Journal of Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2020-077

Research Article

Open Access

Foam Mat Drying of Tommy Atkins Mango: Effects of Air Temperature and Concentrations of Soy Lecithin and Carboxymethylcellulose on Carotenoid Compounds and Colorimetric Parameters

Francine Albernaz Teixeira Fonseca Lobo[1], Josiane Domingues[1], Deborah Falcão[1], Carla Stinco[2], Francisco Rodríguez-Pulido[2], Carlos Eduardo Faria[3], Francisco Heredia[2], Katia Gomes de Lima Araujo[1*] and Dolores Vila[4]

[1]Programa de Pós-Graduação em Ciências Aplicadas a Produtos para Saúde, Faculdade de Farmácia, Universidade Federal Fluminense, Rua Doutor Mário Viana 523, Santa Rosa, Niterói, Brazil

[2]Food Colour and Quality Laboratory, Department of Nutrition and Food Science, Facultad de Farmacia, Universidad de Sevilla, Sevilla, Spain

[3]Nutrition Student, Faculdade de Medicina de Petrópolis, Petrópoilis, Brazil

[4]Department of Analytical Chemistry, Facultad de Farmacia, Universidad de Sevilla, Sevilla, Spain

[*]Correspondence to:
Katia Gomes de Lima Araujo
Programa de Pós-Graduação em Ciências, Aplicadas a Produtos para Saúde, Faculdade de Farmácia, Universidade Federal, Fluminense, Rua Doutor Mário Viana 523, Santa Rosa, Niterói 24241-000, Brazil
Tel: +55 21-2629-9604
E-mail: katia_lima@id.uff.br

Received: November 14, 2019
Accepted: December 31, 2019
Published: January 03, 2020

Citation: Lobo FATF, Domingues J, Falcão D, Stinco C, Rodríguez-Pulido F, et al. 2020. Foam Mat Drying of Tommy Atkins Mango: Effects of Air Temperature and Concentrations of Soy Lecithin and Carboxymethylcellulose on Carotenoid Compounds and Colorimetric Parameters. *J Food Chem Nanotechnol* 6(1): 1-8.

Published by United Scientific Group

Abstract

Mango is an important tropical fruit and a source of bioactive compounds. In this work foam mat drying was used for Tommy Atkins mango pulp. The effects of concentration of the foam stabilizers soy lecithin (L) and carboxymethylcellulose (CMC) (0-1.50 g/100 g) and drying temperature (T) (53-87 °C) were evaluated on the retention of total carotenoid and color parameters using a multilevel factorial design. Carotenoids were determinate by high pressure liquid chromatography method (HPLC-DAD). Carotenoid analysis showed presence of 9-*cis*-, 13-*cis*-, 15-*cis*- and all-*trans*-violaxanthin, luteoxanthin and their derivatives, β-carotene and *cis*-β-carotene. Results of the statistical analysis showed no significant effect of variables studied ($p > 0.05$) on the total carotenoid and β-carotene showing that this preservation method is interesting for obtaining carotenoid compounds rich dried mango pulp, but L had effect ($p < 0.05$) on color parameters L^* and h*ab*. The obtained results indicated that the foam mat drying process was efficient for retention of carotenoids of the mango pulp.

Keywords

Mango pulp, Bioactive compounds, Carotenoids, Foam mat drying, Color indexes

Introduction

Carotenoids are lipid soluble natural pigments responsible for the color of fruits, vegetables and plants, where these substances exhibit antioxidant properties and pro vitamin A activity. In foods, the bioavailability of these compounds is related to different factors, such as physicochemical properties (*trans* or *cis* configuration), the food matrix, processing type or other conditions [1].

Epidemiological data have shown association between decreasing in development of chronic diseases such as cardiovascular, cancer and neurodegenerative disorders and a high consumption of vegetables and fruits, due to the presence of numerous substances with antioxidant activity including vitamins and carotenoids [2].

Mango (*Mangifera indica*) is an important tropical fruit in terms of production and consumption [3] and has high levels of carotenoid content, particularly β-carotene, responsible for its attractive color [4]. This fruit is seasonal, and it

has a short shelf life because of its high moisture content which hinders its utilization by consumers [5]. The mango has great acceptability in worldwide market in the fresh form [3]. However, it is necessary the development of preservation methods in order to extend shelf life and to maintain the bioactive compounds present in the pulp. Mangoes are good sources of beneficial phytochemicals, like mangiferin and carotenoids, and devising effective processing techniques that enable the retention of the compounds which provide health-promoting effects [5].

The industrialization of mango pulp by drying techniques can benefit the productive chain, reducing the excess of crop, improving the distribution and storage between the producers and generating new stable products to consumers in every period of the year [6]. Foam mat drying technique is an alternative for the production, marketing and consumption of mango. By this drying process food in the liquid or semiliquid form is transformed in a stable foam by incorporating air or other gas. The food is dried by application of hot air, until to reach a water activity (Aw) value which prevents the growth of microorganisms and chemical and enzymatic reactions. This method can be used with stabilizers and emulsifiers agents with the objective of keeping the integrity of the foam during the drying, resulting in a short time process when compared to the drying of solid foods [7]. Moreover, the phytosome formation between phospholipid carriers such as soy lecithin and bioactive compounds may influence its bioactivity, since it may increase the absorption of polyphenols and terpenoids from plants. These systems have been developed to improve the oral bioavailability of phytochemicals [8].

Dehydrated powders can be reconstituted into juice and used as a starter for preparation of products like flavor desserts. Thus, dehydrated mangos have promising scope in domestic and market use, because it has reduced weight, volume and lower cost and the packaging and storage and transportation are facilitated. In our previous study, we found the increased retention of phenolic compounds, including the glycosylated xanthone mangiferin and antioxidant capacity in Tommy Atkins mango pulp dehydrated by foam mat drying [9] showing that this preservation method is interesting for obtaining phenolic compounds rich dried mango pulp.

Seeking our goal of studying the process effect on dried food, the objective of this work was to investigate the effect of different experimental parameters for foam mat drying such as drying temperature (T) and concentrations of foam stabilizers like soy lecithin (L) and carboxymethylcellulose (CMC) on the carotenoid concentrations and color parameters of the foam mat dried mango pulp.

Material and Methods

Chemicals

The extraction solvents (hexane, acetone and dichloromethane) were of analytical grade purchased from Carlo-Erba® (Milan Italy). Water was purified in a NANOpure® DIamond™ system (Barnsted Inc. Dubuque, IO). The chromatographic solvents (methanol, acetonitrile and ethyl acetate) were purchased from Fluka® (Madrid, Spain). β-carotene and violaxanthin were purchased from Sigma-Aldrich® (Steinheim, Germany).

Sample

Tommy Atkins mangoes were procured from a market in Rio de Janeiro/Brazil. Fruits were selected for maturity and defects, followed by washing. The pulp sample was obtained by performing manually and the foam mat drying in 17 different conditions varying the concentrations of the foaming agents carboxymethylcellulose (CMC) and soy lecithin (L), as well as the drying temperature (T) was operated in our previous work [9]. Samples were dried in an oven operated with constant air circulation until their Aw reached about 0.4. The dehydrated samples from all 17 conditions were ground using a blender (Metvisa®) and packaged in polyethylene bags and stored at -80 °C until the characterization analyses. To control sample, the pulp (200 g) was dried in a lyophilizer L108 (Liotop®) at -54 °C.

Experimental design

All details of the multifactorial design used were described in our previous work [9] where it was evaluated the effect of drying conditions at different concentrations of CMC and 'L', as well as the different 'T' on phenolic compounds, mangiferin and antioxidant capacity of the mango pulp. In the present work, we are describing the effect of that process conditions on the concentration of mango carotenoid and color parameters. As we showed previously [9] it was used a 2 full-factorial central composite rotational design (CCRD) with 6 axial points (α = 1.68) and 3 replicates at the center point, totaling 17 experiments (Table 1). For the statistical treatment of the data the Statistical v.10.0 (Statsoft Inc. 2325, Tusla, OK, USA) software was used. In all cases, statistically significant level was considered at $p < 0.05$ for a confidence level of 0.95. Pareto diagrams were used to represent the positive or negative effects of the independent variables (CMC, L and T) on the experimental variables (carotenoids and color parameters). In addition, response surface graphs were plotted to relate the most favorable condition for the variables studied.

Extraction of carotenoid compounds

The method for extraction was according to the previously proposed method [2]. The control and dried mango (10 mg) were extracted with 1 mL of the MiliQ-water and then vortexed and centrifuged at 18.000×g for 3 min to remove the aqueous phase. Subsequently, 1 mL of extracting solvent (hexane/acetone, 1:1 v/v) was added, the mixture was vortexed and then centrifuged for 3 min at 18.000×g. After recovering the colored fraction, a further 500 µL of extracting solvent was added, and the mixture was vortexed and centrifuged. These operations were repeated until color exhaustion. The organic colored fractions were collected and dried in a vacuum concentrator at a temperature below 30 °C. The extracts were saponified to hydrolyze the esters with 500 µL of dichloromethane and treated with 500 µL of methanolic KOH (30%, w/v) overnight, under room temperature (25 °C). Finally, the saponified extracts were washed several times with

water to remove any trace of base, dried and dissolved in 100 µL of ethyl-acetate and analyzed by HPLC-DAD. All the samples were extracted in duplicate and injected two times.

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, carotenoid content and β-carotene.

Treatment	CMC (g/100 g)	L (g/100 g)	T (°C)	Carotenoid content[a] (mg/ 100 g)*	β-carotene (mg/100 g)*
1	-1 (0,30)	-1 (0,30)	-1 (60)	8,74 ± 2,07	3,13 ± 1,02
2	1 (0,75)	-1 (0,30)	-1 (60)	8,15 ± 1,59	3,07 ± 0,83
3	-1 (0,30)	1 (1,20)	-1 (60)	2,81 ± 2,07	0,91 ± 0,78
4	1 (1,20)	1 (1,20)	-1 (60)	5,47 ± 0,87	2,09 ± 0,49
5	-1 (0,30)	-1 (0,30)	1 (80)	12,67 ± 7,52	5,41 ± 4,14
6	1 (1,20)	-1 (0,30)	1 (80)	11,21 ± 6,76	2,84 ± 0,21
7	-1 (0,30)	1 (1,20)	1 (80)	8,06 ± 1,46	4,25 ± 0,74
8	1 (1,20)	1 (1,20)	1 (80)	2,81 ± 1,78	1,21 ± 0,65
9	-1,68 (0)	0 (0,75)	0 (70)	3,84 ± 0,43	2,03 ± 0,12
10	1,68 (1,50)	0 (0,75)	0 (70)	4,23 ± 3,25	2,47 ± 2,07
11	0 (0,75)	-1,68 (0)	0 (70)	4,18 ± 3,24	1,89 ± 1,85
12	0 (0,75)	1,68 (1,50)	0 (70)	2,04 ± 1,84	1,01 ± 0,84
13	0 (0,75)	0 (0,75)	-1,68 (53)	5,23 ± 0,77	2,35 ± 0,07
14	0 (0,75)	0 (0,75)	1,68 (70)	5,06 ± 0,46	2,44 ± 0,02
15	0 (0,75)	0 (0,75)	0 (70)	8,29 ± 0,75	3,87 ± 0,20
16	0 (0,75)	0 (0,75)	0 (70)	12,09 ± 0,56	6,02 ± 0,55
17	0 (0,75)	0 (0,75)	0 (70)	5,07 ± 0,29	2,44 ± 0,22

*Values are given as mean ± SD
[a]Sum of all individual carotenoid compounds

Analysis of carotenoid compounds by HPLC-DAD

HPLC 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, according to the method described by Stinco et al. [1] with light modifications. A C30 column (150 x 4.6 mm, 3 µm) (YMC, Wilmington, NC) kept at 28 °C was used as stationary phase. Methanol, methyl-*tert*-butyl ether and water were used in the mobile phase. The flow rate was 1.0 mL/min and the temperature of the column was at 28 °C.

The identification of carotenoids was made by comparison of their chromatographic and UV/vis spectroscopic characteristics with those of standards, while the identification of *cis* isomers assigned as "tentatively identified" was carried out by comparing with the data reported previously [10].

The quantification was carried out by external calibration from the areas of the chromatographic peaks obtained by DAD detection at 450 nm. The corresponding calibration curves were made up of standards β-carotene and violaxanthin. All the isomers were quantified with the calibration curve made with the corresponding all-*trans* standard. The results were expressed as mg carotenoid compound/100 g of dry matter. Total carotenoid was estimated by summing the content of each individual carotenoid compound identified by HPLC-DAD.

Colorimetric Measurements

For colorimetric measurements, a CAS140B array spectrometer coupled to a TOP100 probe was used (Instrument Systems, Munich, Germany). Three consecutive measurements of the visible spectrum (380-740 nm, 1 nm resolution) were taken, and CIELAB color coordinates were calculated as an average of the three replicates by means of IS-SpecWin software and using as reference the illuminant D65 and the observer 10º. The color differences (ΔE*ab) between two points in the CIELAB space are defined as the Euclidean distance between their locations in the three-dimensional space defined by L^*, a^* and b^*. This was calculated using the following equation:

$$\text{Eq. } \Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad \text{----------(1)}$$

Where ΔL^*, Δa^* and Δb^* are differences between the lyophilized mango pulp (control) and the dehydrated mango pulp samples.

Results and Discussion

Drying of mango

In our previous work [9] we discussed the results of the drying process by foam mat drying. The mango pulp was dehydrated in the time interval between 120 to 380 minutes, determined by the final value of the Aw between 0.35 to 0.45 and resulted in a dried product that exhibited an interesting property as facilitated rehydration. The drying conditions evaluated revealed that the process time by foam mat drying is inversely proportional to the process temperature value. About the additives used, the soy lecithin favored the formation of foam and facilitated the scraping of the dried pulp of the trays after the process, because the formed film was more porous. In the present work our focus is to evaluate changes in relation to carotenoids and color parameters with the process of foam mat drying of mango pulp.

Effect of the foam mat drying of Tommy Atkins mango: carotenoid composition

A typical HPLC of carotenoid profile of foam mat dried mango contained 10 carotenoid compounds as shown in figure 1. Compounds 1, 2 and 3 were identified as 15-*cis*-violaxanthin, 13-*cis*-violaxanthin and all-*trans*-violaxanthin, respectively and the compounds 4 and 6 were detected as 9-*cis*-violaxanthin. Peaks 9 and 10 were characterized as all-*trans*-β-carotene and *cis*-β-carotene, respectively. Luteoxanthin and their derivatives represent the peaks 5, 7 and 8. For the lyophilized mango pulp, peaks 2, 4 and 7 were not detected. The identified carotenoid compounds in mango pulp were similar the studies described by other authors [4]. The carotenoid profile has been reported to be influenced by climatic and geographical conditions, different ripening stages and variety of storage and processing conditions [11].

Figure 1 shows that all-*trans*-β-carotene (peak 9) with a retention time of 20.5 min has the highest concentration among the carotenoids identified in the form mat dried mango pulp. The yellow color during the ripening stages of mangoes

have been associated with the accumulation of carotenoids in the mesocarp of tissues. For example, other authors [13, 14] reported the accumulation of β-carotene in different mango cultivars such as the variety Tommy Atkins. This compound is the main carotenoid that contributes to the nutritional quality of the mango [15], due to its chemical structure has β-ionone rings with provitamin A activity [16]. However, when exposed to factors such as thermal process and light the chemical structure of β-carotene can be changed, resulting in *cis*-isomers production. These isomers have different nutritional characteristics [15]. The procedure of saponification during the extraction was essential to improve chromatogram resolution of the carotenoid compounds, because it breaks the ester bonds of the xanthophylls. The hydrolysis allows free carotenoids for analysis, without the presence of esters. The HPLC made possible the simultaneous identification and quantification by HPLC-DAD of carotenoid compounds in the mango pulp in twenty-one minutes. This can reduce the analysis time compared to many conventional HPLC methods [17].

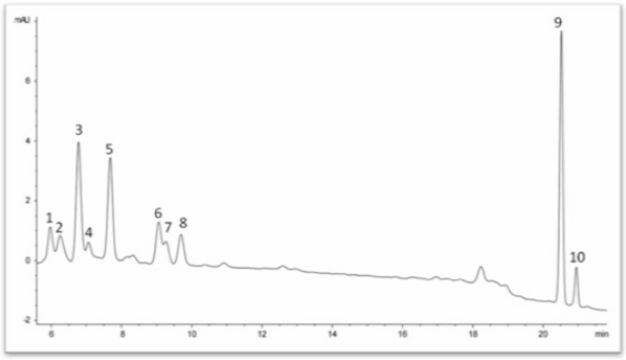

Figure 1: Chromatographic profile of the carotenoid compounds identified in dried mango pulp.

In general, different area for each peak identified in the chromatograms of the foam mat dried samples was observed in relation to the chromatogram obtained for the freeze-dried mango sample, indicating changes in the concentrations of carotenoid compounds. Each peak was identified with a number in figure 1, which is the same used for each compound as shown in table 2, which shows carotenoid compounds identified and quantified in lyophilized mango (control) and foam mat dried mango. It can be observed that the foam mat drying process applied in different conditions change in the quality and quantity of the carotenoid compounds of the mango when compared with mango fresh and possibly due to temperature exposure on the drying method.

The order of carotenoid compounds in lyophilized Tommy Atkins mango pulp from the most abundant to the lowest was violaxanthin and their derivatives (3.12 mg/100 g), β-carotene and its *cis* isomer (2.59 mg/100 g) and the sum luteoxanthin and their derivatives (0.93 mg/100 g). The results showed in table 2 show a great variation in terms of total carotenoids content of dried mango (2.05 – 12.69 mg/100 g). The present study reported higher total carotenoid values for that some conditions of drying when compared with mango pulp fresh lyophilized (6.64 mg/100 g). The fifth condition studied, in

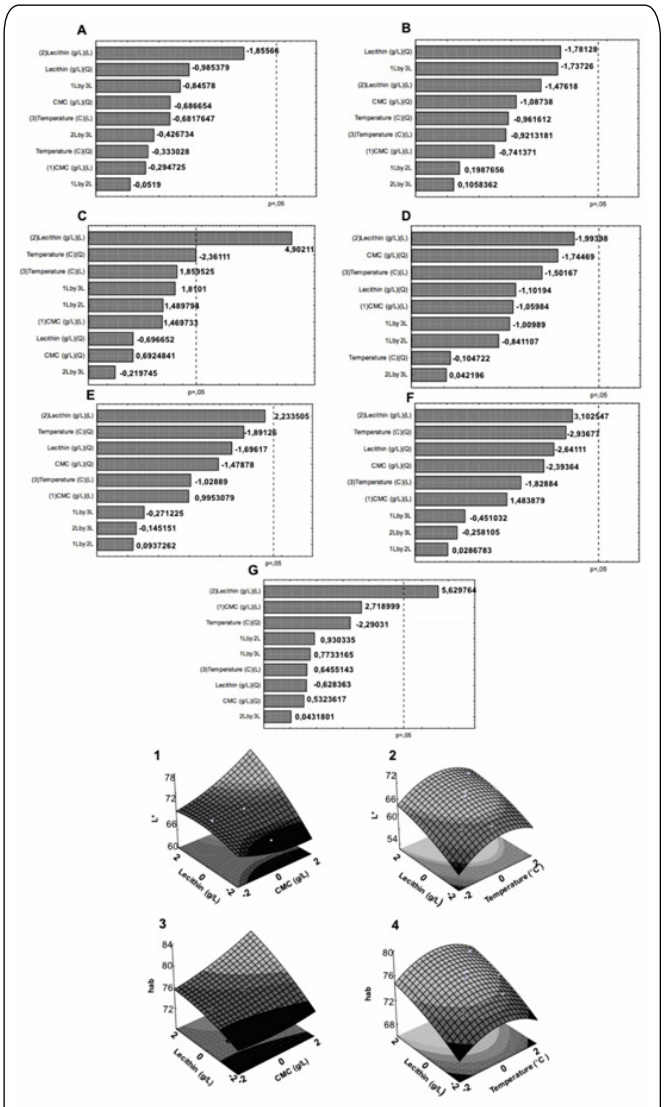

Figure 2: Pareto diagram for the carotenoid content **(A)**, β-carotene **(B)**, value of L^* **(C)**, value of a^* **(D)**, value of b^* **(E)**, C^*ab **(F)** and hab **(G)** and response surfaces for the colorimetric parameters L^* **(1)** and hab **(2)**.

which uses lower concentrations of CMC and L and 80 °C T, showed higher total carotenoid contents (12.69 mg/100g). In some dry samples the carotenoid content was higher when compared to the control sample, this was possible because in foods the cell structure and complexation with proteins impart some protection. During the steps of dehydration, this structure and the complexes are broken, exposing the carotenoid [18]. In our previous study, we obtained higher values of phenolic compounds and antioxidant capacity in mango pulp submitted at the same drying conditions for foam mat drying [9].

The carotenoid compounds having double bonds can exist in the configurations *cis* or *trans*, characterizing the different geometrical isomers. However, some of these isomers are not found in nature, due to the fact that the introduction of the double bond in the configuration *cis* results in a steric hindrance that makes this isomer less stable when compared with the isomer *trans*. The isomers with configuration *cis* with steric hindrance small, normally (9 *cis*) -, (13 *cis*) -, (15 *cis*) - and some (di - *cis*) - isomers, can be formed with facility and

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

Carotenoid compounds	15 cis-violaxanthin (1)	13 cis-violaxanthin (2)	all-trans-violaxanthin (3)	9 cis-violaxanthin (4)	luteoxanthin (5)	9 cis-violaxanthin (6)	D-luteoxanthin (7)	D-luteoxanthin (8)	β-carotene (9)	cis β-carotene (10)
Control	0,81 ± 0,36	Nd	1,43 ± 0,47	Nd	0,68 ± 0,27	0,88 ± 0,30	Nd	0,25 ± 0,07	1,75 ± 0,73	0,84 ± 0,24
Treatment										
1	0,36 ± 0,09	0,42 ± 0,12	0,97 ± 0,22	0,38 ± 0,02	0,92 ± 0,26	0,38 ± 0,20	1,01 ± 0,09	0,46 ± 0,12	3,13 ± 1,02	0,71 ± 0,11
2	0,21 ± 0,17	0,01 ± 0,01	1,09 ± 0,00	0,28 ± 0,22	1,18 ± 0,12	0,26 ± 0,34	0,89 ± 0,44	0,35 ± 0,23	3,07 ± 0,83	0,81 ± 0,10
3	0,07 ± 0,07	0,15 ± 0,11	0,33 ± 0,36	0,06 ± 0,08	0,29 ± 0,11	0,14 ± 0,12	0,30 ± 0,22	0,14 ± 0,09	0,91 ± 0,78	0,42 ± 0,27
4	0,16 ± 0,07	0,24 ± 0,06	0,63 ± 0,30	0,17 ± 0,24	0,55 ± 0,06	Nd	0,71 ± 0,08	0,23 ± 0,06	2,09 ± 0,49	0,69 ± 0,01
5	0,37 ± 0,30	0,20 ± 0,29	1,45 ± 1,39	0,11 ± 0,16	1,84 ± 1,52	0,15 ± 0,22	1,50 ± 0,50	0,03 ± 0,04	5,41 ± 4,14	1,61 ± 1,29
6	0,22 ± 0,06	0,23 ± 0,32	0,61 ± 0,01	0,24 ± 0,05	0,88 ± 0,18	0,08 ± 0,11	5,35 ± 6,18	Nd	2,84 ± 0,21	0,76 ± 0,01
7	0,21 ± 0,01	0,45 ± 0,04	0,41 ± 0,10	0,13 ± 0,19	0,80 ± 0,38	Nd	0,32 ± 0,10	0,33 ± 0,01	4,25 ± 0,74	1,16 ± 0,09
8	0,13 ± 0,02	0,01 ± 0,01	0,32 ± 0,23	Nd	0,49 ± 0,33	0,12 ± 0,17	0,12 ± 0,09	Nd	1,21 ± 0,65	0,41 ± 0,27
9	0,13 ± 0,08	0,11 ± 0,16	0,13 ± 0,09	0,09 ± 0,13	0,43 ± 0,12	0,07 ± 0,10	0,11 ± 0,15	Nd	2,03 ± 0,12	0,74 ± 0,12
10	0,11 ± 0,07	0,07 ± 0,01	0,34 ± 0,06	Nd	0,14 ± 0,05	Nd	0,36 ± 0,34	0,12 ± 0,08	2,47 ± 2,07	0,62 ± 0,57
11	0,21 ± 0,24	0,26 ± 0,27	0,10 ± 0,14	0,15 ± 0,22	0,56 ± 0,45	0,06 ± 0,08	0,27 ± 0,38	0,03 ± 0,05	1,89 ± 1,85	0,65 ± 0,25
12	0,09 ± 0,06	Nd	0,12 ± 0,13	0,19 ± 0,27	0,08 ± 0,03	0,08 ± 0,12	0,07 ± 0,05	Nd	1,01 ± 0,84	0,40 ± 0,34
13	0,53 ± 0,33	Nd	0,42 ± 0,59	0,02 ± 0,03	0,46 ± 0,53	Nd	0,37 ± 0,03	0,39 ± 0,43	2,35 ± 0,07	0,69 ± 0,06
14	0,13 ± 0,03	0,38 ± 0,07	0,52 ± 0,16	0,23 ± 0,22	0,31 ± 0,28	0,13 ± 0,01	Nd	0,14 ± 0,02	2,44 ± 0,02	0,78 ± 0,01
15	0,23 ± 0,10	0,32 ± 0,14	0,81 ± 0,19	0,24 ± 0,34	0,81 ± 0,14	0,65 ± 0,00	Nd	0,31 ± 0,06	3,87 ± 0,20	1,05 ± 0,03
16	0,27 ± 0,01	0,53 ± 0,04	1,23 ± 0,40	0,29 ± 0,41	1,11 ± 0,16	Nd	0,79 ± 0,02	0,50 ± 0,11	6,02 ± 0,55	1,34 ± 0,02
17	0,13 ± 0,03	0,38 ± 0,07	0,52 ± 0,16	0,23 ± 0,22	0,31 ± 0,28	0,13 ± 0,19	Nd	0,14 ± 0,20	2,44 ± 0,22	0,78 ± 0,01

are found in nature [10]. In the present study, it was observed that the geometrical isomer 13-*cis*-violaxanthin was obtained as a result of thermal process of dehydration, and the isomers 9- and 15-*cis*-violaxanthin and all-*trans*-violaxanthin were initially found in mango pulp fresh lyophilized.

The twelfth condition of drying presented lower total carotenoid values (2.05 mg/100 g) when compared with mango pulp fresh lyophilized and all other conditions of drying evaluated. In addition, the third, twelfth and eighth conditions of drying, reported lower β-carotene values for with 0.91 mg/100 g, 1.01 mg/100 g and 1.21 mg/100 g, respectively, when compared with mango pulp fresh lyophilized (1.75 mg/100 g) but all other conditions evaluated resulted in higher β-carotene content compared to the control.

Although the results presented a range of values, the statistical analysis indicated that there was no effect of the process variables on the carotenoid content of the dry mango pulp. This result is in contrast with the work other researchers [19], which reported changes in carotenoid content of Valencia orange juices due to thermal pasteurization. Total carotenoid pigment content loss was significant ($p < 0.05$) after thermal pasteurization at 90 °C for 30 s. Thermal effects caused a reduction on carotenoid pigment contents, especially on violaxanthin (46.4%) and antheraxanthin (24.8%).

The results for statistical analysis for the CCRD used in the present work showed no significant effect ($p > 0.05$) for the studied variable (CMC, L and T) on the total carotenoid compounds of the foam mat dried samples. Figure 2 shows Pareto diagrams obtained from the statistical analysis for the effects of process variables on total carotenoid concentration (A) and β-carotene (B).

Effect of the foam mat drying of Tommy Atkins mango: colorimetric parameters

In relation to the mean levels of the colorimetric parameters, the CIELAB color measurements for dried mango pulp are shown in table 3. In order to compare color of different formulations produced from foam mat drying of mango was analyzed the profile of the colorimetric parameters of the lyophilized mango pulp (control), as can be seen in table 3.

In summary, the mango pulp dried exhibited less chroma, hue and lightness than the control sample. Other authors [20] reported the lyophilized powder brighter (L^* value) than the foam mat dried powder of starfruit pulp, using methocel as foam agent and two drying temperatures (70 °C and 90 °C). However, here the difference in lightness was not statistically significant ($p > 0.05$). From visual inspection, the color of the foam mat powder was slightly brown. This may be attributed to the non-enzymic browning or caramelization of the sugars occurring during the drying process. The same color trends were observed in the rehydrated samples. The browning which inevitably occurred during drying is undesirable because consumers always associate it with poor quality.

Considering the color revealed through the colorimeter, it

Table 3: Coded and real (between parenthesis) variable values for each experimental condition of the Central Composite Rotable Design (CCRD) 2^3 and colorimetric parameters (L^*, a^*, b^*, C_{ab} and $h$ab) obtained.

	Colorimetric parameters					
	L^*	a^*	b^*	C^*ab	hab	ΔE^*
Control	75, 21 ± 0,11	13,80 ± 0,19	57,78 ± 0,05	59,41±0,28	76,61±0,16	-
Treatment						
1	62,17 ± 0,31	14,11 ± 0,08	45,66 ± 0,17	47,84±0,70	72,81±0,14	17,80
2	59,78 ± 0,22	15,32 ± 0,14	50,72 ± 0,13	53,01±0,08	73,61±0,72	17,04
3	65,86 ± 0,35	14,88 ± 0,28	57,02 ± 0,20	59,00±0,35	75,32±0,27	9,44
4	67,25 ± 0,07	13,66 ± 0,16	56,71 ± 0,16	58,39±0,43	76,42±0,09	8,04
5	61,49 ± 0,08	14,27 ± 0,01	46,79 ± 0,07	48,90±0,09	73,03±0,05	17,58
6	63,74 ± 1,21	12,75 ± 0,49	44,28 ± 1,47	46,45±1,38	73,93±0,23	17,74
7	64,37 ± 0,21	14,18 ± 0,7	51,34 ± 0,21	53,18±0,31	74,71±0,55	12,61
8	70,84 ± 0,09	12,1 ± 0,003	55,33 ± 0,37	56,73±0,30	77,68±0,06	5,40
9	68,34 ± 0,66	13,99 ± 0,68	52,97 ± 0,46	54,65±0,52	75,34±0,47	8,39
10	69,88 ± 0,10	13,21 ± 0,10	58,59 ± 0,25	60,13±0,25	77,29±0,06	5,42
11	62,95 ± 0,04	16,55 ± 0,05	54,34 ± 0,24	56,83±0,20	73,06±0,01	13,03
12	70,83 ± 0,25	12,01 ± 0,06	55,66 ± 0,49	56,82±0,42	77,81±0,06	5,18
13	61,95 ± 0,12	16,02 ± 0,03	55,44 ± 0,11	57,74±0,12	73,89±0,04	13,65
14	66,51 ± 0,12	14,65 ± 0,14	53,16 ± 0,32	54,56±0,55	74,46±0,08	9,89
15	64,74 ± 0,11	17,03 ± 0,05	61,26 ± 0,24	60,18±0,19	76,05±0,08	11,50
16	66,92 ± 0,47	13,97 ± 0,24	56,33 ± 0,44	63,47±0,45	74,49±0,09	8,42
17	67,97 ± 0,23	14,49 ± 0,12	58,46 ± 0,02	58,09±0,42	76,05±0,11	7,30

*Values are given as mean ± SD

appears that the foam mat drying process modifies the intense of yellow color mango to a lighter color, when compared with mango pulp fresh. But the statistical analysis of the CCRD reported that the temperature and different concentrations of foam agent CMC and L, as well as the interaction between these parameters not had a significant effect ($p > 0.05$) on the parameter b^* of the foam mat dried samples, showing that the intense of yellow color mango was not modified with the drying conditions. It is important to note that the characteristic yellow color of mango is due to the presence of β-carotene. In addition, it was observed that the thermal processing of foam mat drying did not affected the carotenoid content, in accordance with previous investigations of Lee & Coates [19], Torres Gama & De Sylos [20], Dhuique-Mayer et al. [21].

The parameter a^* was the least affected by different drying conditions and statistical analysis of the CCRD showed that the T and different concentrations of foam agent CMC and L, as well as the interaction between these parameters had not influence on this parameter a^* ($p > 0.05$). This was also observed for the parameter C_{ab}^* that is the relation between the values of a^* and b^*, where represented the actual color of the analyzed sample.

However the table 4 shows a positive linear effect for the foam agent L ($p < 0.05$) on the parameters of color L^* and h_{ab} of the foam mat dried samples that were analyzed, showing also the regression coefficient, the standard error, and the values of t and p.

Table 4: Regression coefficients for L^* and h_{ab} colorimetric parameters of foam mat dried mango.

Variable with statistically significant effect	Regression coeficiente	Standard error	t(1)	p value
L^*				
Mean	66,69790	0,949253	70,26354	0,000202
Lecithin (L)	2,51952	0,446038	5,64867	0,029940
h_{ab}				
Mean	75,57038	0,518908	145,6334	0,000047
Lecithin (L)	1,37268	0,243826	5,6298	0,030133

Figure 2C and D shows Pareto diagrams that were generated from the statistical analysis showing the effects of the different processing variables on the parameters L^* and h_{ab}, respectively 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 Equation (2) and Equation (3), were Y is the L^* and h_{ab} colorimetric parameters, respectively,

and x_1 is the variable L concentration.

$$Y = 66{,}70 + 2{,}52.x_1 \text{----------(2)}$$

$$Y = 75{,}57 + 1{,}37.x1 \text{----------(3)}$$

The results from the analysis of variance (ANOVA) for the model shown in Equations (2) and (3) are summarized in Table 5, along with the coefficient of determination (R^2), F calculated, and F tabulated. According to the ANOVA, the Fisher's F-values calculated for the L^* (24.20) and h_{ab} (25.50) were higher than the F tabulated values (3.68 for both L* and h_{ab}), which allowed us to accept the obtained models. The R^2 obtained for L^* was 0.859 and 0.922 to h_{ab}. With these models is possible to explain 85.9% and 92.2% of the observed variation in the L^* and h_{ab}, respectively.

Table 5: Acceptance of the statistical model for L^* and h_{ab} colorimetric parameters of foam mat dried mango.

Source of variation	Sum of squares	Degree of freedom	Mean square	$F_{calculated}$
L^*				
Regression	32,85	4	8,21	15,13
Residual	5,97	11	0,54	
Total	38,82	15	2,59	
h_{ab}				
Regression	449,35	4	112,34	353,06
Residual	3,50	11	0,32	
Total	482,85	15	32,29	

According to the results obtained with the statistical analysis, the L^* and h_{ab} colorimetric parameters of foam mat dried mango are directly proportional to the amount of foam agent L. From visual inspection of the drying tests it was observed that the conditions with higher concentrations of the foam agent L favored the higher formation of the foam with lighter coloration than the other foams in the different conditions. This justifies that the increase of the concentration of foam agent L increases the values of L^* and h_{ab}, making the mango samples dried by foam mat drying lighter when compared to other conditions. Figure 2 shows the response surfaces for L^* and h_{ab} according to the variables determined by the mathematical models described above.

The total color difference (ΔE^*_{ab}) values between lyophilized mango pulp (control) and dehydrated mango pulp samples (treatment) ranged from 5.18 to 17.80 CIELAB units. The mean value of ΔE^*_{ab} was higher than the commonly-accepted for visual discrimination threshold ($\Delta E^*_{ab} > 3$), which indicates that the color change caused by foam mat drying in the present study could be appreciable visually [22]. The twelfth condition studied, in which uses 1.50 g/100 g of L and 0.75 g/100 g of the CMC and 70 °C T, showed less ΔE^*_{ab} values, indicating lower color change when compared with other treatments tested.

In summary, our results indicated that drying by foam mat drying of mango pulp using CMC and L did not affect the carotenoid content and the colorimetric parameters (a^*, b^* and C^*_{ab}) among the 17 different treatments tested and only the L^* and h_{ab} values were significantly affected for different concentration of L. However, a significant change in color was observed between the dry samples by foam mat drying and the mango pulp (control), through of the total color difference (ΔE^*_{ab}) values. It is necessary to make a sensorial analysis to know the acceptability of the consumers in relation to foam mat dried samples.

Conclusion

This study demonstrated that the process of foam mat drying was adequate for obtaining powder products with color similar to that of fresh fruit and easy rehydration to apply on food. The analysis by HPLC allowed the detection of β-carotene as the high component, the presence also of *cis*-β-carotene, violaxanthin and luteoxanthin and their isomers in lyophilized fresh and dried mango pulp. The effect of the studied variables was not significant for the carotenoid total and colorimetric parameters (a^*, b^*, C_{ab}) and only the L^* and h_{ab} values of foam mat dried mango pulp was significantly affected for different concentration of foam agent L. In general, the total carotenoids 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 carotenoids relative to the other treatments that were evaluated.

Acknowledgments

The authors wish to acknowledge financial support of Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) (Process E-26/111.710/2013). The authors thank the technical staff of the Service of Biology (SGI, Universidad de Sevilla) especially Dr. Modesto Carballo for his technical assistance.

Conflict of Interest

The authors report that there are no conflicts of interest in this study. Only the authors are responsible for the content and writing of the manuscript.

References

1. Stinco CM, Fernández-Vázquez R, Escudero-Gilete ML, Heredia FJ, Meléndez-Martínez AJ, et al. 2012. Effect of orange juices processing on the color, particle size and bioaccessibility of carotenoids. *J Agric Food Chem* 60(6):1447-1455. https://doi.org/10.1021/jf2043949
2. Stinco CM, Benítez-González AM, Hernanz D, Vicario IM, Meléndez-Martínez AJ. 2014. Development and validation of a rapid resolution liquid chromatography method for the screening of dietary plant isoprenoids: carotenoids, tocopherols and chlorophylls. *J Chromatogr A* 1370: 162-170. https://doi.org/10.1016/j.chroma.2014.10.044
3. Martínez R, Torres P, Meneses MA, Figueroa JG, Pérez-Álvarez JA, et al. 2012. Chemical, technological and *in vitro* antioxidant properties of mango, guava, pineapple and passion fruit dietary fibre concentrate. *Food Chem* 135(3): 1520-1526. https://doi.org/10.1016/j.foodchem.2012.05.057

4. Low DY, D` Arcy B, Gidley MJ. 2015. Mastication effects on carotenoid bioaccessibility from mango fruit tissue. *Food Research International* 67: 238-246. https://doi.org/10.1016/j.foodres.2014.11.013
5. Rajkumar P, Kailappan R, Viswanathan R, Raghavan GSV. 2007. Drying characteristics of foamed alphonso mango pulp in a continuous type foam mat dryer. *J Food Eng* 79(4): 1452-1459. https://doi.org/10.1016/j.jfoodeng.2006.04.027
6. Sogi DS, Siddiq M, Roidoung S, Dolan KD. 2015. Total phenolics, carotenoids and antioxidant properties of tommy atkin mango cubes as affected by drying techniques. *LWT-Food Sci Technol* 62(1 part 2): 564-568. https://doi.org/10.1016/j.lwt.2014.04.015
7. Sharma M, Kadam DM, Chadha S, Wilson RA, Gupta RK. 2013. Influence of particle size on physical and sensory attributes of mango pulp powder. *Int Agrophys* 27(3): 323-328. https://doi.org/10.2478/intag-2013-0001
8. Arzhavitina A, Steckel H. 2010. Foams for pharmaceutical and cosmetic application. *Int J Pharm* 394(1-2): 1-17. https://doi.org/10.1016/j.ijpharm.2010.04.028
9. Lobo FA, Nascimento MA, Domingues JR, Falcão DQ, Hernanz D, et al. 2017. 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. *Food Chem* 221: 258-266. https://doi.org/10.1016/j.foodchem.2016.10.080
10. Meléndez-Martínez AJ, Vicario IM, Heredia FJ. 2007. Pigmentos carotenoides: consideraciones estructurales y fisicoquímicas. *Archivos Latinoamericanos de Nutrición* 57(2): 109-117.
11. Ibarra-Garza IP, Ramos-Parra PA, Hernández-Brenes C, Jacolo-Velázquez DA. 2015. Effects of postharvest ripening on the nutraceutical and physicochemical properties of mango (*Mangifera indica* L. cv Keitt). *Postharvest Biol Technol* 103: 45-54. https://doi.org/10.1016/j.postharvbio.2015.02.014
12. Vasquez-Caicedo AL, Heller A, Neidhart S, Carle R. 2006. Chromoplast morphology and beta-carotene accumulation during postharvest ripening of mango cv. 'Tommy Atkins'. *J Agric Food Chem* 54(16): 5769-5776. https://doi.org/10.1021/jf060747u
13. Vásquez-Caicedo AL, Sruamsiri P, Carle R, Neidhart S. 2005. Accumulation of all-trans-β-carotene and its 9-cis and 13-cis stereoisomers during postharvest ripening of nine Thai mango cultivars. *J Agric Food Chem* 53(12): 4827-4835. https://doi.org/10.1021/jf048168h
14. Ornelas-Paz Jde J, Yahia EM, Gardea-Bejar A. 2007. Identification and quantification of xanthophyll esters, carotenes, and tocopherols in the fruit of seven Mexican mango cultivars by liquid chromatography-atmospheric pressure chemical ionization-time-of-flight mass spectrometry [LC-(APCI(+))-MS]. *J Agric Food Chem* 55(16): 6628-6635. https://doi.org/10.1021/jf0706981
15. Lemmens L, Tchuenche ES, Van Loey A, Hendrickx M. 2013. Beta-carotene isomerisation in mango puree as influenced by thermal processing and high-pressure homogenisation. *Eur Food Res Technol* 236: 155-163. http://dx.doi.org/10.1007/s00217-012-1872-y
16. Khoo HE, Prasad KN, Kong KW, Jiang Y, Ismail A. 2011. Carotenoids and their isomers: color pigments in fruits and vegetables. *Molecules* 16(2): 1710-1738. https://doi.org/10.3390/molecules16021710
17. Haghi G, Hatami A, Mehran M. 2013. UPLC and HPLC of caffeoyl esters in wild and cultivated *Arctium lappa* L. *Food Chem* 138(1): 321–326. https://doi.org/10.1016/j.foodchem.2012.10.040
18. Godoy HT, Rodriguez-Amaya DB. 1998. Carotenoid composition of Brazilian nectarine (*Prumus pérsica*). *Revista do Instituto Adolfo Lutz* 1: 73-79.
19. Lee HS, Coates GA. 2003. Effect of thermal pasteurization on Valencia orange juice color and pigments. *LWT - Food Science and Technology* 36(1): 153-156. https://doi.org/10.1016/S0023-6438(02)00087-7
20. Torres Gama JJ, De Sylos CM. 2007. Effect of thermal pasteurization and concentration on carotenoid composition of brazilian valencia orange juice. *Food Chem* 100(4): 1686-1690. https://doi.org/10.1016/j.foodchem.2005.01.062
21. Dhuique-Mayer C, Tbatou M, Carail M, Caris-Veyrat C, Dornier M, et al. 2007. Thermal degradation of antioxidant micronutrients in citrus juice: kinetics and newly formed compounds. *J Agric Food Chem* 55(10): 4209-4216. https://doi.org/10.1021/jf0700529
22. Melgosa M, Pérez MM, Yebra A, Huertas R, Hita E. 2001. Algunas reflexiones y recientes recomendaciones internacionales sobre evaluación de diferencias de color. *Óptica Pura y Aplicada*. 34: 1-10.