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OPTIMIZING DRYING CONDITIONS FOR RED FLESH DRAGON FRUIT: A RESPONSE SURFACE METHODOLOGY APPROACH TO ENHANCE NUTRITIONAL QUALITY

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ABSTRACT

This study investigates the effects of tray drying temperature and slice thickness on the physicochemical properties of red-flesh dragon fruit powder, utilizing Response Surface Methodology (RSM) for optimization. Fresh dragon fruit was sourced locally and subjected to drying experiments at varying temperatures (50, 60 and 70 °C) and slice thicknesses (5, 7 and 9 mm). Moisture content, true protein, fat, total carbohydrates, ash content, and crude fiber were analyzed as response variables. Results indicated that increased drying temperatures significantly reduced moisture content, achieving a minimum of 8.84% (wb) at 70 °C with 5 mm thickness. Conversely, true protein content ranged from 3.84% to 5.36%, decreasing with higher temperatures, consistent with thermal denaturation. Fat content varied from 3.79% to 6.57%, with lower temperatures favoring retention. Total carbohydrates increased, ranging from 64.66% to 72.23%, as moisture content decreased. Ash content was between 3.68% and 4.37%, with higher temperatures enhancing mineral retention, particularly in thinner slices. Crude fiber content varied from 3.96% to 7.56%, indicating that moderate thickness and lower temperatures effectively preserved fiber integrity. Optimization using Design-Expert software yielded an optimal drying condition of 70 °C and 5.76 mm thickness, predicting favorable values for all physicochemical properties: moisture content (9.22%), true protein (4.78%), fat (6.04%), carbohydrates (68.15%), ash (4.29%) and crude fiber (6.40%). This study emphasizes the importance of controlled drying parameters in preserving the nutritional quality of red-flesh dragon fruit powder, contributing valuable insights for food processing applications.

Key words : Drying optimization, Nutritional quality, Red flesh dragon fruit, Response surface methodology.

Introduction

Dragon fruit is the fruit of exotic tropical climbing semi-epiphytic vine cacti of the genera *Hylocereus* and *Selenicereus*, which include roughly 20 different species. It is also known by the names Kamalam, Pitaya, or Pitahaya. Fruit is native to tropical forests in South America, Mexico and Central America, but it is currently grown in more than 20 nations worldwide. Growing in popularity in Southeast Asia, it is mostly grown in Vietnam (Wakchaure *et al.*, 2021). Due to its high resistance to drought, ease of adaptation to increased light intensity and temperature, wide tolerance to a variety of soil salinities, and resistance to a number of pests and diseases, it has recently become a super crop with enormous economic appeal and cultivation benefits. The high nutritional value and bioactive compounds found in it also offer numerous health benefits to humans, including potent natural antioxidants. The moisture content in 100 g of fresh dragon fruit pulp can range from 80%, depending on the species and origins. It contains 1.0 to 2.0 g of protein, 12 to 22.0 g of carbohydrates, and 8.0 to 13.0 g of total sugar. The dragon fruit is commercially promising due to its vibrant color, unique appearance, and abundance of nutra-ceutical compounds including antibiotics, fiber, vitamins, and minerals, earning it the nickname "Health Fruit." Additionally, it has diverse applications in the food, medicinal, and cosmetic industries.

In the future, there will be a consistent surplus of market supply due to increased production, potentially resulting in overstocking and postharvest losses. Therefore, effective postharvest management is crucial for the successful marketing of dragon fruit. This is because it is influenced by cultural requirements, stages of harvesting, inherent product characteristics, environmental conditions and transportation and storage requirements. The supply chain for dragon fruit faces numerous difficulties due to the fact that fruit production, prices, and demand are highly influenced by weather conditions and global uncertainties (Nguyen *et al.*, 2020). A perishable fruit with a relatively short shelf life of 5-7 days and primarily consumed fresh, requires efforts to reduce postharvest losses. The exploration of value-adding methods through processing is urgently required to enable continuous production increase and redirect surplus produce for processing (Karunakaran *et al.*, 2019).

Drying, an ancient method used by humans, is employed to preserve food items for an extended period. The process of drying involves eliminating water until reaching a final concentration, ensuring that the product is microbiologically stable and has the expected shelf-life (Lewicki, 2006). This process aims to achieve the product's highest quality attributes, and it is connected to its intended usage. The process of drying involves the liquid turning into vapor as heat is applied to entire fruit, fruit chips, or pieces/slices. This heat can be supplied through conduction (contact or indirect dryers), convection (direct dryers), radiation, microwave or radio frequency electromagnetic methods. Drying with hot air offers a different approach that reduces drying time and enhances the overall quality of the end product. Various types of dryers, including spray dryers, freeze dryers, vacuum dryers, fluidized bed dryers and tray dryers, are utilized in both household and industrial uses. The final one is commonly utilized for drying fruit due to its simple and cost-effective design (Mohite *et al.*, 2016). It employs a hot air flow throughout the entire chamber with forced circulation to dry the fruit. In addition, tray drying extends the fruit's shelf-life, lowers packaging expenses, enables lighter shipping with environmental benefits, and decreases fruit wastage (such as market-rejected fruit), all while introducing a new product derived from the fruit. The use of tray drying on widely grown tropical fruits like banana (Macedo *et al.*, 2020), mango (Caparino *et al.*, 2012), papaya (Reis *et al.*, 2018) and pineapple (Vidinamo *et al.*, 2021) has recently been the subject of research. So far, there have been only a limited number of studies on dragon fruit that have looked at the impact of various drying methods on fruit texture and antioxidants (Ullah *et al.*, 2018), chemical and microstructural properties (Mishra *et al.*, 2021), carotenoids, and volatile compounds (Farina *et al.*, 2020), as well as the creation of mathematical models (Lahbari and Fahloul, 2020; Mishra and Sharma, 2014). Hence, the impact of tray drying on dragon fruit and the quality properties of the resulting product are not widely recognized. One of the key variables in this process is the temperature of the drying air since it affects both the physicochemical characteristics of the dried product and the drying kinetics (Macedo *et al.*, 2020).

The commercial-scale drying of fruit has regained attention in recent years due to the importance of these products for human health (Sadler *et al.*, 2019; Mossine *et al.*, 2020). Dried fruit snacks and their by-products have the potential to be utilized as a component in bakery and confectionery items, as well as additives in various cereal-based products, yogurts, and cheeses. The aim of this study was to establish a tray drying technique for red-fleshed dragon fruit and examine how the drying process affects the proximate, biochemical and functional characteristics of dried fruit. Hence, we researched various air drying temperatures and slice thickness to identify the optimal drying conditions for producing dragon fruit slices. The aim is to create an inexpensive convective drying technique suitable for dragon fruit processing and applicable in both small and large-scale production. This method aims to yield a new product with an extended shelf life.

Materials and Methods

Experiment details

Fresh red-flesh dragon fruit, ripe and ready to eat, was obtained from the local market in Junagadh, Gujarat, India. The fruit has its typical flavor and texture, and it is ready to be enjoyed. The experiment was conducted at the Department of Processing and Food Engineering at Junagadh Agricultural University in Junagadh, Gujarat, India. The drying experiment utilized a tray dryer developed by Khera Instrumental Pvt Ltd, based in Delhi. The analysis was conducted using analytical grade chemicals.

Several preliminary experiments were conducted to determine the optimal combination of temperature and slice thickness for drying dragon fruit. The raw dragon fruits with skin were washed using tap water. The stainless-steel knife was used to cut and peel the fruits, and then they were sliced into round shapes of varying thicknesses (5 mm, 7 mm and 9 mm) using a stainless-steel adjustable slicer. To dry the sliced dragon fruit samples, 1 kg of each thickness was dried at three different temperatures (50^{0}C, 60^{0}C and 70^{0}C). Before loading the samples, the tray dryer was preheated to the desired temperature. This approach enabled accurate monitoring and control of the drying process, enabling the evaluation of how the quality parameters of the product were affected by slice thickness and drying temperature.

Experimental Design and Statistical Analysis

The experiment was designed as per the Response Surface Methodology (RSM) for optimizing the drying process parameters. Response Surface Methodology is an empirical statistical modeling technique employed for multiple regression analysis using quantitative data obtained from properly designed experiments to solve multivariable equations simultaneously. It was used for designing of the experiment (Myres, 1976; Khuri and Cornell, 1987; Montgomery, 2001).

In this study, two-factor three-level Central Composite Face Centered Design (CCFCD) with suggested model was utilized for the following purposes:

1. To investigate the combined effect of two independent variables, namely temperature (X_1) and thickness of the dragon fruit slices (X_2), on various response variables.
2. To determine the influence of these variables and optimize the selected response variables.

Three different levels for each independent variable in coded form are:

-1, 0, +1

The relationship between the coded and actual values of a factor is given by

Coded value = $X_i = (x_i - x_{cp})/\Delta x_i$

Where,

x_i = Real value of an independent variable

x_{cp} = Real value of an independent variable at centre point

Δx_i = Step change of real value of the variable i corresponding to a variation of a unit for the coded value of the variable I.

The selected levels for the independent parameters along with their coding are presented in Table 1. The range of temperature and thickness of slices were between 50-70 and 5-9 mm, respectively.

Table 1 : Independent parameters and their coded and actual values employed for drying of dragon fruit.

Parameters		Coded variables		
		-1	**0**	**+1**
Temperature (^{0}C)	(X_1)	50	60	70
Thickness of slices (mm)	(X_2)	5	7	9

Table 2 : Experimental run of central composite face centered design for drying of dragon fruit.

Std	Run	Coded variables		Uncoded variables	
		X_1	X_2	Variable 1 A: Temperature (^{0}C)	Variable 2 B:Thickness (mm)
6	1	+1	0	70	7
8	2	0	+1	60	9
13	3	0	0	60	7
9	4	0	0	60	7
12	5	0	0	60	7
2	6	+1	-1	70	5
10	7	0	0	60	7
5	8	-1	0	50	7
7	9	0	-1	60	5
3	10	-1	+1	50	9
4	11	+1	+1	70	9
1	12	-1	-1	50	5
11	13	0	0	60	7

As per the CCFCD, total number of treatment combinations

= $(2)^{\text{No. of variables}}$ + (2 No. of variables) + central points

Here, number of variables: 2

Hence, total number of treatment combinations

= 2^2 + (2 2) + 5 = 4 + 4+ 5 = 13

Hence, a total of 13 combinations including four factorial points, five central points and four extra axial points were carried out in random order according to a CCFCD configuration for the two chosen variables. The experimental design matrix in coded (X) form and at the actual level of variables is presented in Table 2.

The response function (Y) was related to the coded variables by a second-degree polynomial equation as given below:

$$Y = b_0 + \sum_{i=1}^{j} b_i X_i + \sum_{i=1}^{j} b_{ij} X_i{}^2 + \sum_{i \neq j=1}^{j} b_{ij} X_i X_j$$

Where, b_0 is the constant, b_i the linear coefficient, b_{ii} the quadratic coefficient and b_{ij} the interactive coefficient, X_i and X_j are the levels of the independent variable. So, the second order polynomial function for the experiment can be given as under:

$$Y = b_0+b_1X_1+b_2X_2+b_{11}X_1^2+b_{12}X_1X_2$$

Where, Y is the response calculated by the model; X_1 and X_2 are the code of independent variables, *i.e.*, temperature and thickness of slices, respectively, b_0 is constant term, b_1 and b_2 are linear, b_{11}, b_{22} are quadratic and b_{12} is interaction coefficient, respectively (Anderson and Whitcomb, 2005).

The second order polynomial coefficients were calculated by using the software package Design Expert version 13 (Trial version; STAT-EASE Inc., Minneapolis, MN, USA) to estimate the response of the dependent variable. The accuracy and fit statistics of the model were studied based on the analysis of variance (ANOVA) with a significant ($p < 0.05$) model F-value and non-significant lack of fit ($p > 0.05$), the highest coefficient of determination (R^2), minimum coefficient of variation, and standard deviation.

Powder preparation

The hot air tray dried slices of different treatments were separately ground in a domestic mixture to obtain dragon fruit powder. The obtained powder was characterized for physicochemical characteristics to optimize the drying parameters.

Determination of Response Parameters

Moisture content

The moisture content of dragon fruit powder was determined using the hot air oven drying method (AOAC, 2005). Clean petri dishes were placed in an oven at 100°C for 1 hour, cooled in a desiccator with silica gel for 30 minutes and weighed. About 5 g of fresh samples were mixed and placed in the pre-weighed dishes (W_1). The samples were dried in a hot air oven at 65 ± 5°C for 15-16 hours, cooled to room temperature, and reweighed (W_2). Moisture content was calculated as the percentage of mass loss using the formula:

$$\text{Moisture content (\%wb)} = \frac{W_1 - W_2}{W_1} \times 100 \qquad (1)$$

True Protein

The true protein content of dragon fruit powder was determined using the Folin-Lowry method (Lowry *et al.*, 1951). A dried sample (0.1-0.2 g) was placed in a test tube with 10 ml of 0.1 N NaOH and left overnight for extraction. The supernatant was collected for analysis. Standard BSA solutions (0.2, 0.4, 0.6, 0.8, and 1 mL) and 0.2 mL of the sample supernatant were transferred to separate test tubes. The volume was adjusted to 1 mL with distilled water. After mixing, 5 mL of reagent C was added and left for 10 minutes, followed by 0.5 mL of reagent D (FCR). The tubes were incubated in the dark for 30 minutes until a blue color developed. The optical density was measured at 660 nm, and the true protein content was calculated using following formula:

True protein (%)

$$= \frac{\begin{array}{c}\textit{Initial mass of sample} \times G.F. \times \textit{Total volume} \\ \times \textit{Dilution volume} \times 100\end{array}}{\textit{Volume of aliquots taken} \times \textit{Mass of sample} \times 10^6} \qquad (2)$$

Fat content

The fat content of dragon fruit powder was determined using the Soxhlet extraction method (AOAC, 2005). A moisture-free sample (2 g, W_1) was placed in a thimble and inserted into a Soxhlet extractor with a pre-weighed beaker (W_2). Fat was extracted with petroleum ether (boiling point 60-70°C) for 2 hours. After extraction, the remaining ether was evaporated in a hot oven at 100°C for 30 minutes. The beaker was then cooled in a desiccator and reweighed (W_3) to calculate the ether-soluble fat content using the provided formula:

$$\text{Fat content (\%)} = \frac{W_3 - W_2}{W_1} \times 100 \qquad (3)$$

Total carbohydrates

The carbohydrate content of the sample was determined using the phenol sulphuric acid method (Dubois *et al.*, 1956). A dried sample (0.1-0.2 g) was hydrolyzed with 10 ml of 2.5 N HCl in a boiling water bath for 3 hours and cooled. The supernatant was collected and 0.2 ml was pipetted into test tubes. The volume was adjusted to 1 ml with distilled water. Then, 1 ml of 5% phenol reagent and 5 ml of 96% H_2SO_4 were added and the contents were mixed. The tubes were left at 25-30°C for 25-30 minutes. Glucose standards were also processed. Optical density was measured at 490 nm and carbohydrate content was calculated using provided formula:

Total carbohydrates (%)

$$= \frac{\begin{array}{c}\textit{Initial mass of sample} \times G.F. \times \textit{Total volume} \\ \times \textit{Dilution volume} \times 100\end{array}}{\textit{Volume of aliquots taken} \times \textit{Mass of sample} \times 10^6} \qquad (4)$$

Ash content

The ash content of sample was analyzed using a muffle furnace according to the method outlined in AOAC (2005). A 5g sample was placed in a silica crucible and heated over a Bunsen burner until the fumes ceased (churning process), then transferred to a muffle furnace until a clean ash was obtained. The furnace temperature was increased to 550 °C. The remaining mass was recorded, and the ash content was calculated using the following formula:

$$\text{Ash content (\%)} = \frac{\textit{Weight of ash}}{\textit{Weight of sample}} \times 100 \qquad (5)$$

Crude fibre

Crude fiber estimation involved weighing 2 g of the sample into a fiber flask, adding 100 ml of 0.25N H_2SO_4, and heating under reflux for 1 hour. The mixture was filtered, and the residue was placed back in the flask with 100 ml of 0.1N NaOH, then refluxed for another hour. The mixture was filtered again, and 10 ml of acetone was added. The residue was rinsed, transferred to a crucible and dried at 105°C overnight. After cooling and weighing (W_1), the crucible was ashed at 550°C for 4 hours. The crucible was reweighed (W_2), and the fiber content was calculated as the difference between W_1 and W_2. According to AOAC (2006), the percentage of fiber can be calculated using the following formula:

$$\text{Crude fibre (\%)} = \frac{W_1 - W_2}{\textit{Weight of sample}} \times 100 \qquad (6)$$

Results and Discussion

Influence of Tray Drying Parameters on Responses and Model Fitting

Moisture content

Table 3 presents the moisture content of dragon fruit powder across all treatment combinations. The results indicate that moisture content decreases with increasing drying temperature and decreasing slice thickness. Figure 1 illustrates the interactive effect of temperature and slice thickness on moisture content. Run 6 in Table 3 shows the lowest moisture content at 8.84% (wb), corresponding to the highest temperature and minimum thickness. The highest moisture content, 12.98% (wb), was observed at a temperature of 50°C and a slice thickness of 9 mm. This trend can be attributed to the fact that higher temperatures accelerate the diffusion of water molecules, leading to reduced moisture content. Thicker slices, however, have greater internal resistance to moisture migration, which slows down the drying process, while thinner slices, with a higher surface area-to-volume ratio, lose moisture more quickly. These findings align with

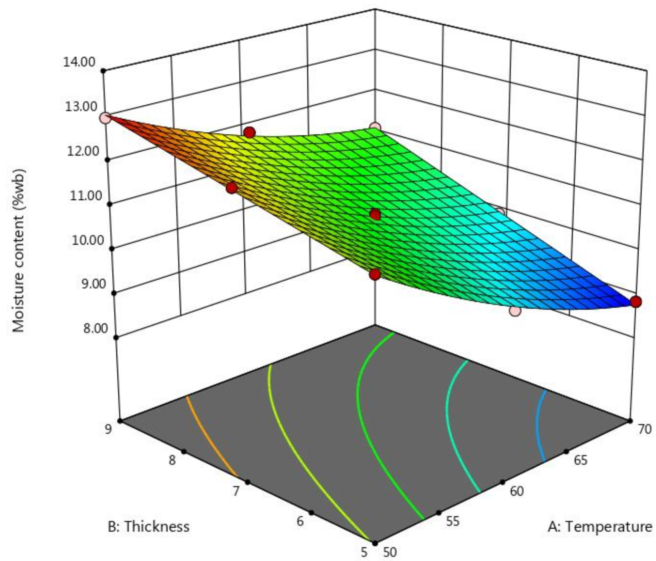

Fig. 1 : Response surface plot for moisture content as a function of temperature and thickness of slices.

Melesse and Emire (2022), who reported that dried samples had significantly lower moisture content ($p<0.05$) compared to fresh samples, noting that as temperature increases and slice thickness decreases, the moisture content of dried products decreases. Similarly, Akagbe *et al.* (2020) found that higher temperatures provide more energy for water molecules to escape from the surface, facilitating faster drying compared to lower temperatures. Table 4 shows that the linear effects of temperature and thickness had significant negative and positive impacts on moisture content, respectively ($P<0.0001$). The quadratic effect of temperature was positive and significant ($P<0.0001$), while the quadratic effect of thickness was negative and not significant. Although the interaction between temperature and thickness was positive, it was not statistically significant. The quadratic model provided the best fit for the experimental data, with an analysis of variance showing high significance ($p<0.0001$) and an F-value of 614.51. The lack-of-fit F-value was 8.37 ($p>0.05$), indicating excellent model predictability. The model's coefficient of determination ($R^2 = 0.9977$), low coefficient of variance (0.63%), and standard deviation (0.068) further confirm the model's robustness. The derived model giving the empirical relationship between the moisture content and the test variables in coded units was obtained as under given in equation 7:

$$\text{Moisture content (\%wb)} = 10.80 - 1.19X_1 + 0.9467X_2 + 0.2200\,X_1X_2 + 0.3369X_1^2 - 0.0031X_2^2 \qquad (7)$$

True protein

The true protein content of dragon fruit powder decreased due to thermal processing by tray drying,

Table 3 : Experimental values of different proximate composition of dried dragon fruit powder at various treatment combination.

Std	Run	Temperature ^0C	Thickness mm	Moisture content% wb	Protein %	Fat %	Carbohyd-rates %	Ash content %	Fibre %
6	1	70	7	9.89	4.41	5.65	67.73	4.15	6.7
8	2	60	9	11.82	4.13	4.55	72	3.68	3.96
13	3	60	7	10.76	4.74	5.77	68.39	3.9	6.08
9	4	60	7	10.85	4.71	5.65	68.31	3.91	6.06
12	5	60	7	10.79	4.67	5.72	68.42	3.89	6.11
2	6	70	5	8.84	4.95	5.86	69.57	4.37	5.55
10	7	60	7	10.8	4.77	5.64	68.65	3.92	6.09
5	8	50	7	12.37	4.9	6.57	64.66	3.93	7.56
7	9	60	5	9.76	5.26	5.12	70.45	4.23	5.47
3	10	50	9	12.98	4.54	6.51	67.28	3.73	5.06
4	11	70	9	11.09	3.84	3.79	72.23	3.98	6
1	12	50	5	11.61	5.36	4.74	67.79	4.17	7.04
11	13	60	7	10.78	4.64	6.02	68.37	3.96	6.61

ranging from 3.84% to 5.36%. The influence of various tray drying temperatures and sample thicknesses on true protein was best predicted by a polynomial equation, as shown in Equation 8. The 2FI model provided the best fit for the experimental data, with an analysis of variance showing high significance (P<0.0001) and an F-value of 229.82. The lack-of-fit F-value was 1.12 (P>0.05), indicating excellent predictability. The model's coefficient of determination (R^2 = 0.9871), low coefficient of variance (1.15%) and standard deviation (0.054) further supported the model's accuracy. The interaction between tray drying temperature and sample thickness on true protein content is visualized in the three-dimensional response surface plot (Fig. 2). Temperature, thickness, and their interaction had a significant effect on the true protein of tray-dried dragon fruit powder (Table 4). Both higher temperatures and thicker slices had a negative impact on true protein, with the highest true protein content observed in run 12 (50°C, 5 mm slices) in Table 3. The reduction in protein content is likely due to denaturation and thermal degradation of proteins at higher temperatures and thicknesses during drying. Melesse and Emire (2022) found significant differences (p<0.05) in protein content across different drying temperatures and slice thicknesses in mango, with an average protein content of 2.602% at 70°C compared to 2.501% at 80°C. Bhat *et al.* (2022) also reported a decrease in protein content with increasing drying temperatures for kiwi fruit. This protein loss is likely due to denaturation caused by higher air temperatures (Isik *et al.*, 2018). Some protein components are highly sensitive to convective drying, and optimizing drying conditions can help minimize protein loss.

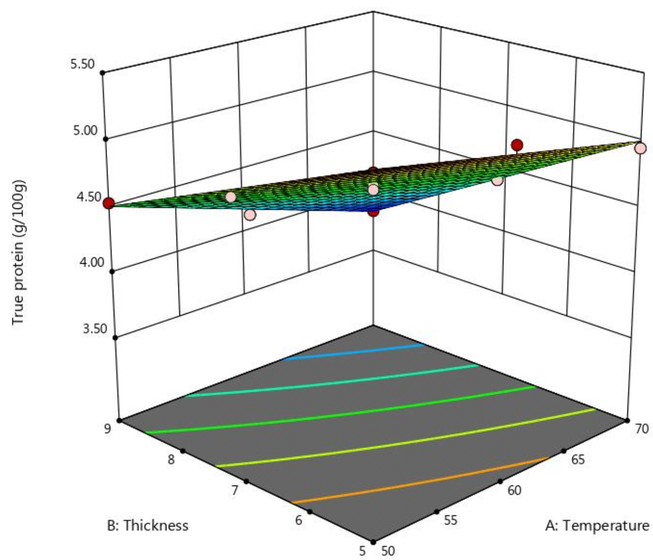

Fig. 2 : Response surface plot for true protein as a function of temperature and thickness of slices.

$$\text{True protein (\%)} = 4.69 - 0.2667X_1 - 0.5100X_2 - 0.0725\,X_1X_2 \quad (8)$$

Fat content

Fat content is sensitive to thermal processing, with most losses occurring during convective hot air drying. The fat content of tray-dried dragon fruit powder ranged from 3.79% to 6.57%, as shown in Table 3. These losses can be minimized through optimization of the drying process. The effect of independent variables on fat content was analyzed by fitting the experimental results into a polynomial equation. The quadratic model provided the best fit, with a significant F-value of 62.26 (Table 4, Equation 9). Model fit was further supported by a high

R^2 value and low coefficient of variance and standard deviation (Table 4). The interaction effect of independent variables on fat content is illustrated in the three-dimensional response surface plot (Fig. 3). The regression coefficient of the quadratic model reflects the expected change in fat content with unit changes in the independent variables, assuming other factors remain constant. The linear effects of temperature and thickness, as well as the quadratic effect of temperature, resulted in a non-significant decrease in fat content. However, the interaction between temperature and thickness, along with the quadratic effect of thickness, had a significant impact on the fat content of tray-dried dragon fruit powder. Higher temperatures and thicker slices led to fat degradation or oxidation, causing greater reductions in fat content. Lower drying temperatures and moderate slice thickness preserved the highest fat content. Melesse and Emire (2022) also found significant differences ($p<0.05$) in the fat content of mango chips based on drying air temperature and slice thickness. As slice thickness increased, fat content decreased and higher drying temperatures further reduced fat content. Bhat et al. (2022) observed fat content ranging from 5.50% to 7.22% in dried kiwi slices, with a gradual loss of lipids as air temperature increased. Chakraborty *et al.* (2020) similarly reported lipid loss due to higher air temperatures, leading to reduced fat content in dried samples.

$$\text{Fat content (\%)} = 5.75 - 0.4200X_1 - 0.1450X_2 - 0.9600X_1X_2 + 0.36993X_1^2 - 0.9057X_2^2 \quad (9)$$

Total carbohydrates

The total carbohydrate content of dragon fruit powder across all treatment combinations is presented in Table 3, ranging from 64.66% to 72.23%. The effect of varying tray-drying temperatures and sample thickness on the total carbohydrates was best predicted by fitting the experimental data into a polynomial equation. The quadratic model provided the best fit, with high significance ($p<0.0001$) and an F-value of 32.45. The lack-of-fit F-value was 2.73 ($P>0.05$), indicating the model's excellent predictability. The coefficient of determination ($R^2 = 0.9957$), low coefficient of variance (0.25%), and standard deviation (0.17) further support the model's fit. The interaction between drying temperature and slice thickness on total carbohydrates is visualized in the three-dimensional response surface plot (Fig. 4). The main effects of temperature and thickness (X_1 and X_2), their interaction (X_1X_2), and the quadratic terms (X_1^2 and X_2^2) all significantly influenced the total carbohydrates of tray-dried dragon fruit powder, as shown in Table 4 and Equation 10. As fresh dragon fruit has high moisture content, increasing temperature and thickness had a positive impact on total carbohydrate levels. Higher temperatures likely enhance drying efficiency, reducing moisture content and concentrating the carbohydrates. In contrast, lower temperatures may not remove moisture as effectively, leading to lower carbohydrate concentrations due to the higher water content. Thicker slices may retain more carbohydrates because of prolonged drying times, allowing the carbohydrates to concentrate as water evaporates. Conversely, thinner slices, which dry faster, might show slightly lower carbohydrate concentrations due to quicker moisture loss. These findings suggest that thicker slices at higher temperatures result in greater carbohydrate concentration as moisture evaporates. This is consistent with Melesse

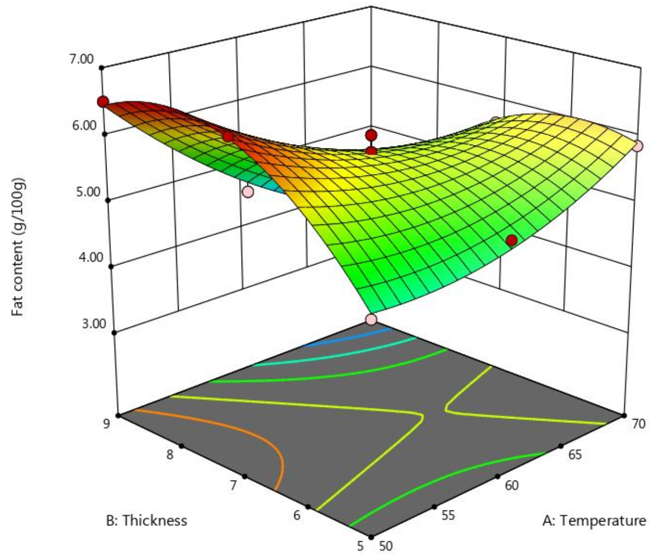

Fig. 3 : Response surface plot for fat content as a function of temperature and thickness of slices.

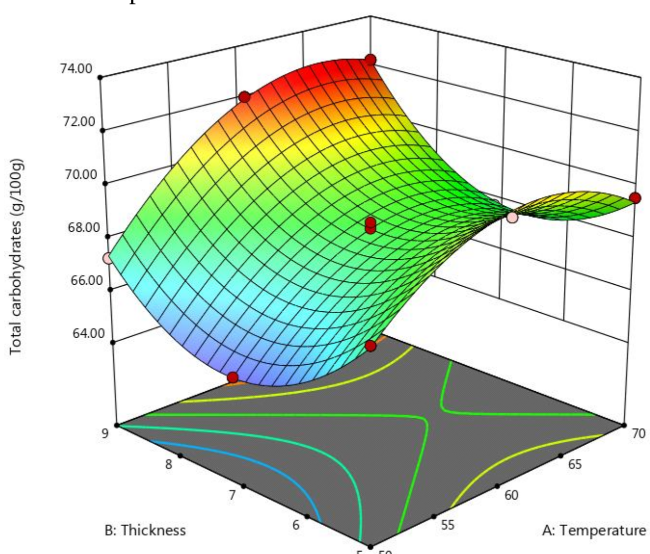

Fig. 4 : Response surface plot for total carbohydrates as a function of temperature and thickness of slices.

Table 4 : Analysis of Variance (ANOVA) and regression coefficients for response surface model of different proximate composition of dried dragon fruit powder.

Source	Moisture content (%)	True protein g/100g	Fat content g/100g	Total Carbohydrates g/100g	Ash content g/100g	Crude fibre g/100g
Intercept	10.80	4.69	5.75	68.40	3.92	6.15
X_1	-1.19**	-0.2667**	-0.4200	1.63**	0.1117	-0.2350
X_2	0.9467**	-0.5100**	-0.1450	0.6167**	-0.2300**	-0.5067*
$X_1 X_2$	0.2200	-0.0725*	-0.9600**	0.7925**	0.0125	0.6075*
X_1^2	0.3369**	-	0.36993	-2.12**	0.1160	1.06
X_2^2	-0.0031	-	-0.9057**	2.91**	0.0310	-1.35**
R^2	0.9977	0.9871	0.9780	0.9957	0.9799	0.9429
Adj-R^2	0.9961	0.9828	0.9623	0.9925	0.9656	0.9022
Pred.-R^2	0.9796	0.9667	0.8911	0.9706	0.8525	0.6293
Adeq. Precision	91.7821	51.8853	27.7110	64.8400	27.7584	16.3317
F-value	614.51	229.82	62.26	320.45	68.29	23.13
Lack of fit	S	NS	NS	NS	NS	NS
C.V.%	0.6259	1.15	2.75	0.2503	0.9090	4.72
Std. Dev.	0.0685	0.0540	0.1514	0.1721	0.0362	0.2845

Table 5 : Constraints and criteria for numerical optimization of dried dragon fruit powder.

Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
Independent parameters						
X_1:Temperature (^{0}C)	is in range	50	70	1	1	3
X_2:Thickness (mm)	is in range	5	9	1	1	3
Dependent parameters						
Moisture content (%wb)	minimize	8.84	12.98	1	1	5
True protein (%)	is in range	3.84	5.36	1	1	3
Fat content (%)	is in range	3.79	6.57	1	1	3
Total carbohydrates (%)	is in range	64.66	72.23	1	1	3
Ash content (%)	maximize	3.68	4.37	1	1	5
Crude fibre (%)	maximize	3.96	7.56	1	1	5

and Emire (2022), who reported that increasing temperature and thickness significantly elevated carbohydrate levels in dried products. Similarly, Akagbe *et al*. (2020) noted that carbohydrates were the most sensitive to drying temperature, increasing nearly fourfold as temperature nearly doubled.

$$\text{Total carbohydrates (\%)} = 68.40 + 1.63X_1 + 0.6167X_2 + 0.7925X_1X_2 - 2.12X_1^2 + 2.91X_2^2 \quad (10)$$

Ash content

The ash content of tray-dried dragon fruit powder ranged from 3.68% to 4.37%, as shown in Table 3. These losses in ash content can be reduced by optimizing the drying process. The effect of independent factors on ash content was analyzed by fitting the experimental results into a polynomial equation, with the quadratic model providing a better fit. The model had a significant F-value of 68.29 (Table 4, Equation 11). The model's predictability was confirmed by the highest R^2 value and the lowest coefficient of variance and standard deviation, as shown in Table 4. The interaction between the independent factors and ash content is illustrated in the three-dimensional response surface plot (Fig. 5). The regression coefficient of the quadratic model predicts changes in ash content based on variations in the independent factors, while keeping all other factors constant. The linear effect of temperature, as well as the interaction and quadratic effects of temperature and thickness, were not significantly associated with changes in ash content. However, the linear effect of thickness had a significant

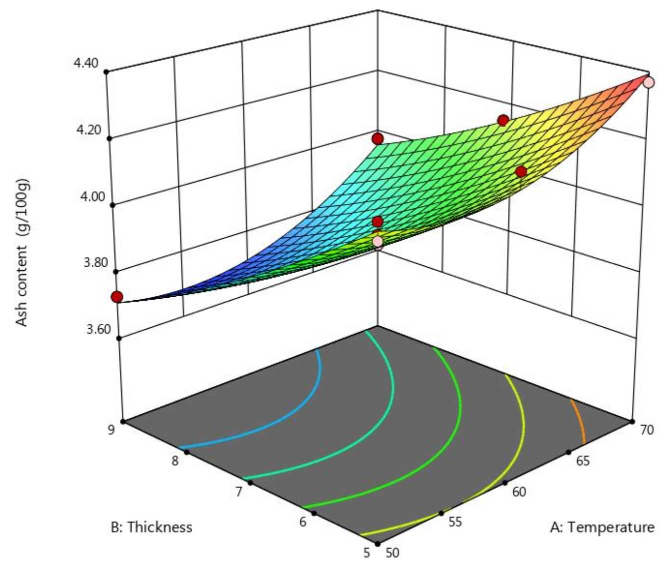

Fig. 5 : Response surface plot for ash content as a function of temperature and thickness of slices.

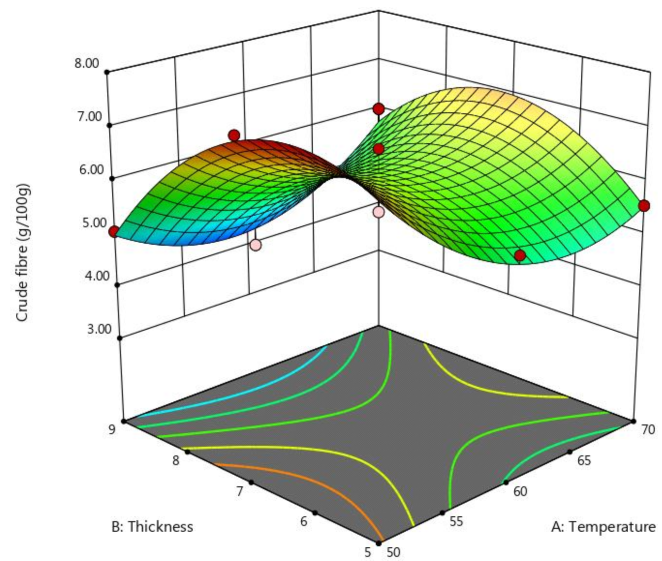

Fig. 6 : Response surface plot for crude fibre as a function of temperature and thickness of slices.

impact. Higher temperatures led to better ash retention, particularly in thinner slices, as observed in run 6 (Table 3). This may be because faster drying reduces the loss of mineral components by accelerating moisture removal, thereby preserving the ash content. Conversely, in thicker slices, the ash content decreased slightly, potentially due to slower moisture evaporation and increased degradation of minerals at higher temperatures. These findings align with Akagbe *et al.* (2020), who noted a marginal increase in ash content with higher drying temperatures during the tray drying of bananas. Similarly, Yusufe *et al.* (2017) reported that the ash content of tomatoes was significantly affected ($p \leq 0.001$) by the interaction between drying duration and temperature.

Table 6 : Optimized condition for tray-dried dragon fruit powder as an output of Design-Expert Software.

Constraints	Predicted values	Desirability
Temperature (^{0}C)	70	0.818
Thickness (mm)	5.758	
Moisture content (%wb)	9.216	
True protein (%)	4.781	
Fat content (%)	6.041	
Total carbohydrates (%)	68.152	
Ash content (%)	4.293	
Crude fibre (%)	6.4	

$$\text{Ash content (\%)} = 3.92 + 0.1117X_1 - 0.2300X_2 + 0.0125X_1X_2 + 0.1160X_1^2 + 0.0310X_2^2 \quad (11)$$

Crude fibre

The crude fiber content of dragon fruit powder across various treatment combinations is presented in Table 3, with values ranging from 3.96% to 7.56%. The impact of a broad range of tray-drying temperatures and sample thickness on crude fiber was best modeled using a polynomial equation. The quadratic model proved to be the most effective fit for the experimental data, showing a high level of significance ($p < 0.005$) with an F-value of 23.13. The F-value for lack of fit was 2.07 ($P > 0.05$), indicating the model's strong predictability. The coefficient of determination ($R^2 = 0.9429$), along with a coefficient of variance of 4.72% and a standard deviation of 0.28, further supports the model's validity. The interaction effect of tray drying temperature and sample thickness on crude fiber is depicted in the three-dimensional response surface plot shown in Fig. 4. The main effect of sample thickness (X_2), along with its interaction (X_1X_2) and the quadratic effect of thickness (X_2^2), significantly impacted the crude fiber content of tray-dried dragon fruit powder (refer to Table 4 and equation 12). Conversely, the linear and quadratic effects of temperature (X_1 and X_1^2) did not significantly affect the dried dragon fruit powder. The findings suggest that moderate thickness and lower temperatures are most effective for retaining crude fiber. This may be attributed to the fact that higher temperatures can lead to the thermal degradation of cellulose, hemicellulose, and lignin components within the fiber. Lower temperatures, in contrast, facilitate gentler drying, which helps preserve the fiber structure. Additionally, thicker slices tend to retain moisture, resulting in longer drying times and greater exposure to heat, which can break down fiber content. On the other hand, thinner slices dry more efficiently at lower temperatures, allowing them to retain more fiber due to reduced heat exposure.

Melesse and Emire (2022) reported significant differences ($p < 0.05$) in crude fiber content across all drying air temperatures.

$$\text{Crude fibre (\%)} = 6.15 - 0.2350X_1 - 0.5067X_2 + 0.6075X_1X_2 + 1.06X_1^2 - 1.35X_2^2 \quad (12)$$

Optimization of Drying Parameters

Optimization of tray drying process parameters for dragon fruit were based on fixed-set goals and importance as shown in Table 5. Design-Expert software generated the possible solutions for independent factors and their corresponding responses. As shown in Table 6, the highest desirability 0.818 was found at optimized condition with temperature of 70^0C and thickness of slices 5.758 mm and predicted values of moisture content, true protein, fat content, total carbohydrates, ash content and crude fibre at optimized condition were found 9.22, 4.78, 6.04, 68.15, 4.29 and 6.40%, respectively.

Conclusion

This study evaluated the effects of tray drying temperature and slice thickness on the physicochemical properties of red-flesh dragon fruit powder, employing Response Surface Methodology for optimization. The findings revealed that increasing drying temperatures significantly decreased moisture content while impacting the nutritional quality of the powder. Specifically, the moisture content was lowest at 70°C with 5 mm slice thickness, highlighting the efficacy of higher temperatures in moisture removal. Conversely, higher temperatures and thicker slices resulted in reduced true protein and fat content, indicating protein denaturation and fat loss due to thermal processing. This is in line with previous literature, emphasizing the delicate balance between drying parameters and nutrient preservation. Total carbohydrate content increased with higher temperatures, reflecting the efficient moisture reduction while maintaining essential carbohydrates. Similarly, ash content was positively correlated with temperature, particularly in thinner slices, confirming the enhanced mineral retention under certain conditions. Crude fiber content demonstrated significant interaction effects, revealing that moderate thickness combined with lower temperatures effectively preserved fiber integrity. Optimization of drying parameters through Design-Expert software indicated that a temperature of 70°C and a thickness of approximately 5.76 mm maximized overall desirability, achieving desirable nutritional attributes. The optimized conditions yielded moisture content of 9.22%, true protein at 4.78%, fat content of 6.04%, total carbohydrates at 68.15%, ash content at 4.29%, and crude fiber at 6.40%. Overall, the study underscores the importance of precise control over drying parameters in preserving the nutritional quality of red-flesh dragon fruit powder, offering valuable insights for food processing applications aimed at enhancing product quality while ensuring efficiency.

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