Wiley
Journal of Food Processing and Preservation
Volume 2024, Article ID 5773594, 8 pages
https://doi.org/10.1155/2024/5773594

WILEY

Research Article

Convective Drying of Pumpkin Flower (*Cucurbita maxima*): Effect of Temperature and Airflow on Carotenoid Content

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Received 4 March 2024; Revised 22 April 2024; Accepted 14 June 2024

Academic Editor: Charles Haminiuk

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This study evaluated the change in the carotenoid content and colorimetric properties of the pumpkin flower (*Cucurbita maxima*) in convective drying. Three factors were studied: drying temperature (45, 50, and 55°C), airflow (0.3, 0.6, and 0.9 m/s), and shape of the flower (whole, half, and petals). The initial lightness value of 64.38 tends to decrease with drying temperature and time; however, the lightness increases as the pumpkin flower shape passes from the petals to the whole shape because of the high moisture content. During drying, the *a* and *b* parameters ranged from 16.61 to 30.03 and 34.61 to 61.46, respectively. An increment in *a* value indicates that the pumpkin flower tends to be redder, and the increase in *b* values indicates a yellow color movement. The hue angle increased when the airflow goes from 0.3 to 0.9 m/s and when the drying temperature increased from 50 to 55°C; therefore, the pumpkin flower tended to be more yellow when the drying temperature passed from 50 to 55°C. The best properties of pumpkin flowers were obtained during the drying process at a temperature ranging from 50 to 55°C. At this temperature range, moisture content was around 3.11% to 10.2% and water activity was from 0.225 to 0.334, respectively. It was also noted that drying at higher temperatures leads to loss of color and carotenoid content because of the presence of heat-sensitive molecules, which is also why low drying temperature is used in this process.

1. Introduction

Edible flowers have been of great importance in Mexican gastronomy over the years. These flowers have many colors, flavors, and shapes and are used as ingredients for salads, soups, garnishes, desserts, drinks, or even fresh in their natural form [1]. Mexico has a wide variety of flower species that are employed in the elaboration of regional dishes. Edible flowers can add color, flavor, aroma, essential oil, and visual appeal to foods, as well as positive effects on health due to biomolecules present in them; edible flowers have also been employed in the preparation of infusions, teas, and extracts for medicinal purposes [2, 3] and sweet fragrance for ornamental purposes [4] and to improve the shelf life of food [5].

Pumpkin flowers (*Cucurbita maxima* or *Cucurbita pepo*) are commonly used in traditional Mexican cuisine; flowers can be yellow or orange according to maturity. Zhou et al. [6] reported that pumpkin species can contain polyphenols, phytosterols (*α*-spinasterol), carotenoids, mono- and polyunsaturated

fatty acids, vitamins C and E, and selenium. Those biomolecules have been widely documented as antitumor, antigenotoxic, antimutagenic, antibacterial, and anti-inflammatory; besides, Gosh and Rana [7] reported a critical mineral and polyunsaturated fatty acid content in pumpkin flowers.

Despite this flower's benefits, its main disadvantage is its short perennial stage. Unfortunately, flowers suffer darkening, wilting, dehydration, and discoloration of the petals during the postharvest phase [2]; additionally, attractive colors are lost very quickly after harvesting, and that is a critical quality attribute of raw and processed foods as it significantly impacts the first consumer's perception and influences other essential quality factors, such as aroma and flavor [8]. Thus, an alternative for its preservation is dehydration or drying; the rapid decomposition of foods is related to their water content since this is the leading cause of increased metabolic activity and chemical and physical changes in the product during storage, so it is essential to reduce the initial plant's moisture content by drying or dehydrating to preserve quality for consumption after harvest [9].

Convective drying has been one of the most employed techniques for food preservation throughout history; water content in fresh food is reduced using this process; thus, transportation, distribution, and storage cost are reduced. Likewise, drying is the cheapest method and is especially suitable for communities that do not have other conservation possibilities [10]. Since ancient times, through trial and error, sun drying was used in foods such as fruits, grains, vegetables, meat, and fish to have food in times of scarcity [10]; however, the main disadvantage of drying by sunlight is that the temperature is not controlled and can reach above 60°C, leading to quality property deterioration such as color, flavor, and texture. Additionally, there is a loss of antioxidant compounds and sensitive nutrients in dry matter [11]. Over the years, different techniques and instruments have been developed to perform food drying more effectively using new equipment and resources (besides the sun). Convective drying is the most widely employed dehydration process for fruit preservation; it is currently used with pretreatments such as osmotic dehydration (osmosis), blanching, and vacuum impregnation to increase the quality of the dehydrated product and reduce drying time [12]. In addition to this, the authors have recorded optimal results concerning the preservation and use of dried edible flowers [13], aromatic ones [14], for medicinal and ornamental purposes [15], and finally, analysis of the physicochemical properties generated by such a process [16, 17]. Among the flowers that have been mostly used in the past in terms of gastronomy, the pumpkin flower protrude (*Cucurbita pepo y Cucurbita maxima*), *cempasúchil* (*Tagetes erecta*), *colorín* (*Erythrina americana*), *maguey* (*Agave legrelliana*), *manzanilla* (*Matricaria recutita*), and Satureja Khuzistanica Jamzad, among others [18]. The pumpkin is available in different shapes, sizes, and colors depending on the variety and climate [19]; the pumpkin flower (*Cucurbita maxima*) is an edible flower used in various dishes in Mexico, primarily characterized by its vibrant shades and colors (yellow and orange). Chenfei et al. [20] stated a relationship between anthocyanins/carotenoids and the color space values of a flower, demonstrating the association of colorimetry with the physicochemical properties of edible flowers. Therefore, the spectrum of the flower's properties must be studied when subjected to a drying process used for their conservation. In the present study, the change in the colorimetry of the *Cucurbita maxima* squash flower (whole, halved, and in petals) is analyzed during a convective drying process under controlled conditions using temperatures of 45, 50, and 55 degrees Celsius and airflow of 0.3, 0.6, and 0.9 meters per second. This analysis will help decipher the possible effects of the drying process on the flower, specifically in the color's property, as it becomes the means of catching the eye of a consumer; besides that, a novel food product with good quality attributes could be developed employing dry pumpkin flowers.

2. Material and Methods

2.1. Raw Material. Pumpkin flowers were obtained from a local market located in Temixco, Morelos, Mexico (18.84° N, 99.2356° W at 1258 mamsl). Flowers are available in local markets throughout the year. Samples were washed and disinfected before drying. Initial physicochemical analysis and color properties of pumpkin flowers are shown in Table 1.

2.2. Drying Process. The convective dryer has an acrylic chamber and a metallic tray of 0.35 m^2. The pumpkin flower was dehydrated at 45, 50, and 55°C. The hot air circulates through the drying chamber to the outside. The air velocity (0.3, 0.6, and 0.9 m/s) was controlled using a variable current connected to the fan. The fan has a maximum volumetric flow rate of 570 m^3/h. The heating system consists of three resistors (1500 W); each resistor can work independently, and the temperature is controlled by a proportional-integral-derivative controller which uses a PT1000 thermocouple as a temperature sensor located in the air diffuser between the drying chamber and the resistances. The air is driven by a 1/20 hp motor coupled to a fan (Figure 1).

2.3. Experimental Design. A face-centered central composite design represented as $2^3 + 2(3) + 1$ was used. In this design, three factors (drying temperature, airflow, and shape) were studied. Two levels were used for each variable, with six central points on the faces and one central point (Table 2).

Fifteen experiments were evaluated, and the response variables were analyzed in triplicate (Table 3). The experimental results were analyzed by Minitab 19 (Table 4). The dependent variables were the final moisture content, water activity, and colorimetric properties such as lightness, *a*, *b*, chroma, hue angle, total color difference, and carotenoid range in dried pumpkin flowers.

2.4. Analytical Methods. The moisture content was obtained using a thermobalance (OHAUS, MB45) at 105°C, and 3 g of the sample was distributed uniformly on an aluminum pan inside the equipment. Water activity (a_w) was determined with a Rotronic water activity meter (Higrolab C1) at 25°C, where the disposable sample cup was covered entirely and introduced inside the kit for 20 minutes. The color properties were determined with a High-Quality Colorimeter

Table 1: Physicochemical analysis of pumpkin flower.

Analysis	Mean values ± standard deviation
Moisture (w.b)	96.18 ± 0.68
Water activity	0.980 ± 0.01
Total soluble solids (°Brix)	1.5 ± 0.01
Carotenoid (μg/g)	3000 ± 0.135
L	64.38 ± 2.89
a	18.45 ± 4.37
b	49.95 ± 5.39
Chroma	52.27 ± 0.28
Hue	76.52 ± 0.87

L: lightness; a: greenness-redness; b: yellowness-blueness.

(NR60CP). The values were expressed as L (lightness), a (red-green), b (yellow-blue), H (hue angle), and C (chroma-saturation). From the results obtained, it was possible to calculate the color difference (ΔE) between the raw and dried samples, chroma, and hue angle as reported by Luna et al. [21]:

$$\begin{aligned} \Delta E &= \left(\Delta L^2 + \Delta a^2 + \Delta b^2\right)^{1/2}, \\ C &= \sqrt{(a)^2 + (b)^2}, \\ H &= \operatorname{arctg}\left(\frac{b}{a}\right). \end{aligned} \tag{1}$$

For carotenoid content, around 0.1 g of each sample was dissolved with 10 mL of acetone in a volumetric flask, shaken for 10 min, and then vortexed at 5000 rpm for 10 min. Absorbances of the final extracts were obtained from a spectrophotometer at 472 and 508 nm (UV-Vis Spectrophotometer, Thermo Scientific). All experiments were evaluated in triplicate, and data were employed in the following equations:

$$\begin{aligned} C^R &= \frac{A_{508} * 2144.0 - A_{472} * 403.3}{270.9}, \\ C^Y &= \frac{A_{472} * 1724.3 - A_{508} * 2450.1}{270.9}, \\ C^T &= \mathrm{C}^R + C^Y. \end{aligned} \tag{2}$$

C^T represents the total carotenoid content (μg/mL), which is the sum of the red (C^R) and yellow (C^Y) isochromatic fractions. Ascorbic acid content was obtained following the procedure described by Nweze et al. [22].

3. Results and Discussion

3.1. Characterization of Pumpkin Flower. The initial moisture content of the pumpkin flower was 96.18%, and the water activity was 0.980; according to López et al. [23], the moisture content of flowers is up to 80%. García et al. [13] reported different moisture content in the pumpkin flower that ranged from 85.03 to 96%; therefore, it has a short shelf life. Parameters a and b were positive during the color analysis (Table 1); this means that the color of the pumpkin flower ranges from red to yellow. On the other hand, the hue angle measures the color transition from red to yellow in the product when the hue angle ranges from 0° to 90° [24]. The chroma values in the pumpkin flower were 52.27. The color's saturation is related to the pigment concentration; therefore, the yellow color is pure and intense [13]. Finally, the carotenoid content in pumpkin flowers was 3000 μg/g.

3.2. Moisture Content and Water Activity. The moisture content of the fresh product was reduced from 96.18% to values below 10.2% (Table 4), so dried pumpkin flowers could be stored with a low risk of detrimental reactions [25]. The analysis of variance (Table 3) showed a significant effect of the drying temperature on the moisture content. As seen in Figure 2(a), the moisture content decreased as the temperature increased from 45 to 55°C. García et al. [13] reported a final moisture content in pumpkin flowers from 3.03 to 5.19% with drying temperatures from 50 to 55°C in the solar drying process. Although the shape of the pumpkin flower was insignificant in the final moisture content, Figure 2(a) shows high moisture in the pumpkin flower with the whole shape and decreases with the petal form. Figure 2(b) shows the effect of the independent variables on the final water activity in the dried pumpkin flower. The water activity value in raw pumpkin flower was 0.980, which was reduced during the drying process. In Table 4, the water activity of dried samples ranged from 0.143 to 0.428; this means that biological processes and chemical reactions will not occur quickly. ANOVA demonstrated that drying temperature significantly affected the final water activity and decreased as the drying temperature increased from 45 to 55°C and when the pumpkin flower shape passed from whole to petals form.

3.3. Color Analysis in Dried Pumpkin Flower. The initial lightness value in the raw pumpkin flower was 64.38; as the sample's water content decreases due to temperature and passing time, this colorimetric property tends to decrease because the reflectance of color has been affected by moisture content. Figure 3(a) shows that the lightness increases as the pumpkin flower shape changes from the individual petal to the whole single shape. This behavior is because the high moisture content was observed in the pumpkin flower samples with the whole shape (Figure 1). Yildiz [26] reported a significant increase in lightness by using the freeze-drying process; according to their report, the temperature in the convective and microwave drying causes the reduction in lightness. In this study, the lightness values ranged from 37.87 to 60.80 (Table 4); this means that samples tend to be dark [27]. In the previous analysis of García et al. [13], a decrease in lightness from 65.27 to 61.11 was reported during the solar drying of pumpkin flowers using modified solar dryers. Izli et al. [28] reported that lightness changed from 66.07 to 39.99 as the temperature increased from 50 to 80°C during the convective drying of kumquat slices. Similar behavior was reported by Yildiz [26] in the convective and microwave drying of carrot slices; their results showed that lightness decreased from 71.02 to

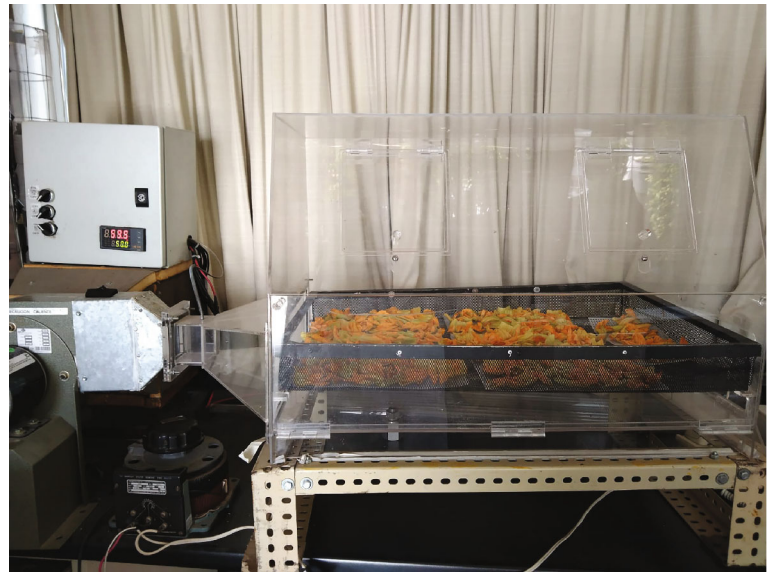


Figure 1: Convective dryer used in the drying process of pumpkin flower (*Cucurbita maxima*).

Table 2: Drying conditions in the convective process of pumpkin flower.

Factors	Symbol	Coded variables		
		(-1)	(0)	(+1)
Drying temperature (°C)	X_1	45	50	55
Airflow (m/s)	X_2	0.3	0.6	0.9
Shape	X_3	Petals	Half	Whole

47.84 in microwave drying and from 71.02 to 58.14 in convective drying as a result of the nonenzymatic browning reactions. García et al. [29] reported a decrease in lightness in peach slices when the airflow pass from 0.3 m/s to 0.9 m/s; as a result, an increment in the browning index was observed. The parameter *a* indicates a color range from 0 (achromatic) to 80 (red) when it is positive; in this case, the initial *a* value in the pumpkin flower was 18.45. During the drying process, this colorimetric parameter ranged from 16.61 to 30.03. The analysis of variance showed that drying temperature significantly affected parameter *a*. According to Figure 3(b), an increment in *a* value was observed when the temperature ranged from 45 to 50°C and decreased from 50 to 55°C. On the other hand, a slight increment in *a* parameter was observed when the airflow increased from 0.3 m/s to 0.9 m/s. An increment in *a* value means that the pumpkin flower tends to be redder. García et al. [13] reported a decrease in *a* value from 18.45 to 13.37 in a polycarbonate dryer and an increment from 18.45 to 20.31 and 20.36 during the solar drying of pumpkin flowers using polyethylene and selective surface, respectively. The loss of water content changes in pH, modification of cellular structure, and degradation of carotenoids may influence the final food color. Parameter *b* indicates a color range from 0 (achromatic) to 80 (yellow) when it is positive; the initial value of this colorimetric parameter was 49.95, and it changed from 34.61 to 61.46 (Table 4). Figure 3(c) shows how the *b* parameter increases as the airflow increases from 0.3 to 0.6 m/s and then tends to decrease when the airflow passes from 0.6 to 0.9 m/s. The increase in *b* values means that the pumpkin flower goes yellow, and the dry product will be less yellow when it decreases. On the other hand, high *b* values were observed in the pumpkin flower with the whole shape because the water content in the dry product prevents color deterioration. Yildiz [26] observed that the microwave and convective drying in carrot slices increased the initial *a* parameter from 12.1 to 25.3 and from 12.1 to 17.4, respectively; however, in freeze-drying, the *a* parameter was closed (11.8) to the initial value (12.1). The hue angle measures the property of the food color, and it is expressed in degrees; the color in the sample went from red to yellow when the hue angle oscillates between 0° and 90°. In this study, the hue angle was 76.52°; therefore, the pumpkin flower is near yellow, which is the natural color of the samples. Figure 3(d) shows that the hue angle increased when the airflow increased from 0.3 to 0.9 m/s, and the drying temperature ranged from 50 to 55°C, resulting in dried flowers with an intense yellow color. García et al. [29] reported that an increase in hue angle means that the color of the peach tends to be yellow, whereas the peach slices tend to be red when the hue angle decreases; on the other hand. García et al. [13] reported that decreasing the hue angle means that the pumpkin flower tends to be orange or less yellow. This behavior was observed in pumpkin flowers' drying process using modified solar dryers; their study reported a decrease in hue angle from an initial value of 76.52° to 69.52° and 70.23° in polyethylene and selective surface dryers. In this case, the opposite effect was observed because the drying temperatures were lower (50-55°C) than the temperatures reported by García et al. in the solar dryers, 75-80°C in polycarbonate dryer, and 60-65 in selective surface dryer; therefore, if a more yellow color is desired in the final product, the drying temperature should be between 50 and 55°C. Chroma takes values from 0 to 60, which refers to the purity

Table 3: Physicochemical properties of dehydrated pumpkin flower.

Coded variables						Response variables						
Test	X_1	X_2	X_3	Moisture content (%)	Water activity	L	a	b	c	H	ΔE	Carotenoid (μg/g)
1	-1	-1	-1	5.65	0.428	47.47	25.67	49.61	55.86	62.67	17.32	1672.82
2	-1	1	-1	5.76	0.272	37.87	20.48	40.22	45.14	63.06	18.14	1963.26
3	1	-1	-1	4.71	0.302	50.96	26.63	34.61	35.24	79.16	37.44	2867.40
4	1	1	-1	5.22	0.163	57.21	18.36	55.39	58.36	71.65	15.34	2244.59
5	-1	-1	1	10.2	0.334	46.66	16.61	37.63	41.15	66.20	21.06	2555.36
6	-1	1	1	8.30	0.225	40.38	23.05	39.73	45.94	59.89	28.05	2253.19
7	1	-1	1	3.11	0.225	53.57	23.78	48.80	54.29	64.04	20.35	1413.29
8	1	1	1	4.70	0.218	60.80	19.34	54.44	57.78	70.44	12.35	1214.30
9	0	-1	0	4.33	0.208	47.42	27.94	53.54	60.40	62.42	17.52	2353.70
10	0	1	0	2.78	0.295	42.75	21.09	42.09	47.09	63.48	35.84	2679.82
11	0	0	0	2.50	0.291	52.82	24.81	53.22	58.72	65.01	19.01	2525.68
12	-1	0	0	5.13	0.273	52.77	24.50	58.25	63.23	67.17	4.830	2134.96
13	1	0	0	3.17	0.143	57.55	19.40	57.30	60.50	71.29	8.070	1293.46
14	0	0	-1	4.33	0.253	60.85	30.03	61.46	68.40	63.97	16.69	1909.15
15	0	0	1	3.67	0.275	52.57	25.88	52.21	58.29	63.69	28.94	1454.84

X_1: drying temperature; X_2: airflow; X_3: shape; L: lightness; a: greenness-redness; b: yellowness-blueness; c: chroma; H: hue; ΔE: color difference.

Table 4: Analysis of variance of response variables.

	P value		
Factor	Moisture content	Water activity	Lightness
X_1	0.028*	0.025*	0.020*
X_2	0.712	0.186	0.057
X_3	0.331	0.208	0.622
	a	b	Chroma
X_1	0.031*	0.621	0.808
X_2	0.071	0.171	0.235
X_3	0.680	0.915	0.970
	Hue angle	Color difference	Carotenoids
X_1	0.01741*	0.221	0.491
X_2	0.71935	0.336	0.225
X_3	0.41900	0.662	0.945

*Significant differences at $\alpha = 0.05$.

or intensity measurement of the product. The fresh pumpkin flower chroma value was 52.07. Results showed that chroma parameter values range from 35.24 to 68.40. Experience has shown that decreasing the chroma parameter leads to a darker sample, and more intense and purer colors can be obtained when the parameter increases. Chroma will increase with increasing pigment concentration and decrease as the sample becomes darker. According to García et al. [29], a product's darkening is related to the increment in $+a$ parameter and decrement in lightness and chroma; this behavior was observed in peach slices. Figure 3(e) shows how chroma increases as the airflow increases from 0.3 to 0.6 m/s and decreases as the airflow passes from 0.6 to 0.9 m/s. Finally, high chroma values were observed in the pumpkin flower with the wall shape. Color difference (ΔE) contrasts fresh and dried flower samples. In Table 4, ΔE values are shown. This parameter presented ranges from 4.830 to 37.44. It is known that when ΔE parameter has values ranging from 0 to 0.5, it indicates a trace level difference and from 0.5 to 1.5 means a slight difference. An ΔE level from 1.5 to 3.0 indicates an unnoticeable difference; from 3.0 to 6.0 is appreciable. From 6.0 to 12 indicates a large difference, and up to 12 means an obvious difference concerning the standard [30]. In this case, although the lowest color difference was 4.830, the color change resulted appreciably. Figure 3(f) shows that the total color difference increases as the temperature increased from 45 to 55°C and when the airflow passes from 0.3 to 0.9 m/s; on the other hand, the lowest ΔE was observed in the pumpkin flower with the whole shape; this behavior can be related with the high moisture content observed in the pumpkin flower with the whole shape (Figure 2(a)).

3.4. Carotenoids. The impact of different air flow and temperatures is plotted in Figure 4; it can be seen that drying at high speed and temperature leads to a higher carotenoid value. This phenomenon could be attributed to the less time employed for drying and the less time the product stays inside the drying chamber affected by the hot air. Similar behavior was observed by Majdi et al. [31] who studied the convective drying of fruit with varying air flow rates and temperatures. P values indicate that the model terms are insignificant; temperature and airflow are unimportant; however, a short drying process is desirable due to the less carotenoid loss in the samples. A similar pattern was reported by Achmad et al. [32], who evaluated the influence of temperature, airflow, and geometry during the convective drying of apples. According to Figures 3(f) and 4, it can be seen that ΔE and carotenoid content follow a similar pattern, so when temperature and airflow rise from one level to

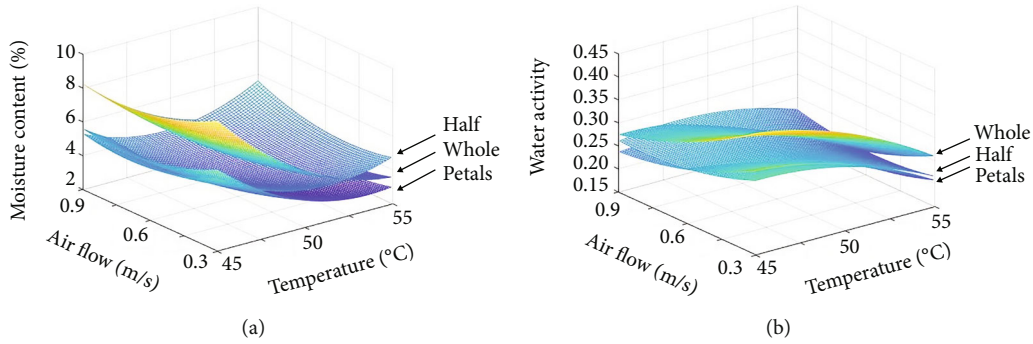


Figure 2: Effect of independent variables on (a) moisture content and (b) water activity.

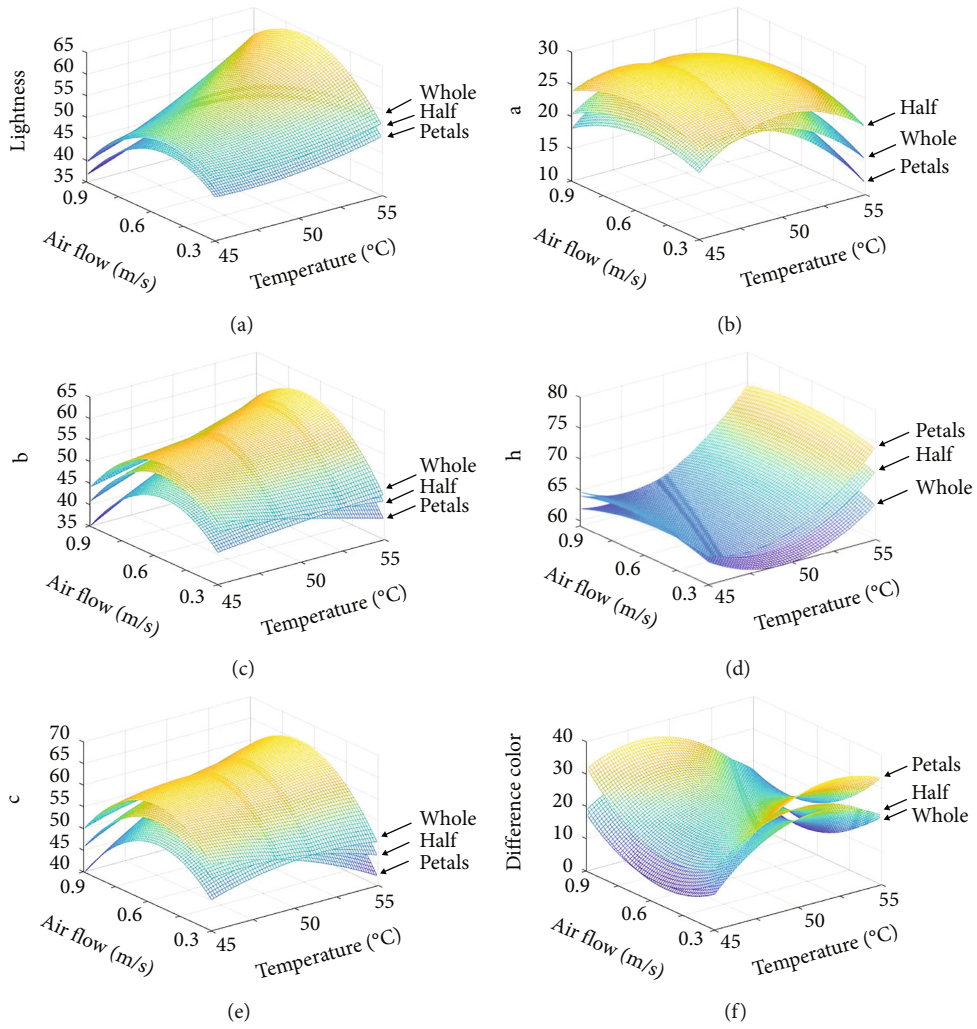


Figure 3: Effect of independent variables on (a) lightness, (b) *a*, (c) *b*, (d) hue, (e) chroma, and (f) color difference.

another, changes are noticeable that might be associated with the intrinsic nature of carotenoids, which are typically red or yellow, and when they are being affected by the surrounding atmosphere tend to change. Drying at a higher temperature leads to a loss in color and carotenoid content due to the nature of heat-sensitive molecules, which is one of the main reasons for keeping drying temperatures as low as possible. However, when that process is conducted, most thermolabile molecules are easily degraded due to the slow evaporation process [31]. Increasing the temperature could reduce drying time, which was more beneficial due to the energy consumption cost. A faster drying process was observed when using a higher drying temperature; the mass of water molecules vaporizing from the surface of the pumpkin flowers increased, accelerating the diffusion of water from the inside of the sample to the surface [33].

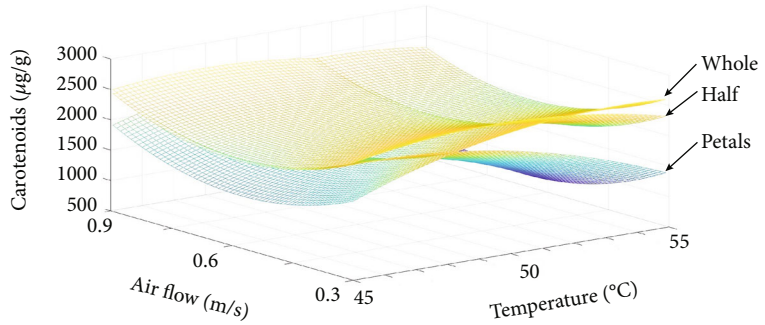


Figure 4: Effect of independent variables on carotenoid content.

Water vapor pressure inside the pumpkin flowers and the equipment's airflow are the main driving forces when drying. The warmer the air, the more water vapor can be transported [34]. Hidar et al. [34] reported a similar behavior during the solar drying of stevia leaves. It was observed that chlorophyll A and flavonoid content decreased with an air-drying temperature increase (50 to 80°C); the variation in pigments is caused by simultaneous heat and mass transfer occurring at the surface of the stevia samples and was depended on the drying temperature. They concluded that prolonged drying at higher temperatures favored undesirable biochemical reactions that caused a decrease in pigments, which is why short drying times are always preferred.

4. Conclusions

The convective drying process of pumpkin flowers was achieved with an excellent final quality product; when the process temperature ranged from 50 to 55°C, the moisture content in the samples was from 3.11 to 10.2%, and water activity was from 0.225 to 0.334, respectively; those intervals are commonly accepted as an indicator of good stability for dry products. It was found that the shape of the flowers and the airflow did not affect the drying process. Still, the inlet temperature significantly affected the moisture content, water activity, hue angle, *a* parameter, and lightness. As the airflow rate increased from 0.3 to 0.9 m/s, the hue angle also did, which means that pumpkin flowers tend to be more yellow. The results of the present work can help preserve the quality attributes of pumpkin flowers during drying processes to develop a new food product with attractive colors and preserved biomolecules. Additionally, they are important for the design of dryers for rural community centers in Mexico, where the production and losses of fruits, vegetables, and edible flowers are high.

Data Availability

Data supporting the findings of this study are available from the corresponding authors upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Alfredo Domínguez-Niño was responsible for the writing, review, and editing. Octavio García-Valladares was responsible for the conceptualization, writing, review, and editing. Ana María Lucho-Gómez was responsible for the data analysis. Paulina Guillén-Velázquez was responsible for the investigation and methodology. César Antonio Ortíz-Sánchez was responsible for the experimentation and data analysis. Beatriz Castillo-Téllez was responsible for the formal analysis, grammar, and editing. Guadalupe Luna-Solano was responsible for the investigation. The authors whose names are listed above agree to be accountable for the content and conclusions of the article.

Acknowledgments

This research was developed through the project 319188 Centro Comunitario para el Deshidratado Solar de Productos Agropecuarios de Pequeños Productores Indígenas de Hueyapan, Morelos CONAHCyT and Investigadores for México CONAHCyT.

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