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ARTICULO DE INVESTIGACIÓN

EFFECT OF SPRAY DRYING CONDITIONS ON TOMATO POWDER COLOR PROPERTIES

EFECTO DE LAS CONDICIONES DE SECADO POR ASPERSIÓN SOBRE LAS PROPIEDADES DE COLOR DEL TOMATE EN POLVO

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ABSTRACT
The objectives of this work were to determine the effects of spray drying conditions on color properties of powder prepared from tomato paste and establish models to predict the response of each property to the spray drying conditions. Response surface methodology was used to evaluate the effect of spray-drying conditions on tomato powder color properties. Independent variables were: inlet air temperature (140-160 ºC) and feed low rate (350-600 mL/h). Responses variables were chroma and total color difference. Chroma and total color difference were significantly influenced by inlet air temperature and feed flow rate. Chroma was negatively affected, while total color difference was directly related. Multiple response optimization showed that an inlet air temperature of 140 ºC and feed flow rate of 600 mL/h were predicted to provide the lowest total color difference and the higher chroma.

Keyword: tomato powder, spray drying, color properties, response surface methodology, optimization.

RESUMEN
Los objetivos de este trabajo fueron determinar los efectos de las condiciones de secado por aspersión sobre las propiedades de color del polvo preparado a partir de pasta de tomate y establecer modelos para predecir la respuesta de cada propiedad a las condiciones de secado por aspersión. La metodología de superficie de respuesta se utilizó para evaluar el efecto de las condiciones de secado por aspersión en las propiedades de color del tomate en polvo. Las variables independientes fueron la temperatura del aire de entrada (140-160 ºC) y velocidad de flujo de alimentación (350-600 mL/h). Las variables de respuesta fueron la cromaticidad y la diferencia de color total. La cromaticidad y la diferencia de color total se vieron significativamente influenciadas por la temperatura del aire de entrada y el caudal de alimentación. La cromaticidad se afectó negativamente, mientras que la diferencia de color total estuvo directamente relacionada. La optimización de respuesta múltiple mostró que una temperatura del aire de entrada de 140 ºC y una velocidad de flujo de alimentación de 600 mL/h proporcionaron la diferencia de color total más baja y la cromaticidad más alta.

Palabras claves: polvo de tomate, secado por aspersión, propiedades de color, metodología de superficie de respuesta, optimización.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is an important source of nutrients and antioxidants, and also is low in fat and calories. Tomato is a good source of vitamins, fiber and potassium, and thus, constitute essential part of people's diet (Waheed et al., 2020). It is consumed fresh and processed, for example, in powder, which is used in instant soups, sauces, dressings and seasonings, among others.

Color is one of the most important sensory parameters in evaluating the characteristics and consumer acceptance of the food. The main coloring matter responsible for the characteristic deep-red color of tomato fruit and tomato products is lycopene, which is important not only because of the color it imparts but also because of the documented health benefits associated with its presence (Collins et al., 2022). Several studies reported the existence of a linear correlation between the color parameters *a* and *b* with the concentration of carotenoids and have suggested the use of color determination instead of pigment content to control the quality of the products (Ahmed et al., 2002; Nawirska et al., 2009). Works on tomato drying chose to assess color rather than lycopene content (Tontul et al., 2016; Qiu et al., 2019; Kaur-Sidhu et al., 2019).

Powdered tomato has many advantages: it is stable, space-effective, and easy to transport (Pui et al., 2022). Among the commercial drying process available, spray drying is the most efficient technique used which can yield powder of specific properties (Shishir & Chen, 2017). However, parameters like juice concentration, additives, inlet/outlet air temperatures and feed flow rate are important to assure the quality of powder and their close maintenance is significant for an efficient process (Tontul & Topuz, 2017). It is known that processing of tomato products causes isomerization and oxidation of lycopene (Anguelova & Warthesen, 2000; Goula & Adamopoulos, 2005).

Several researchers have studied the process for spray drying of tomato products up-to-date (Goula & Adamopoulos, 2005; Candelas-Cadillo et al., 2005; Santos-Souza et al., 2008; Kumar et al., 2017; Montiel-Ventura et al., 2018; Sidhu et al., 2019). However, there is limited published researches on color changes related to operational parameters during tomato spray drying. Therefore, the objectives of this work were to determine the effects of spray drying conditions on color properties of powder prepared from tomato paste and establish models to predict the response of each property to the spray drying conditions.

MATERIALS AND METHODS

MATERIALS

Tomato paste was supplied by Conchita Company (Pinar del Río, Cuba, 2023). The physicochemical properties of the paste are given in Table 1. Maltodextrin DE 10 manufactured by IMSA, México, was used as carrier.

Table 1. Physicochemical properties of the tomato paste

Total soluble solids (°Brix)	22,8 ± 0,2
Moisture (g/100 g)	77,2 ± 0,3
Titrable acidity (g/100 g, as citric acid)	1,85 ± 0,04
pH	4,00 ± 0,01
Sodium chloride (g/100 g)	3,7 ± 0,1
Sucrose (g/100 g)	0,24 ± 0,02
Glucose (g/100 g)	8,41 ± 0,80
Fructose (g/100 g)	3,47 ± 0,33
L	25,35 ± 1,86
a	23,08 ± 1,60
b	23,77 ± 1,74
Chroma	33,13 ± 3,12

Mean value ± confidence limit at p ≤ 0.05

Spray drying

Maltodextrin was dissolved in an adequate amount of water and this solution was added to the tomato paste to obtain a 20 % w/w solids infeed solution with a ratio of concentrate's solids to carrier of 1:0.7 (40 % w/w maltodextrin content in dry basis of tomato paste). This composition was defined in preliminary tests as the amount needed for obtaining a reasonable yield of powder. The mixture was stirred at 800 min^{-1} for 3 min before spray drying. An amount of 100 g of the infeed solution was prepared for each experimental condition. A Buchi Mini spray dryer B290 (Labortechnik AG, Flawil, Switzerland) was used for dehydration. The drying conditions were mixture feed temperature 25 °C; 0,5 mm injector nozzle, aspirator flow rate 35 m^3/h, drying air flow rate 473 L/h and outlet air temperature between 75 and 85 °C. Inlet air temperature between 140 and 160 °C and feed flow rate between 350 and 600 mL/h were evaluated. These parameters were chosen based on preliminary experiments, which yielded an acceptable spray dried powder. The powder collected from the cyclone and from the walls of spray dryer was weighed and stored in high-density polyethylene bags and placed in a desiccator under darkness for no more than three days before analysis. Drying of tomato paste with maltodextrin was achieved, according to an experimental design (Table 2).

Table 2. Experimental design with coded and decoded values of independent variables and spray drying responses

Inlet air temperature (°C)	Feed Flow rate (mL/h)	*L*	*a*	*b*	Chroma	Total color difference
150 (0)	475 (0)	19,22	16,57	17,42	24,04	11,0
140 (-1)	350 (-1)	22,53	19,45	19,29	27,39	6,4
150 (0)	600 (+1)	19,26	15,89	15,67	22,32	12,4
160 (+1)	600 (+1)	18,15	9,49	7,19	11,91	22,6
160 (+1)	475 (0)	18,48	12,60	13,29	18,31	16,3
150 (0)	475 (0)	19,69	16,75	17,07	23,92	10,8
140 (-1)	600 (+1)	21,46	18,52	22,05	28,80	6,2
150 (0)	475 (0)	20,07	16,29	14,99	22,14	12,3
150 (0)	350 (-1)	21,06	16,94	18,55	25,12	7,7
140 (-1)	475 (0)	20,07	18,78	19,45	27,04	8,1
150 (0)	475 (0)	19,66	16,10	16,49	23,05	11,6
160 (+1)	350 (-1)	19,05	15,30	17,24	23,05	12,0

Tomato paste analysis

Tomato paste was analyzed for total soluble solids, moisture content, titrable acidity, pH value, and sodium chloride according to standard methods (AOAC, 2012). The concentration of glucose, fructose and sucrose was quantified by HPLC, using a YL9100 HPLC system (YL Instrument Co. Ltd., Korea) equipped with a refractive index detector. Separation was performed using a Carbosep COREGEL 87C (300 x 7,8 mm; 9 µm) column (Transgenomic Inc., Omaha, USA) by elution with ultra-high purity water at a flow rate of 0,6 mL/min (Aragüez-Fortes et al., 2019). Color evaluation of samples was measured with an UV-2600 spectrophotometer (Shimadzu Corp., Japan) using the ISR-2600 Integrating Sphere Attachment manual at a wavelength range 380 to 780 nm. The data was analyzed by the program UVPC Color Analysis ver. 3.12 from Shimadzu Corp. (Japan) which provides CIE *L*, *a*, and *b* coordinates.

Powder color analysis

Color evaluation of powder samples was measured with the same procedure described for tomato paste. An amount of water, calculated by mass balance (considering the moisture of the sample) was added for each gram of powder to achieve a mixture with solid content comparable to the original paste. Different parameters were calculated from the *L*, *a*, and *b* values (Tontul et al., 2016): chroma (equation 1) and total color difference (equation 2). Chroma is the purity of a color (a high chroma has no added black, white or gray), while color difference is defined as the numerical comparison of a sample's color to the standard, so it indicates the differences in absolute color coordinates and is referred to as ΔE.

$$Chroma = \sqrt{a^2 + b^2} \quad (1)$$

$$\Delta E = \sqrt{(L - L_o)^2 + (a - a_o)^2 + (b - b_o)^2} \quad (2)$$

Where

L_o, a_o and b_o represent the color parameters for the raw tomato paste.
L, *a* and *b* represent the color parameters of the reconstituted paste.

Sensory analysis

Tomato powder obtained with the best conditions was reconstituted with distilled water up to its original moisture and the intensity of the characteristic color of tomato paste was evaluated. The perceived intensity was rated on a 10-cm continuous structured scale (0: absent; 0,1 to 2,5: light; 2,6 to 5,0: moderate; 5,1 to 7,5: marked and 7,6 to 10: very marked) (Lawless & Heymann, 2010). The reconstituted paste was presented on a covered glass dish and labeled with a random 3-digit code. The sample was tested by seven trained panelists (between 22 and 50 years old, 71% men). Evaluations were made by duplicate.

Response surface methodology

Response surface methodology coupled with a 2-factor-3-level design with four replicates at the center point was used to examine the individual and interactive effects of two independent variables viz inlet air temperature (X_{IAT}) and feed flow rate (X_{FFR}) on chroma and total color difference via Design-Expert 12.0.3.0 (State-Ease Inc., Minneapolis, MN, USA) statistical package. Polynomial models were established to show the relationship between dependent and independent variables. The adequacy of the models was assessed by ANOVA, determination coefficients and test for the lack of fit. Optimum conditions were determined by the desired function methodology. Desirability is an objective function that ranges from zero outside of the limits to one at the goal. The numerical optimization finds a point that maximizes the desirability function. The optimum condition criteria applied for numerical optimization was to maximize chroma, while minimizing total color difference.

RESULTS AND DISCUSSION

The experimental design with coded and decoded values of independent variables and spray drying responses is presented in Table 2. Chroma assesses the color intensity or saturation and total color difference measures the variation in color of the powder in comparison with the raw feed. In general, the reconstituted powders had less lightness, redness and yellowness than the paste. It was expected that the lightness of the powders would be higher due to the white color of the maltodextrin. Powders had less redness and yellowness due to loss of lycopene and non-enzymatic browning reactions that can occur on drying (Qiu et al., 2019).

This implied that the color of the powders has become darker in comparison with the original tomato paste. Similar results were also found in the spray drying of tomato juice and pulp (Santos-Souza et al., 2008; Candelas-Cadillo et al., 2015).

ANOVA confirmed that the coded polynomial models (Table 3) were significant with low residual values, satisfactory coefficient of determination (R^2) and nonsignificant lack of fit which implies that all models correlated well with the measured data. Predicted R^2 and adjusted R^2 was found to be in reasonable agreement with each other for all the independent parameters. Therefore, the models provide adequate predictions of the response variables.

Chroma of spray-dried tomato powder was found to be in the range of 11,91-28,80 (Table 2), like those found for 22,21-26,60 in the spray drying of tomato juice with higher level of maltodextrin (Candelas-Cadillo et al., 2015). Chroma was significantly influenced by inlet air temperature and feed flow rate (Table 3). The coefficients of the first order terms with coded variables indicated that chroma increased with the decrease in both operating parameters, and that inlet air temperature had a major effect on chroma. Deep-red is the predominant color in tomato paste due to the presence of lycopene. When inlet air temperature increased, lycopene become more susceptible to oxidation because of isomerization of all-*trans* form to more oxidable *cis* isomers (Anguelova & Warthesen, 2000; Goula & Adamopoulos, 2005; Demiray et al., 2013) and consequently, parameter *a* (related to redness) decreases. On the other hand, an increase in the feed flow rate means that more water enters to the system to evaporate with the consequent lower energy for the lycopene oxidation. Overall, the chroma of the powders decreased.

Total color difference (ΔE) of spray-dried tomato powder varied from 6 to 23 (Table 2). Values of ΔE up to 1,5 are considered as not perceptible, while values greater than this value are considered clearly visible (Obón et al., 2009). Therefore, all the ΔE results were higher than 1,5; so, the color changes were clearly visible. The linear effects of both operating parameters on ΔE were significant and with a positive relationship (Table 3). Again, inlet air temperature had a major effect on the response variable. The changes of ΔE might be due to the oxidation of lycopene at higher temperature. Besides this, higher inlet air temperature resulted in higher ΔE probably because of the nonenzymatic browning reactions (Horuz et al., 2012; Chen et al., 2014).

Table 3. Parameters of the coded models

Parameter	**Chroma**	**Total color difference**
Intercept	23,09	11,45
X_{IAT}	-4,99**	5,03**
X_{FFR}	-2,09**	2,53**
$X_{IAT}X_{FFR}$	-3,14**	2,71**
F Model	86,67**	63,06**
Lack of Fit	0,50	3,52
R^2	0,970	0,959
Adjusted R^2	0,959	0,944
Predicted R^2	0,913	0,889
Adeq Precision	30,9	24,9

*X_{IAT}: inlet air temperature, X_{FFR}: feed flow rate, *: $p \leq 0,05$; **: $p \leq 0,001$*

Optimized conditions for tomato powders were determined to obtain maximum chroma and minimum total color difference within the studied ranges of inlet air temperature and feed flow rate. To determine these conditions, desirability function was used for numerical and graphical optimization (Figure 1). These goals were fulfilled with a high desirability value of one at an inlet air temperature of 140 ºC and feed flow rate of 600 mL/h. The predicted values for chroma of 29,13 and total color difference of 6,2 were close to the experimental values (<1,2 % difference) of 28,80 and 6,2; respectively. Therefore, it was confirmed the validity and adequacy of the models for predicting response variables.

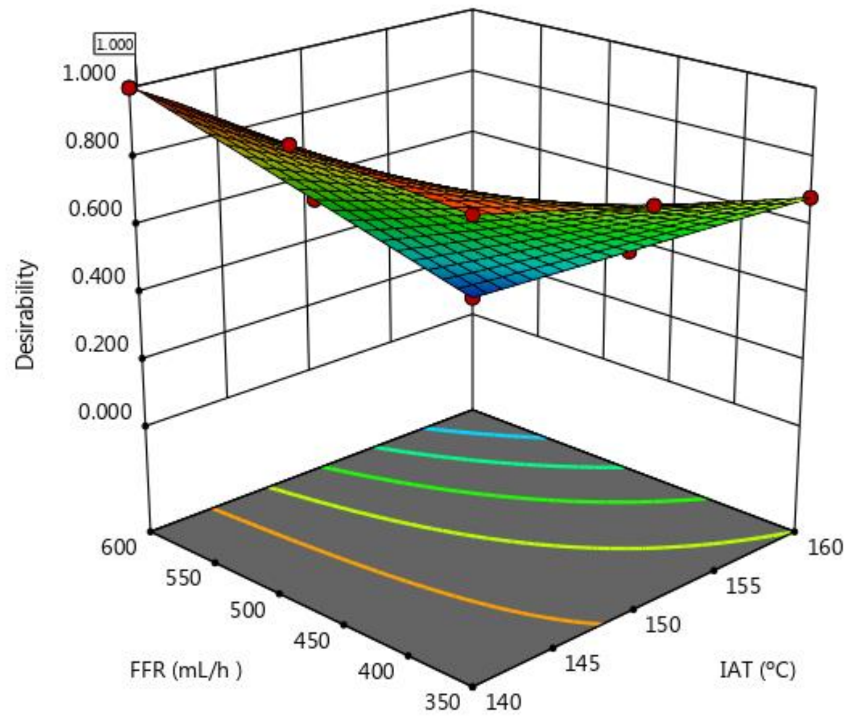

Fig. 1. *Response surface plot for optimization of the spray-drying process for tomato paste. FFR: Feed flow rate, IAT: Inlet air temperature.*

According to the sensory evaluation carried out on the reconstituted tomato paste, all the trained panelists considered that the product had the characteristic color of the tomato paste and gave an average value of 8,5 ± 0,8, which is equivalent to very marked.

CONCLUSIONS

Response surface modelling and desirability methods were applied to evaluate the effect of the operating parameters of spray drying. The operating parameters are strongly interrelated: chroma and total color difference were significantly influenced by inlet air temperature and feed flow rate. Chroma was negatively affected, while total color difference was directly related. Optimization was carried out by maximizing chroma and minimizing total color difference. To preserve the tomato powder color, the use of an inlet air temperature of 140 ºC and a feed flow rate of 600 mL/h is recommended. The results indicate that good quality tomato powder can be produced by spray drying, which reveal the great potential for the use of such powders in the food industry.

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Este articulo no presenta conflicto de intereses.