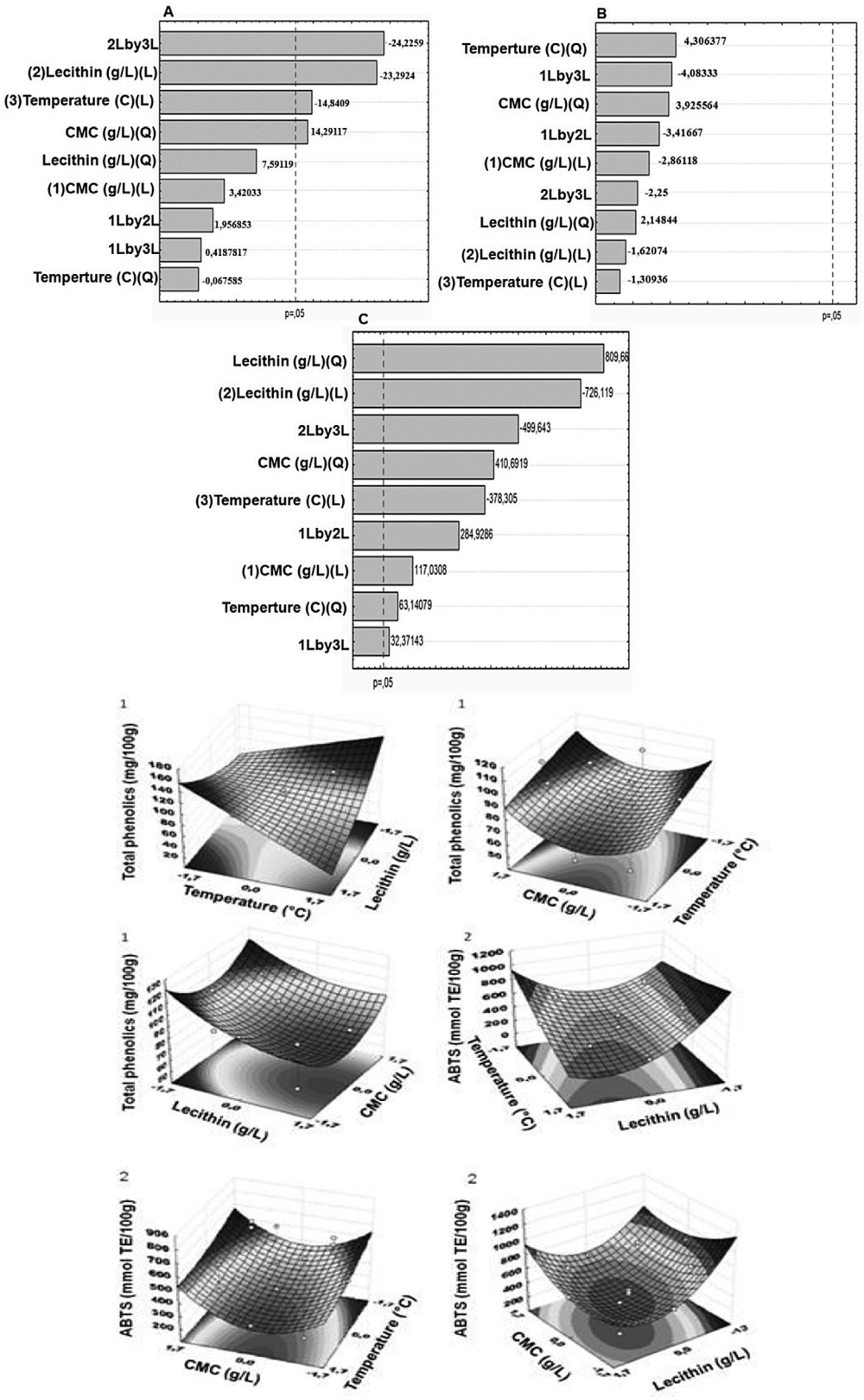

Fig. 2. Pareto diagram for the phenolic content (A), mangiferin (B) and antioxidant capacity (C) and Response surface for the phenolic content (1) and antioxidant capacity (2).

method for the retention of the bioactive compounds, and different drying conditions did not change the qualitative profile of the phenolic compounds in mango pulp. However, the concentrations of the individual phenolic compounds could change during the drying process. Increasing the phenolic compounds content in dried mango pulp in some conditions may result in a product with better functional properties.

In contrast, statistical analysis for the mangiferin concentration in the dried samples showed no significant effects for CMC, L, or T when using foam mat drying ($p > 0.05$), suggesting that mangiferin

Table 4
Acceptance of the statistical model for phenolic content and antioxidant capacity of foam mat dried mango.

Source of variation	Sum of squares	Degree of freedom	Mean square	$F_{calculated}$
Phenolic content (R^2 0.657)				
Regression	4667.06	4	1166.76	88.98
Residual	144.24	11	13.11	
Total	4811.30	15	320.75	
Antioxidant capacity (R^2 0.915)				
Regression	480,318.60	9	53,368.73	1,601,062.00
Residual	0.20	6	0.03	
Total	480,318.80	15	32,021.25	

aids in stabilizing the mango pulp under the different conditions using in the foam mat drying processing. Fig. 2B shows Pareto diagrams obtained from the statistical analysis of the effects of the processing variables on mangiferin concentration for foam mat dried mango pulp. The effects with values located to the left of the dashed line were not significant at 5% level of significance. Previously, Sanugul et al. (2005) described a mechanism of action for mangiferin, indicating that the heterosidic binding in this xantone occurs through a carbon-carbon bond, which makes it more resistant to acid, alkali and enzymatic hydrolysis than are other phenols. This finding may partially explain the results obtained for mangiferin because mango is an acidic fruit and the pulp was submitted to heat during the process. However, Ichiki et al. (2007) studied mangiferin stability during the drying of rhizome of *Anemarrhena asphodeloides*, a medicinal plant used in Japan, and the authors noted that mangiferin was thermally unstable. Specifically, these researchers observed that mangiferin retention was dependent on drying conditions because mangiferin content tended to decrease remarkably with increasing temperature (from 30 °C to 80 °C) for samples having high thickness, whereas samples treated at the same temperatures, but having thin thickness showed a slight decrease in the mangiferin content at the higher temperature. In addition, they showed that the rhizome thickness influenced the drying time, which ranged from 16 to 61 days in the group with high thickness, and from 10 to 30 days in the thin group. One advantage of the drying method used in the present work were the low drying times, that varied from 120 to 380 min, depending on the specific processing conditions. This may explain the retention in mangiferin concentration observed after foam mat drying of mango pulp because short drying times were observed for all of the evaluated conditions. Notably, short drying times observed in the present work were possible due to the transformation of mango pulp in a stable foam before drying.

Berardini et al. (2005) and Dorta et al. (2012) reported that the pulp is generally poor in polyphenols for bananas and mangoes. It has also been observed that the mangiferin content in mango peels ranges from one to four times more than the pulp content (Ruiz-Montañez et al., 2014). Differences among the extraction methods, such as temperature, agitation, and extraction time have been attributed to the variables that interfere with the concentration of mangiferin (Sharapin, 2000). The results obtained in the present work demonstrate stability of mangiferin concentration in foam mat dried mango pulp. This finding is important because the presence of mangiferin in dried mango pulp can increase the incorporation of this bioactive component in formulated foods.

The ABTS assay indicated a high level of antioxidant capacity in mango pulp after the foam mat drying treatment (Table 1). Specifically, the antioxidant capacity of the control sample showed an initial antioxidant value of 325.58 mmol TE/100 g dry basis, whereas the treated samples had higher values compared to control in some of the drying conditions (175.37–825.24 mmol TE/100 g dry base). It is important to note that the foam mat drying process is a method used to lower exposure to high temperatures and long processing times, which may explain the high antioxidant capacity in dried samples.

The seventh and fourteenth drying conditions used high concentrations of L (1.20 and 0.75 g/100 g), and high drying T (80° and 87 °C), respectively. Under these conditions the antioxidant capacity (175.37 and 318.69 nmol TE/g) was lower compared to lyophilized mango pulp. These results are in agreement with the total phenolic content determined by UHPLC-DAD. Thus, the use of L and high drying T negatively affects the retention of phenolic compounds, thereby resulting in lower antioxidant capacity. The highest value for antioxidant capacity of the dried sample was found using drying condition 11 (825.24 nmol TE/g) without L. Taken together, the present study confirms that the foam mat drying, in several conditions tested, increases the antioxidant capacity measured in mango pulp by ABTS assay. In contrast, Sogi, Siddiq, Greiby, and Dolan (2013) found a negative effect of the drying on the antioxidant capacity in the seed of Tommy Atkins mango powder using heat, and infrared vacuum.

Table 3 shows that significant effects ($p < 0.05$) were found for the antioxidant capacity after foam mat drying under different conditions of L, T and CMC. These parameters were included in the model shown in Eq. (2), were Y is the antioxidant capacity (mmol TE/g), x_1 is the variable L concentration, x_2 is the variable drying T and x_3 is the variable carboxymethylcellulose concentration.

$$Y = 348.55 - 87.44x_1x_2 + 49.86x_1x_3 - 5.66x_2x_3 - 97.30x_1 + 131.83x_1^2 - 50.69x_2 + 10.28x_2^2 + 15.68x_3 + 66.87x_3^2 \quad (2)$$

The ANOVA for Eq. (2) is summarized in Table 4 along with the coefficient of determination (R^2), the F calculated and the F tabulated for the model. According to the ANOVA, Fisher's F-value for the antioxidant capacity in the present study was higher than the F tabulated value ($F_{9;\ 6;\ 0.05} = 4.10$), and the R^2 that was obtained (0.915) made it possible to validate the codified model because it can explain 91.58% of the observed variation for antioxidant capacity. According to results obtained from statistical analysis, the antioxidant capacity of foam mat dried mango is inversely proportional to the amount of L, and T, and the effect of these variable was additive. These results showed that foam mat dried mango pulp with high concentration of antioxidant capacity can be obtained using low levels of L and T, considering the levels evaluated in this work. However, interactions between L and CMC, T and CMC, and a positive quadratic effect for CMC were also obtained.

The Pareto graphics are shown in Fig. 2. The different parameters have an effect on the antioxidant capacity of foam mat dried mango. There was similarity between the parameters that showed significant effects for the total phenolic compounds (Fig. 2 A) and antioxidant capacity (Fig. 2 C), but these parameters had no effect on mangiferin (Fig. 2 B). Taken together, the result showed that optimization of the experimental conditions make it possible to develop an drying condition that enables the best recovery of antioxidant compounds from mangoes. In the Pareto graphs, the bars that extend beyond the region to the right of the vertical line (where indicated $p = 0.05$) denote the parameters that have a significant effect on the estimated index.

It was observed that the concentration of L also showed a significant negative effect ($p < 0.05$) on the antioxidant capacity. This behavior was similar to the effect observed for total phenolic compounds. Similarly, the interaction between L and T showed a significant negative effect on the antioxidant capacity. The results also indicate that the phenolic compounds and the antioxidant capacity were higher in the absence of L. The positive quadratic effect found

for CMC also followed that observed for the sum of phenolic compounds, indicating that the intermediary value used for CMC concentration caused the minimum antioxidant capacity in foam mat dried mango pulp.

Fig. 2 shows the response surfaces for total phenolic composition and antioxidant capacity according to the variables determined by the mathematical models described above. The curved surfaces represent combinations of factors that cause changes in the assessed responses. Total phenolics (1) and antioxidant capacity (2) increased due to the lower concentration of L and T, especially with the interaction between these parameters. In contrast, the concentration of CMC positively effected the sum of the individual phenolics identified, but with a quadratic effect. Phospholipids, such as L, are natural food grade surfactants, and appear to have the potential for expanded use in food due to their amphiphilic character and viscoelastic properties (Pichot, Watson, & Norton, 2013). In this study, L promoted greater foaming properties for the drying process, which resulted in a high capacity for foam formation and stabilization. This property produced a more porous final powder product that most likely contributed to the oxidative degradation of phenolic compounds due to a high oxygen diffusion during the drying process. Collectively, this likely resulted in L decreasing the antioxidant capacity.

According to the results obtained in the present work, higher concentrations of L had significant negative effect on phenolic compounds and antioxidant capacity of foam mat dried mango pulp. However, the low concentration the L could be particularly important when systems with potential application as carriers of bioactive compounds are considered. In practical terms, the presence of L also facilitates the removal of the dried product from the drying trays, which makes its incorporation in the drying process technologically important. Thus, low concentrations of L should be used in the foam mat drying process for mangoes.

Foam stability is one of the most important features for foam mat drying, and it emphasizes the need for knowledge of the optimal concentrations of the additives used. The results from this study demonstrate that with a quick drying time, a 0.30 g concentration of CMC and L was beneficial, compared to other drying conditions. Consequently, these conditions are favorable for the food industry in order to obtain a product with high concentrations of bioactive compounds, and it does not affect the drying time. Furthermore, L is required as an additive for the formation of a considerable volume of foam for drying. This facilitates the stage of scraping pulp from the trays after the foam mat drying process because it allows the film to become more porous, compared to conditions without L.

The effect of the concentration of CMC in the volume of pulp during foam mat drying was evaluated by Kaushal, Sharma, and Sharma (2011). The authors observed that increasing the amount of CMC (0.5%–3.0%) resulted in a significant increase in the volume of the foam after stirring the processed pulp. However, the maximum increase in foam was observed after mixing the pulp with 2.0% and 2.5% CMC, which remained completely stabilized during the drying step. These authors also observed that below this level (0.5%–1.5%) the foam was unstable during drying, while the pulp with 3.0% CMC formed a thick gel, and both conditions were unsuitable for drying. Notably, these results are different than ours, and might be because the present study used lower levels of stabilizers, and lower drying time was necessary. The possibility of a synergistic effect between L and CMC is also worth consideration because interactions between these factors were observed for the antioxidant capacity.

For the sum of the phenolic compounds, there was no interaction between L and CMC, but there was a positive quadratic effect for CMC. By the response surface graphs, it can be observed that the retention of phenolic compounds decreases at the mid-level (0) for the amount of CMC that was added to form the foam for the drying process. For the antioxidant capacity there was an interaction between L and CMC, and there was also a positive quadratic effect for CMC. Taken together, our data suggest that both additives are beneficial, even in low concentrations. Foam mat drying is a novel method for drying and retaining bioactive compounds. Therefore, future work is necessary to evaluate the bioaccessibility of components from foam mat dried mango that are of interest for consumers and the food industries.

4. Conclusions

This study demonstrated that the process of foam mat drying is adequate to obtain mango powder products with high retention of phenolic compounds, including mangiferin, and antioxidant capacity. The effects of the studied variables were significant for the sum of phenolic compounds and antioxidant capacity. High concentration of L and high drying T decreased the retention of these compounds, whereas the concentration of CMC showed a significant positive quadratic effect on these parameters. In general, the total phenolics and antioxidant capacity of foam mat dried mango were higher compared to lyophilized mango. Our results indicate that a drying T of 80 °C and a concentration of 0.30 g/100 g of CMC and L (featured in the fifth condition of experimental design) are optimal for the operating parameters and can increase the retention of total phenolic and antioxidant capacity relative to the other treatments that were evaluated.

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