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Optimization of spray-drying process for tomato paste

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Abstract

Response surface methodology was used to optimize spray-drying process for tomato paste with 10DE maltodextrin. Independent variables were: inlet air temperature (140–160 °C) and feed low rate (350–600 mL/h). Responses variables were powder yield, moisture, and total color difference. Inlet air temperature a positive effect on powder yield and total color differences and a negative effect on moisture content. Feed flow rate led to lower powder yield, but increased moisture content and total color differences. The best spray drying conditions to produce higher powder yield and lower moisture content and total color differences were inlet air temperature of 159 °C and feed flow rate of 350 mL/h. The average particle size D_{43} was 23.0 ± 0.5 μm. According to the sensory evaluation carried out on the reconstituted tomato paste, the product had the characteristic color of the tomato paste and tomato paste-like flavor, confirmed that spray drying is a promising mild drying technology to produce powder with tomato paste character.

Keywords: tomato powder, paste, spray drying, powder properties, response surface methodology, optimization

1. INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is one of the most important vegetables in the world, both if fresh consumption and industrialization are considered. The fruit is eaten fresh and used in the manufacture of processed products such as puree, paste, powder, ketchup, sauce, soups, and canned tomatoes. It is healthy for several reasons: low in fat, calories, and cholesterol-free; good source of fiber and protein, rich in USD 2.29 billion by 2030, growing at a compound annual growth rate of 3.06% (Research and Markets, 2023). A major final consumer of tomato powder is the soup industry, which is dominated worldwide by a few multinational companies. Other uses are sauces, consommés and condiments for snacks. Spray drying is used extensively for dehydration of fruits and vegetables (Shishir and Chen, 2017). However, a major problem vitamins A and C, β-carotene, potassium, and lycopene (Waheed et al., 2020; Collins et al., 2022). Lycopene is a proven antioxidant that has the highest protective effect against free radicals (Rao et al., 2006). In the same sense, tomato powder is one of the most important products, due to its quantity and value. The global tomato powder market was valued at USD 1.5 billion in 2022 and is projected to reach during spray drying of sugar-rich foods is their thermoplastic behavior. The chemical composition of fruit juices comprises monosaccharides and organic acids with a low glass transition temperature (T_g), which affects product yield and properties (Pui and Saleena, 2022). This problem can be minimized by the addition of high molecular weight additives, such as maltodextrin, before atomizing to prevent stickiness of product by increasing the

T_g during the process and/or optimizing the drying parameters. In the same way, the use of maltodextrin with low dextrose equivalent improves the drying process (Muzaffar et al., 2015).

Dehydration of tomato has another problem related to lycopene degradation via isomerization and autoxidation which cause a decrease in the lycopene content, a reduction in the proportion of all-*trans* lycopene, loss of color and the formation of off-flavors (Anguelova and Warthesen, 2000; Goula and Adamopoulos, 2005a).

Several researchers have studied the process for spray drying of tomato pulp (≤ 8 % total solids) up-to-date (Candelas-Cadillo et al., 2005; Goula and Adamopoulos, 2003, 2005a, b,c, 2008a,b; Santos-Souza et al., 2008; Tontul et al., 2016; Kumar et al., 2017; Montiel-Ventura et al., 2018; Sidhu et al., 2019). However, there are no reports concerning the optimization of spray drying process of tomato paste (>18% total solids) and considering the powder yield and color changes in relation to operating parameters. Therefore, this study was undertaken to investigate the effect of inlet air temperature and feed flow rate, on the powder yield, moisture content, and color changes during the spray drying of tomato paste and to determine the optimum drying conditions for the process, by using response surface methodology.

2. MATERIALS AND METHODS

2.1. Materials and chemicals

Tomato paste was supplied by Conchita Fruit Processing Company (Pinar del Río, Cuba, 2023). The physicochemical properties of the paste are given in Table 1. A 10DE maltodextrin manufactured by IMSA, México, was used as carrier. Glucose, fructose and sucrose as reference standards for identification and quantitation were supplied by Aldrich (Steinheim, Germany).

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

2.2. 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. Two ratio of tomato paste solids/maltodextrin solids (1:0.7 and 1:1) were evaluated. 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℃, 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 (IAT) between 150 and 190℃ and feed flow rate (FFR) between 350 and 600 mL/h were evaluated. These parameters were chosen based on preliminary experiments, which yielded an acceptable spray dried product. 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.

2.3. Tomato paste analysis

Tomato paste was analyzed for total soluble solids, moisture content, titratable acidity, pH value, and sodium chloride according to 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). Identification of sugars was made by retention times comparison with reference standards and quantitative analysis was performed by calibration curves. Color evaluation of samples was measured with a 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.

2.4. Tomato powder analysis

Powder yield was estimated by the percentual ratio between the total mass of product recovered by the mass of extract fed to the system, both in dry basis (Rojas-Molina et al., 2022) and moisture content was determined at 105 °C by a thermobalance MA37 (Sartorious, Göttingen, Germany). 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. Total color difference was calculated from the color parameters (Tontul et al., 2016).

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

The whiteness index WI was calculated according to McDonald (1997).

$$WI = 100 - [(100 - L)^2 + (a^2 + b^2)]^{1/2}$$

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

2.5. Scanning electron microscopy

Juice powders were subjected to microstructural characterization by means of a scanning electron microscope (Tescam 5130 SB, Prague, Czech Republic), setting a magnification equal to ×720. The diameter of each particle was determined by analyzing six photomicrographs of the powder and was expressed as the average particle size D_{43} (μm).

2.6. 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 and flavor of tomato paste were 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 and Heymann, 2010). The reconstituted paste was served on a glass dish (for color) or on a salt cracker (for flavor) labeled with random 3-digit codes. Samples were tested by seven trained panelists (between 22 and 50 years old, 71% women). Panelists were required to cleanse their palate with distilled water between each sample. Evaluations were made by triplicate.

2.7. 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: inlet air temperature (X_{IAT}) and feed flow rate (X_{FFR}) on powder yield, moisture content, 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. The optimum condition criteria applied for numerical optimization was to maximize chroma, while minimizing total color difference. Validation of developed models was achieved by conducting additional runs within the selected factors range.

3. RESULTS AND DISCUSSION

Preliminary experiments in drying tomato paste without addition of maltodextrin and with different feed solids contents (20 and 30 % solids), as well as combinations of X_{IAT} (140 and 160 °C) and X_{FFR} (300 and 600 mL /h) gave very low yields given the high proportion of product stuck to the equipment walls, mainly in the drying chamber. Therefore, this possibility was ruled out. In general, the amount of maltodextrin required for successful spray drying depends on three main factors: product composition, drying temperature, and type of maltodextrin, and is largely based on trial and error, as well as of operator experience. Bhandari et al. (1997) developed a semi-empirical drying aid index Y, based on product yield, which was successfully used to determine the optimal fruit juice/maltodextrin ratio in a bench-scale dryer. The calculations made for the ratios 1:0.7 and 1:1 of tomato paste solids/maltodextrin resulted in Y values of 0.86 and 0.96, respectively. According to Bhandari et al. (1997) only the 1:1 ratio would be close to unity, which is recommended for successful drying with a yield >50 %. Preliminary experiments were carried out to obtain a dry product having better appearance, color and performance. For this purpose, the two m/m solids ratios were tested with X_{IAT} of 160 °C and X_{FFR} of 600 mL/h. The product yields were similar, 48 and 49 % for the solid ratios 1:0.7 and 1:1, respectively. However, the color of the powder obtained with the 1:1 ratio showed a lighter coloration as a result of a higher proportion of added maltodextrin. To confirm this observation, both powders were reconstituted and color determinations were made (Table 2).

Table 2. Comparison of the color of dehydrated pastes with two ratio of paste solids: support

Parameter	1:0.7 ratio	1:1 ratio
L	18.15^{b} (0.8)	20.40^{a} (0.9)
a	9.49^{a} (0.5)	9.15^{a} (0.5)
b	7.19^{a} (0.4)	7.54^{a} (0.5)
WI	17.3^{b} (1.0)	19.5^{a} (1.1)

(): standard deviation; WI: whiteness index. Different letters indicate significant difference at $p \leq 0.05$.

Of the values of L, a and b of the two samples, only a significant increase ($p \leq 0.05$) was found for the luminosity with the increase in the proportion of the support. As a consequence of this increase in L, the value of the whiteness index also showed a significant increase. Therefore, the lowest concentration of maltodextrin (1:0.7 m/m solids ratio) was selected to carry out the experimental design, with a view to less affectation in product color.

The experimental design with coded and decoded values of independent variables and spray drying responses is presented in Table 3. Powder yield ranged between 25.4% and 54.3% wb, which is higher than those reported in several previous studies: 13–28% wb for tomato pulp with 14% total solids and without carrier (Goula and Adamopoulos, 2003), 23.55–40.17% wb for tomato juice at 5.5% soluble solids and vegetable proteins as carrier (Tontul et al., 2016), and 6.10–9.13% wb for tomato juice with 6% total solids and maltodextrin addition (Sidhu et al., 2019), all them using laboratory spray dryers.

Table 3. Experimental design for tomato paste spray drying

IAT (°C)	FFR (mL/h)	Yield (%)	Moisture (% m/m)	ΔE
150 (0)	475 (0)	33.3	9.00	10.5
140 (-1)	350 (-1)	40.2	10.47	15.1
150 (0)	600 (+1)	28.7	9.76	11.0
160 (+1)	600 (+1)	44.4	9.10	7.9
160 (+1)	475 (0)	51.0	8.20	10.0
150 (0)	475 (0)	30.2	9.27	12.7
140 (-1)	600 (+1)	25.4	10.65	8.1
150 (0)	475 (0)	28.1	9.36	12.8
150 (0)	350 (-1)	44.4	8.37	21.7
140 (-1)	475 (0)	28.1	10.52	8.8
150 (0)	475 (0)	28.7	9.20	9.1
160 (+1)	350 (-1)	54.3	7.56	8.8

IAT: inlet air temperature, FFR: feed flow rate, ΔE: total color difference. In parenthesis the coded variable.

These yields are substantially lower than the ideal parameters of at least 50% (Bhandari et al., 1997). On the other hand, the estimated results are lower than 36.62–65.86% wb for tomato pulp with 14% total solids without carrier addition (Goula and Adamopoulos, 2005b) and 80–90% wb for tomato pulp with 18% total solids and maltodextrin at a ratio of tomato pulp solids/maltodextrin solids of 1:4 (Goula and Adamopoulos, 2008a), both using a higher cost process with dehumidified air in a laboratory spray dryer.

Powder moisture content varied from 7.56% to 10.65% wb, which are generally consistent with the findings of previous studies: 4.16–11.27% wb for tomato pulp with 14% total solids and without carrier (Goula and Adamopoulos, 2003), 8.76–9.91% wb for tomato juice with two maltodextrin concentrations, 80% and 100% based on total soluble solids (Candelas-Cadillo et al., 2005), 2.91–12.41% wb for tomato pulp with 18% total solids and maltodextrin using dehumidified air in a laboratory spray dryer (Goula and Adamopoulos, 2008b), and 6.1–9.1% wb for tomato juice with 6% total solids and maltodextrin addition (Sidhu et al., 2019). On the contrary, the estimated results are higher than 3.11–9.43% wb for tomato pulp with 14% total solids without carrier addition and using low humidity air (Goula and Adamopoulos, 2005b), 4.0–6.8% wb for tomato pulp blended with 10DE maltodextrin (10% dry matter) dried in a pilot scale spray dryer at 200 °C (Santos de Souza et al., 2009), and 3.4–4.7% wb for tomato juice at 5.5% soluble solids and vegetable proteins as carrier (Tontul et al., 2016).

The only known report about changes on total color difference is attributed to Tontul et al. (2016), who spray dried tomato juice at 5.5% soluble solids combined with different vegetable proteins. Total color differences were 6.2–22.6, which are very high compared to 0.65–1.98 reported earlier. The total color difference can be related to the lycopene of the feed material which is sensitive to drying process (Anguelova and Warthesen, 2000; Goula and Adamopoulos, 2005a). One

possible reason for the low total color difference in the previous study can be related to the low amount of carrier agent used.
Table 4 shows the coded polynomial models. ANOVA confirmed that the polynomial models 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. The adequate precision (signal-to-noise ratio) were greater than four indicating adequate discrimination of the model. Hence, the models provide adequate predictions of the response variables.

Table 4. Summary of statistics and parameters of the coded regression models

Parameter	Yield	Moisture	Total color difference
Intercept	32.23	9.29	11.45
X_{IAT}	9.33**	-1.13**	5.03**
X_{FFR}	-6.73**	0.52**	2.53**
X_{IAT}^2	8.33**	-	-
$X_{IAT}X_{FFR}$	-	0.34*	2.71**
F model	27.18**	64.75**	63.06**
F lack of fit	3.04	2.82	3.52
R^2	0.911	0.960	0.959
Adjusted R^2	0.877	0.946	0.944
Predicted R^2	0.804	0.842	0.889
Adequate precision	15.9	25.5	24.9

*X_{IAT}, X_{FFR}: inlet air temperature and coded feed flow rate, respectively. *: $P \leq 0.05$; **: $P \leq 0.001$.*

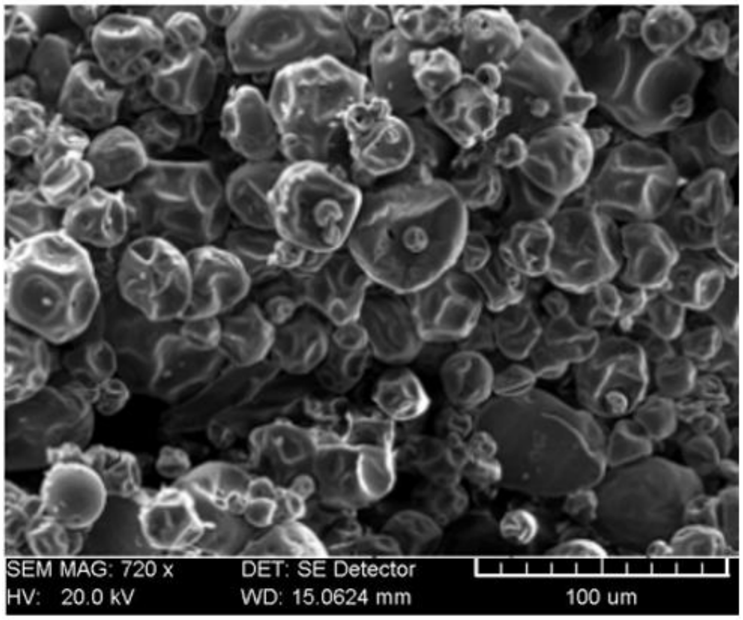

Fig. 1. Scanning photomicrograph of spray dried tomato paste.

The linear terms and the quadratic term for the IAT were significant in the model for powder yield (Table 4). The linear term of IAT in absolute value was higher than the linear term of FFR, which indicates that it had a greater importance. As the IAT increased, the yield showed a positive outcome, while there was a negative effect of FFR on yield. According to

Goula and Adamopoulos (2005b), the effect of IAT on the recovery of the product is determined by its effect on the accumulation of residues, since the fixation of spray drops and dry dust to the walls of the drying chamber is the main cause of total loss of product. The deposits on the walls decrease as the IAT increases, since due to the higher temperature the drops are more dried when they hit the wall and the deposits on it that are attributable to inadequate drying of the particles decrease. Roos (2003) reported that the rapid removal of water results in the vitrification of liquid droplets in a short time and the formation of a solid particle surface. The rapid formation of a dry surface layer around the particle increases the T_g at the surface and this is a basic requirement for successful spray drying, since solidification of the surface does not allow the formation of liquid bridges between the surfaces of the particles. particles in contact or adhesion of particles on the internal surfaces of the drying equipment. Similar yield behaviors with IAT were reported for tomato paste drying (Banat et al., 2002; Al-Asheh et al., 2003; Goula and Adamopoulos, 2005b). On the other hand, the increase in powder yield due to the decrease in FFR can be explained by a reduction in the mass of water introduced into the dryer under constant drying conditions. These results were in accordance with the studies by several authors (Banat et al., 2002; Al-Asheh et al., 2003).

In the model for moisture, both linear terms and their interaction were significant (Table 4). The linear term of IAT in absolute value was two times greater than the linear term of FFR, which indicates that it had a greater importance. There was a significant difference between the linear effect of IAT and FFR on the moisture content. While the increase in IAT decreased the moisture content of the samples, the increasing FFR enlarged the moisture content of the samples. According to Goula and Adamopoulos (2005c), the greater the temperature difference between the drying medium and the particles, the greater the rate of heat transfer in the particles, which provides a driving force for moisture removal. When the drying medium is air, temperature plays a second important role. As water is removed from the particles in the form of water vapor, it must be entrained or moisture will create a saturated atmosphere on the particle surface, thereby slowing the rate of water removal. The hotter the air is, the more moisture it will take in before becoming saturated. Therefore, a high air temperature in the vicinity of the drying particles will absorb the moisture expelled from the food to a greater extent than with cooler air. Similar behaviors for the relationship between IAT and FFR with the moisture content in tomato paste and puree drying were reported by several authors (Banat et al., 2002; Al-Asheh et al., 2003; Goula and Adamopoulos, 2005c).

In the model for total color difference, both linear terms and their interaction were significant (Table 4). The linear term of IAT in absolute value was almost two times greater than the linear term of FFR, indicating that it had greater importance. The coefficient of the linear term of the IAT was positive, so that an increase in this factor led to a higher total color difference in the product. Likewise, the linear term for the FFR was also positive, so it can be affirmed that an increase in this factor increased the total color difference of the product. Higher IAT resulted in significantly higher total color difference values probably due to non-enzymatic browning reactions in several studies (Kha et al., 2010; Jiménez-Aguilar et al., 2011; Chen et al., 2014) and loss of lycopene (Goula and Adamapoulos, 2005a; Goula et al., 2006). According to Tontul and Topaz (2017), only one study is known that reported the effect of FFR on global color difference. Furthermore, increasing the FFR increased the value of total color difference (Chen et al., 2014). This increase could be related to a higher moisture content of the powders produced at a higher FFR.

After analyzing the polynomial models depicting the effect of spray drying process on processing factors, optimization process was carried out by desirability function methodology. The best solution was inlet air temperature 159 °C and feed flow rate 350 mL/h on the basis of highest desirability value (0.89). The predicted values for powder yield, moisture content, and total color difference were 54.3%, wb 7.44% wb, and 11.0 respectively, which were close to the experimental values (< 3.0% difference) of 53.2% wb, 7.28% wb, and 10.7 respectively, of product. The average particle size D_{43} was 23.0 ± 0.5 μm. With the same drying technique, D_{43} = 13.3 and 21.4 μm have been reported in açai juice (Tonon et al., 2008), 1.2 to 9.1 μm in banana (Chávez-Rodríguez et al., 2013), 11.8 μm in guava pulp (Shishir et al., 2016) and 16.3 μm in acerola pulp (Pino et al., 2020).

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 a mean value of 8.5 ± 0.8, which is equivalent to very marked. Furthermore, panelists also detected a characteristic tomato paste-like flavor and gave a mean intensity of 8.7 ± 0.7, confirmed that spray drying is a promising mild drying technology to produce powder with tomato paste character.

4. CONCLUSIONS

In the present study, some parameters of spray dried tomato paste were examined under different process conditions such as inlet air temperature and feed flow rate using response surface methodology. Increasing inlet air temperature would increase powder yield and total color difference but at the same time decrease the moisture content. On the other hand, increasing feed flow rate would increase the moisture content and total color difference while decreasing the powder yield. Best spray drying conditions were established at inlet air temperature (159 °C) and feed flow rate (350 mL/h). With these conditions, quality tomato paste powder with maximum yield, low moisture content and low total color difference could be produced. The results obtained from verification experiments were in good agreement with predicted values. Spray drying obtained for tomato powder developed after following the optimal conditions of spray drying.

Regarding the microstructure of the tomato powder obtained with the optimized parameters (*Fig. 1*), it was noted that the particles have a very similar external morphology: a rounded surface with concavities and teeth, characteristic of this type of tomato paste using 10DE maltodextrin shows that spray drying can generate high-quality powders with optimal moisture content and color retention, indicating that such powders have a lot of promise for usage in the food industry.

Ethical Approval

None.

Declaration of Interests

The authors of this study declared no conflict of interests.

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Author Contribution

Concept: D C-R, JAP
Design: DC-R, JAP
Data collecting: D C-R, Y A-F, MAAAV
Statistical analysis: D C-R, Y A-F, MAAAV
Literature review: D C-R, Y A-F, MAAAV
Writing: D C-R, MAAAV, JLR
Critical review: JLR, JAP

REFERENCES

Al-Asheh, S., Jumah, R., Banat, F. & Hammad, S. (2003). The use of experimental factorial design for analysing the effect of spray dryer operating variables on the production of tomato powder. *Trans IChemE*, 81, 81-88.

Anguelova, T. & Warthesen, J. (2000). Lycopene stability in tomato powders. *Journal of Food Science*, 65(1), 67-70.

AOAC (2012). Official Methods of Analysis (19th ed.). Association of Official Analytical Chemist. AOAC International. Washington DC.

Aragüez-Fortes, Y., Robaina-Morales, L.M., & Pino, J.A. (2019). Optimization of the spray-drying parameters for developing guava powder. *Journal of Food Process Engineering*, 42(6), e13230.

Banat, B.F., Jumah, B., Al-Asheh, S., & Hammad, S. (2002). Effect of operating parameters on the spray drying of tomato paste. *Engineering in Life Science*, 12(2), 403-407.

Bhandari, B.R., Datta, N., Crooks, R., Hoves, T., & Rigby, S. (1997). A semi-empirical approach to optimise the quantity of drying aids required to spray dry sugar-rich foods. *Drying Technology*, 15, 2509-2525.

Candelas-Cadillo, M.G., Alanís-Guzmán, M.G.J., Bautista-Justo, M., Del Río-Olague, F., & García-Díaz C. (2005). Lycopene content in spray-dried tomato juice. *Revista Mexicana de Ingeniería Química*, 4(3), 299-307.

Chávez-Rodríguez, A.M., Pérez-Martínez, J.D., Ibarra-Junquera, V., Escalante-Minakata, P., Villa Velázquez-Mendoza, C.I., Dibildox-Alvarado, E., & Ornelas-Paz, J.J. (2013). Microencapsulation of banana juice from three different cultivars. *International Journal of Food Engineering*, 9(1), 9-16.

Chen, Q., Bi, J., Zhou, Y., Liu, X., Wu, X., & Chen, R. (2014), Multi-objective optimization of spray drying of jujube (*Zizyphus jujuba* Miller) powder using response surface methodology. *Food Bioprocessing Technology*, 7, 1807-1818.

Collins, E.J., Bowyer, C., Tsouza, A., & Chopra, M. (2022). Tomatoes: An extensive review of the associated health impacts of tomatoes and factors that can affect their cultivation. *Biology*, 11: 239. https://doi.org/10.3390/biology11020239

Goula, A.M. & Adamopoulos, K.G. (2003). Spray drying performance of a laboratory spray dryer for tomato powder preparation. *Drying Technology*, 21(7), 1273-1289.

Goula, A.M. & Adamopoulos, K.G. (2005a). Stability of lycopene during spray drying of tomato pulp. *LWT*, 38, 479-487.

Goula, A.M. & Adamopoulos, K.G. (2005b). Spray drying of tomato pulp in dehumidified air: I. The effect on product recovery. *Journal of Food Engineering*, 66, 25-34.

Goula, A.M. & Adamopoulos, K.G. (2005c). Spray drying of tomato pulp in dehumidified air: II, The effect on powder properties. *Journal of Food Engineering*, 66, 35-42.

Goula, A.M., Adamopoulos, K.G., Chatzitakis P.C., & Nikas V.A. (2006). Prediction of lycopene degradation during a drying process of tomato pulp. *Journal of Food Engineering*, 74, 37-46.

Goula, A.M. & Adamopoulos, K.G. (2008a). Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: I. Drying kinetics and product recovery. *Drying Technology*, 26(6), 714-725.

Goula, A.M. & Adamopoulos, K.G. (2008b). Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: II. Powder properties, *Drying Technology*, 26(6), 726-737.

Jiménez-Aguilar, D., Ortega-Regules, A., Lozada-Ramírez, J., Pérez-Pérez, M., Vernon-Carter, E., & Welti-Chanes, J. (2011). Color and chemical stability of spray dried blueberry extract using mesquite gum as wall material. *Journal of Food Composition and Analysis*, 24, 889-894.

Kha, T.C., Nguyen, M.H., & Roach, P.D. (2010). Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder. *Journal of Food Engineering*, 98(3), 385-392.

Kumar, V., Sharma, H.K., & Mishra, S. (2017). Simulation of spray drying of tomato juice using computational fluid dynamics (CFD). *Cogent Food & Agriculture*, 3, 1310596.

Lawless, H.T. & Heymann, H. (2010). Sensory Evaluation of Food. Principles and Practices. Springer Science+Business Media, LLC.

McDonald, R, (1997). Colour Physics for Industry. Society of Dyers and Colourists, Bradford, England.

Montiel-Ventura, J. Luna-Guevara, J.J., Tornero-Campante, M.A., Delgado-Alvarado, A., & Luna-Guevara, M.L. (2018). Study of encapsulation parameters to improve content of lycopene in tomato (*Solanum lycopersicum* L.) powders. *Acta Alimentaria*, 47(2), 135-142.

Muzaffar, K., Nayik, G.A., & Kumar, P. (2015). Stickiness problem associated with spray drying of sugar and acid rich foods: A mini review. *Journal of Nutrition and Food Science*, S12, 003.

Pino, J.A., Aragüez-Fortes, Y., & Rodríguez, L.M. (2020). Optimization of the spray-drying parameters for developing mature acerola powder. *Journal of Raw Materials to Processed Foods*, 1(2), 40-46.

Pui, L.P. & Saleena, L.A.K. (2022). Effects of spray-drying parameters on physicochemical properties of powdered fruits. *Foods and Raw Materials*, 10(2). https://doi.org/10.21603/2308-4057-2022-2-533

Rao, A.V., Ray, M.R., & Rao, L.G. (2006). Lycopene. *Advances in Food and Nutrition Research*, 51, 99-164.

Research and Markets (2023). Global Fruit & Vegetable Wholesalers - Industry Report. Available at:

https://www.researchandmarkets.com (Accessed 21 June 2023).

Rojas-Molina, J.O., García, M.A., & Pino, J.A. (2022). Microencapsulation of oregano essential oil by spray-drying using maltodextrin: gum arabic blends. *Acta Alimentaria*, 51(3), 403-412.

Roos, Y. (2003). Phase and state transitions in food dehydration. Symposium EUDrying '03, Heraklion, Crete, Greece.

Santos-Souza, A., Vilela-Borges, S., Ferreira-Magalhães, N., Vaz-Ricardo, H., Pascoli-Cereda, M., & Daiuto, E. R. (2009). Influence of spray drying conditions on the physical properties of dried pulp tomato. *Ciência e Tecnologia de Alimentos, Campinas*, 29(2), 291-294.

Shishir, M.R.I., Taip, F.S., Aziz, N.A., Talib, R.A., & Sarker, M.S.H. (2016). Optimization of spray drying parameters for pink guava powder using RSM. *Food Science and Biotechnology*, 25(2), 461-468.

Shishir, M.R.I. & Chen, W. (2017). Trends of spray drying: A critical review on drying of fruit and vegetable juices. *Trends in Food Science & Technology*, 65, 49-67.

Sidhu, G.K., Singh, M., & Kaur, P. (2019). Effect of operational parameters on physicochemical quality and recovery of spray-dried tomato powder. *Journal of Food Process and Preservation*, 43(10), e14120.

Tonon, V.R., Brabet, C., & Hubinger, M. (2008). Influence of process conditions on the physicochemical properties of açai powder produced by spray drying. *Journal of Food Engineering*, 88, 41141-41148.

Tontul, I., Topuz, A., Ozkan, C., & Karacan, M. (2016). Effect of vegetable proteins on physical characteristics of spray-dried tomato powders. *Food Science and Technology International*, 22(6), 516-524.

Tontul, I. & Topuz, A. (2017). Spray-drying of fruit and vegetable juices: Effect of drying conditions on the product yield and physical properties. *Trends in Food Science & Technology*, 63, 91-102.

Waheed, K., Nawaz, H., Hanif, M.A., & Rehman, R. (2020). Tomato. In: Hanif, M.A., Nawaz, H., Khan, M.M., and Byrne, H.J. (Eds.), Medicinal Plants of South Asia. Elsevier Ltd., Amsterdam