

Research Article

Optimization of Drying Parameters for Pretreated Green Banana Slices Using Response Surface Methodology

Kushal P. Dhake ¹, Sanjay Kumar Jain ², Sandeep Jagtap ^{3,4} and Pankaj B. Pathare ⁵

¹Section of Agricultural Engineering, College of Agriculture, Mahatma Phule Krishi Vidyapeeth, Muktainagar, Rahuri, Maharashtra, India

²Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India

³Division of Engineering Logistics, Lund University, Lund 22363, Sweden

⁴Sustainable Manufacturing Systems Centre, Cranfield University, Cranfield MK43 0AL, UK

⁵Department of Soils, Water and Agricultural Engineering, College of Agricultural & Marine Sciences, Sultan Qaboos University, Muscat 123, Oman

Correspondence should be addressed to Pankaj B. Pathare; pankaj@squ.edu.om

Received 12 October 2024; Accepted 8 January 2025

Academic Editor: Ravi Pandiselvam

Copyright © 2025 Kushal P. Dhake et al. Journal of Food Quality published by John Wiley & Sons Ltd. This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

In this study, the influence of drying temperature and pretreatment on the drying kinetics and quality metrics of green banana slices was investigated. The present investigation included the drying of 4 ± 1 mm green banana slices with potassium metabisulfite (KMS) at levels of 0 (control), 0.5%, 1%, and 1.5% in a tray dryer. A numerical optimization method was utilized to optimize the drying rate, color, water activity, rehydration ratio, and attractiveness of the banana slices, using a variety of input factors such as drying temperature and pretreatment. The results revealed that the untreated samples and those treated with 1.0% and 1.5% KMS required a longer drying time than the samples treated with 0.5% KMS. The process parameters were optimized using response surface methodology, adopting an I-optimal design for this investigation. The best solution yielded a drying air temperature of 60.62°C and a pretreatment level of 0.786% KMS, resulting in a drying time of 346.28 min, a color (L^*) value of 76.23, a water activity (a_w) of 0.299, and a rehydration ratio of 2.81. Similar outcomes were obtained when the optimized conditions were tested and compared with experimental data using an experimental validation process.

Keywords: color; green banana slices; optimization; pretreatment; rehydration; response surface methodology

1. Introduction

Banana (*Musa paradisiaca*) is an herbaceous tropical plant belonging to the Musaceae family. Among all fruits, bananas are the most abundant, inexpensive, and nutrient-dense [1–3]. They are widely regarded as the most important tropical fruit in the global market, and people of all ages enjoy them in various forms (both dried and fresh) [4]. The banana is the fourth most important crop in the world, following rice, wheat, and maize. Besides this, postharvest losses represent a major concern for green bananas due to improper handling. As a perishable fruit, such losses can be

minimized through the processing of green bananas and conversion of dried green bananas into various products [5–7]. While processing fruits, preservation and processing techniques become crucial. These techniques include canning, frying, and drying, which encompasses methods such as osmotic dehydration and convection drying. Drying is regarded as the best method for preserving fresh produce, as it reduces not only the volume of raw material but also its weight. It involves reducing moisture to a predefined level under controlled conditions through a simultaneous heat and mass transfer process. Drying is one of the earliest methods of preservation and is particularly suited for

bananas because of its simplicity, affordability, and ease of use [8]. Apart from these advantages, drying reduces the weight of food, which lower costs associated with packing, handling, storing, and shipping. It also facilitates handling and processing procedures. A lower moisture content increases shelf life and reduces postharvest losses [9, 10]. However, there are some disadvantages to drying, including high energy cost, low efficiency, and undesirable changes in the final products.

Adding value is crucial for lowering losses and boosting the economic benefits of green bananas. Both green and mature bananas can be dried using various types of dryers, including solar, mechanical, and sun drying methods. However, the slow and uncontrolled nature of the solar drying process can lead to a product with undesirable color, texture, taste, and changing flavors, significantly affecting market acceptance. Over the years, several drying methods have been developed. Hot air drying, whether in convectional tray, cabinet, or vacuum dryers, is the most basic and cost-effective method for dehydrating products. Pretreatments play an important role in food processing by reducing the negative effects of drying, as suggested by some researchers [11–13]. To improve the drying system, pretreatments are commonly used prior to hot air drying. An appropriate pretreatment shortens processing times, consumes less energy, and boosts the quality of final products. Therefore, optimizing the drying processes is aimed at minimizing these issues in order to accomplish rapid and efficient drying.

Consumers prefer for dried fruit over fresh fruit, according to several studies, and they try to find out the factors influencing their selection [14]. For the preparation of green banana flour, dried green banana slices are essential. The demand for green banana flour is steadily increasing due to its many health benefits. It contains different types of starches, bioactive compounds, cellulose, phenolics, carotenoids, flavonoids, and other phytochemicals. Dried green banana slices are used in the preparation of various foods, especially during fasting periods. Some researchers have reported that people preferred dried foods for their convenience [14]. Preliminary studies showed that dried green banana slices prepared without any pretreatment have a shorter shelf life. Over time, the color of these slices fades, changing from white to black. Furthermore, very few studies are available on the optimization of dried green banana slices using various pretreatments, and no material is available pertaining to the *Nendran* variety. Preparing dried green banana slices using a tray drier is a convenient and low-cost method. This investigation focuses on improving the tray drying of green banana slices, concentrating on drying time, color, rehydration characteristics, and water activity.

Optimization is one of the most crucial elements of drying technology. In order to have greater influence over the characteristics, productivity, and cost of the processes, the parameters were optimized. Additionally, the consumer demand for healthier products necessitates the modeling and further improvement of drying conditions to reduce the negative quality changes during the drying process. A set of statistical and mathematical methods for creating empirical

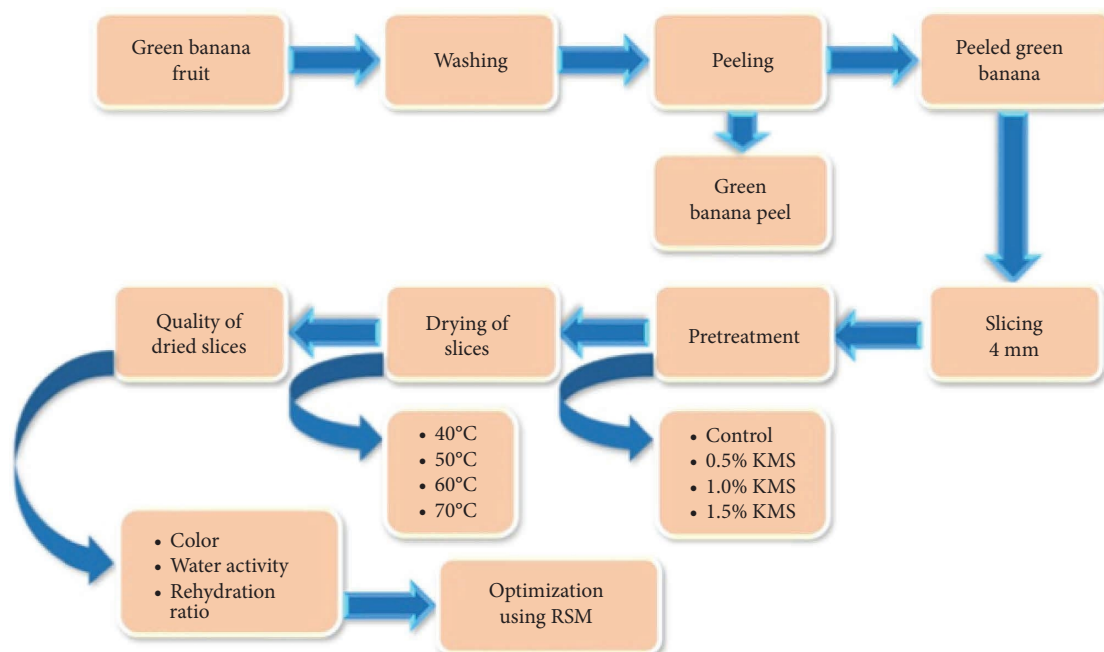
models, collectively referred to as response surface methodology (RSM), is becoming increasingly well known as an effective strategy for process optimization and product enhancement. In situations where an output or a response of interest is impacted by several factors, RSM is regarded as a valuable modeling and analytical tool [15, 16]. This approach has been extensively employed in the food processing industry to optimize several processes, including enzymatic hydrolysis, extraction, drying, blanching, and the generation of microbial metabolites [17].

The current research aims to establish optimal drying conditions for producing dehydrated green banana slices. The study investigates how hot air temperature, pretreatment methods, and water activity affect the color, water activity, rehydration ratio, and drying duration of green banana slices. However, there is limited information available regarding the drying temperature and pretreatment of these slices. RSM is a robust and effective method for determining the ideal circumstances to achieve desired results, optimizing numerous variables, and modeling intricate processes. It allows for precise control of the drying process, minimizes the number of required tests, and offers insightful information into parameter interactions, all of which improve product quality and lower costs. At present, there is no specific standard defined for assessing the quality of banana varieties. Therefore, standardizing the drying procedure for these varieties is vital to achieve the optimum drying conditions for ultimate output in terms of quality aspects. The effectiveness of the drying process directly impacts the product quality, nutrient retention, shelf life, energy efficiency, and environmental sustainability of green banana slices. Both major industrial companies and small-scale businesses that wish to supply wholesome, high-quality products while cutting waste and operating expenses must use this approach. This study was conducted to investigate variations in the drying behavior of the slices in relation to factors such as drying time, water activity, color, and rehydration ratio. It also aims to maximize hot air drying parameters, including temperature and pretreatment concentration, for infused green banana slices. The main parameters of the experiment for hot air drying green banana slices were optimized using the RSM approach.

2. Materials and Methods

Fresh green bananas, harvested at maturity stage 2 and physiologically developed and farmed under the cv. *Nendran* (variety), were sourced from the Savina market in Udaipur, Rajasthan, India. Washing the bananas with running water eliminated dust, grime, and other foreign particles. Figure 1 shows the process flowchart for the green banana slices.

2.1. Sample Preparation. The green banana fruits were peeled using a hand peeler, as there are no appropriate machines available for peeling green bananas. The peeled bananas were then sliced longitudinally into pieces approximately 4 ± 0.5 -mm thick using a hand slicer. A solution of KMS at concentrations of 0.5%, 1.0%, and 1.5% was



prepared [11, 18, 19]. After that, these slices were immersed in the KMS solution for 10 minutes. A tray dryer was utilized to dry the pretreated and control green banana slices at four different temperatures: 40°C, 50°C, 60°C, and 70°C [20–22].

2.2. Drying Experiment. Afterward, a tray dryer (Figure 2) was used to dry the control and pretreated green banana slice samples (Make: Lab Line, Gujarat; Model: 12 TD, loading density: 1.089 kg/m^2 , no. of heaters: 4, air velocity: 2.5 m/s). After approximately 30 minutes of adjustments to maintain the desired temperature within the drying chamber, the drying process for the banana slices commenced. The slices were spread out on a preweighed tray and placed into the tray dryer.

2.3. Response Surface Experimental Design. To produce dried goods of superior quality, optimization techniques are frequently used. The RSM is an effective solution for process optimization and product enhancement, which consists of a set of statistical and mathematical technologies for empirical modeling [23]. To achieve optimal system effectiveness and dried product quality at an affordable price as well as time is the aim of optimizing the food drying technique [16].

Design Expert Software Stat Ease v 11 is used to create the experiments. The design consists of two factors viz. temperature (A) and pretreatment (B). Factor A has a range from 40 to 70°C, while pretreatment was from 0% to 1.5% KMS. In this design, a quadratic model with four levels for each variable was utilized, as shown in Table 1. The design includes a total of 16 experimental runs.

The numerical optimization system is applied to the convective drying of green banana slices in order to optimize a variety of input parameters such as drying temperature and pretreatment, as well as optimize responses such as water activity, color, and rehydration ratio.



2.4. Drying Characteristics

2.4.1. Moisture Content. The moisture content of green banana slices was determined by using the hot air oven method. The green banana slices were placed in a hot air oven maintained at 105°C for 3 h. After 3 h, green banana slices were weighted again to calculate moisture content [24].

2.4.2. Moisture Ratio. The moisture ratio is the ratio of the initial moisture content to the moisture content at any given time. Equation (1) was used to compute it as recommended by [25]

$$MR = \frac{M - M_e}{M_o - M_e}, \quad (1)$$

TABLE 1: Design of an experiment for drying slices of green banana.

Run	Coded		Factor 1 A: Temperature (°C)	Factor 2 B: Pretreatment % KMS
	A	B		
1	1	1	70	1.5
2	-0.33	1	50	1.5
3	1	-0.33	70	0.5
4	0.33	-1	60	0
5	1	0.33	70	1.5
6	-0.33	0.33	50	1
7	1	-0.33	70	0
8	-1	0.33	40	1
9	-1	0.33	40	1
10	-1	-1	40	0
11	-0.33	1	50	1.5
12	0.33	-0.33	60	0.5
13	-0.33	-0.33	50	0.5
14	0.33	-0.33	60	0.5
15	-1	-0.33	40	0.5
16	0.33	-0.33	60	0.5

where M = moisture content at time, t (% db), M_o = initial moisture content (% db), M_e = equilibrium moisture content (% db).

For a longer drying time, M/M_o can be interpreted as the moisture ratio since the equilibrium moisture (M_e) content is very small when compared to M and M_o .

2.4.3. Drying Rate. To determine the amount of moisture lost from the banana slice samples during a certain time period, the moisture content data collected throughout the tests were examined. The following mass balance equation (equation (2)) was used to determine the drying rate of slices of green banana pulp [4]:

$$R = \frac{\text{Weight of moisture loss}}{\text{Time interval} \times \text{Dry Matter}}, \quad (2)$$

where R = drying rate, g, of moisture evaporated per g of bone-dry matter per min, weight of moisture loss = initial mass of sample – mass of sample after time, θ .

2.5. Quality Parameters

2.5.1. Water Activity. An automated device (Novasina—Lab Swift-a_w, Lachen, Switzerland) (Figure 3) was used to measure the water activity of dried green banana pulp slices [24].

2.5.2. Color. One of the most important qualitative factors in determining whether customers will accept a product is its color. Green banana slices were tested for color using a Hunter colorimeter (Color Flex, CFLX-45-2, Hunter lab, Reston, VA, USA) as shown in Figure 4 using a D-65 illuminant and a 10° observer. Initially, a standard white plate was used to calibrate the device, followed by a black plate. The L^* displays a lightness coefficient on the vertical axis that ranges from 0 (black) to 100 (white). Since lightness is

essential for slicing banana pulp, the process only takes L^* into consideration [26]. The total color difference (ΔE) was calculated using the following equation (3):

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}. \quad (3)$$

2.5.3. Rehydration Ratio. A 100-mL beaker containing a dried sample was submerged in 50 mL of distilled water at 60°C for 30 min. After draining the extra water, samples were removed. Before weighing, surface moisture was absorbed using paper towels. The rehydration ratio of the dried samples was determined by equation (4) [23, 27, 28]:

$$\text{Rehydration ratio} = \frac{\text{Mass of rehydrated samples (g)}}{\text{Mass of dehydrated samples (g)}}. \quad (4)$$

2.6. Statistical Analysis. The process parameters of green banana pulp slices were optimized with quality in mind. Design Expert Software Stat Ease v 11 was utilized for the process parameter optimization and for statistical analysis. ANOVA was used to see whether factors had a significant influence on the replies. The estimated F-value and tabulated values for various degrees of freedom were used to assess significance. The regression model was estimated for each answer, and the appropriate R^2 , adjusted R^2 , and CV values were computed [29].

3. Results and Discussion

3.1. Drying Characteristics of Green Banana Pulp

3.1.1. Effect of Drying Air Temperature on Drying Characteristics of Green Banana Slices. Figure 5 shows the variation in moisture content, % (db), with the drying time. Early in the drying process, moisture loss was high; however, as the drying time increased, the moisture loss decreased. A decreasing drying rate was seen during the drying process [30]. The lack of a steady rate period suggested that green banana slices had no surface moisture. Comparable outcomes were also attained by [30] for banana slices.

The effects of air temperature and pretreatment on the drying time of banana slices are shown in Table 2. The initial moisture content of the green bananas, which ranged from 378.86% to 395.71% (db), remained essentially unchanged after soaking in a KMS solution for 10 min. Dried banana slices had an ultimate moisture content of 5.95–8.95% (db). Table 2 demonstrates how the temperature of the drying air affected the drying time of the banana slices. The control samples of green banana slices took longer to dry than the samples treated with KMS (0.5%, 1.0%, and 1.5%). For the control banana slice samples, the drying time decreased from 480 to 420 min at a temperature of 40–50°C, marking a reduction of 12.50%. However, the drying time decreased to 360 and 330 min at a temperature of 60°C and 70°C, as well as a 25.00% and 31.25% reduction, respectively, compared to the drying time at 40°C.



FIGURE 3: Water activity meter.



FIGURE 4: Hunter lab colorimeter.

For banana slice samples treated with 0.5% KMS, the drying time decreased by 7.69%, 15.38%, and 23.08% when the temperature was raised from 40°C to 50°C, 60°C, and 70°C, respectively. Similarly, the drying time for banana slices treated with 1% KMS decreased by 7.14%, 21.43%, and 28.57%, respectively, when the temperatures were increased from 40°C to 50°C, 60°C, and 70°C. Table 2 further demonstrates that for banana slice samples treated with 1.5% KMS, raising the temperature to 40°C, 50°C, 60°C, and eventually 70°C shortened the drying time by 7.69%, 23.08%, and 30.77%.

Figure 5 shows an inverse relationship between the drying air temperature and drying time, meaning that the drying time increases as the drying air temperature rises. This indicates that the rate of moisture removal increases with the drying air temperature. Higher drying air temperatures provide better drying potential and heat transfer capacity, which improves moisture removal from the product. Drying is a simultaneous heat and mass transfer process.

As seen in Figure 2, green banana slices dried more slowly at 40°C and 50°C than at 60°C and 70°C. The final moisture content was reached at a greater drying air temperature in a shorter amount of time, which is in line with

findings from prior research that dried a variety of fruits and vegetables, including banana slices [31–34], blanched pumpkin slices [35], and lotus pollen [36].

3.1.2. Influence of Pretreatment on Drying Green Banana Slices. The drying properties were clearly altered by pretreatment with various concentrations of KMS, as shown in Figure 6 and Table 2. When compared to other levels of pretreatment and control samples, the 0.5% KMS pretreatment samples dried faster. Furthermore, it was discovered that samples treated with 1.0% and 1.5% KMS required a greater drying time than those treated with 0.5% KMS. Similar findings were recorded by [37] for carrot slices and [38] for mango slices. One of the possible reasons is that the chemical treatment may vary the mass transfer rate from the product [39].

The drying time was reduced following pretreatment with the KMS solution (Table 2), which may be attributable to differences in the cell wall of banana slices, which influenced the resistance of moisture migration from the product's interior to the surface. These results are also in confirmation of findings reported by [40] for citric acid and potassium metabisulfite pretreatment of banana slices before drying and by [39] for potassium metabisulfite and ascorbic acid pretreatment to peach slices before drying.

3.1.3. Effect of Air Temperature and Pretreatment on Drying Rate of Green Banana Slices. When a 0.5% KMS treated material was initially dried at 70°C air temperature, the maximum drying rate was 0.046 g w/g-dm-min. According to the statistics, the drying rate was greater at the start of the drying process and then reduced as the moisture content of the product decreased. The drying rate for different air temperatures likewise fluctuated during the first 90–120 min, but as the drying advanced, the rate of drying remained constant for all temperatures.

Figure 7 clearly shows that a constant rate of drying was completely absent and that full drying of green banana slices occurred in a decreasing rate period at all temperatures and pretreatments used in this study. Other studies indicated that the usual drying curve for food products was in a decreasing phase. It is readily evident that the initial drying rate was high and thereafter decreased significantly [41].

As the moisture content decreased, the corresponding drying rate also reduced; this might be due to the availability of free moisture at the onset of the drying process [42], and afterward, inner layers of the slices were not able to supply a sufficient amount of moisture. Similar results were obtained and reported by [30, 43, 44] for green banana slices.

3.2. Optimization of Process Technology of Drying of Green Banana Slices. Regression equations are generated with RSM for analyzing the relationships between the independent variables (input) and dependent variables (response) [16]. In this regard, I optimum design's response surface technique (RSM) was employed to improve the drying process parameters of green banana slices. Design

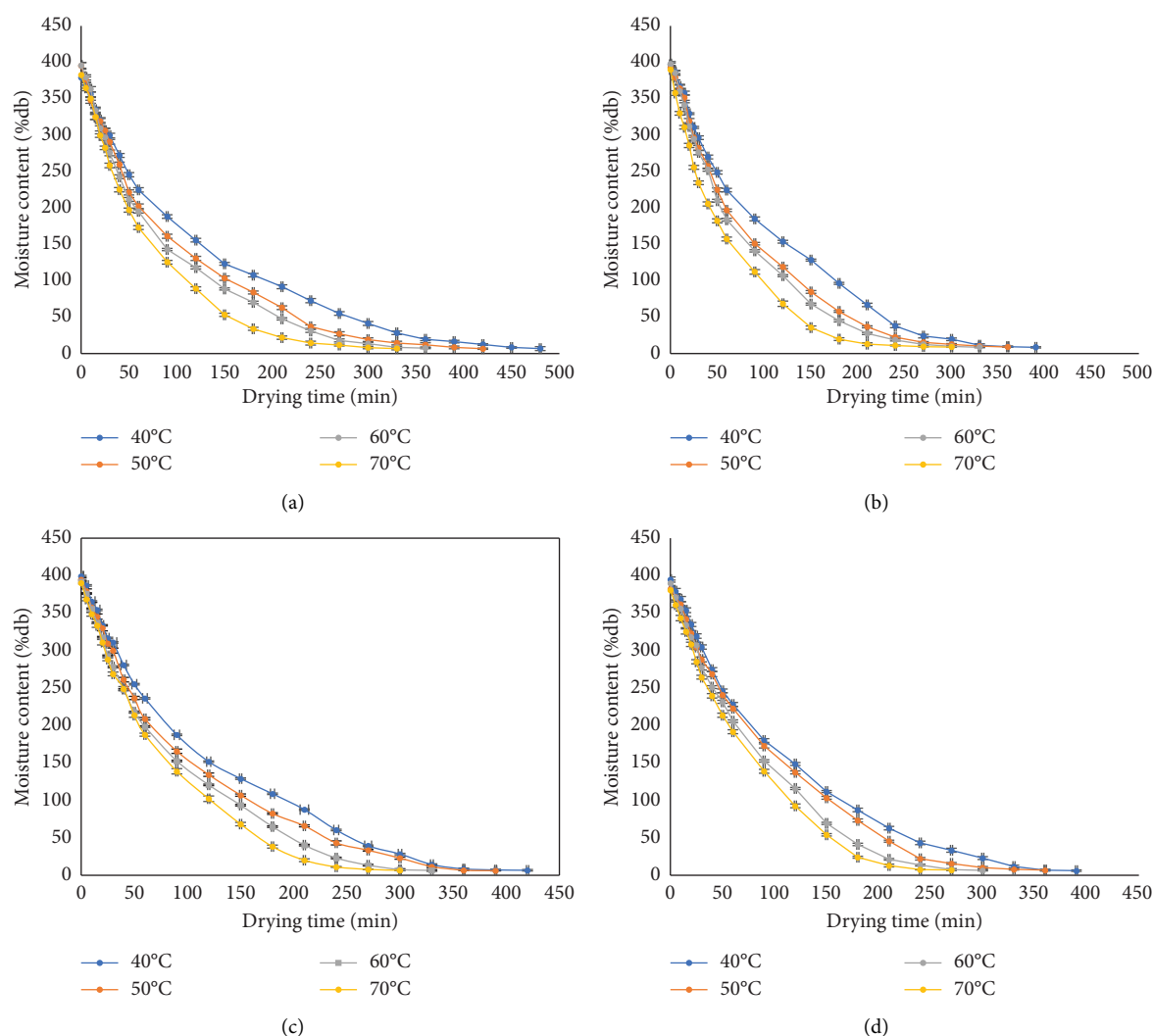


FIGURE 5: Variation in the moisture content with drying time for (a) untreated (control) and KMS-treated green banana slices, i.e., (b) 0.5% KMS, (c) 1.0% KMS, and (d) 1.5% KMS at various drying air temperatures.

TABLE 2: Drying time of green banana slices drying under different temperatures and pretreatments.

Pretreatment, %, KMS	Temperature (°C)	Initial moisture content, % (db)	Final moisture content, % (db)	Drying time (min)	Reduction in drying time (%)
0 (control)	40	378.86	6.80	480	—
	50	395.19	6.66	420	12.50
	60	395.71	7.42	360	25.00
	70	382.38	6.76	330	31.25
0.5	40	396.71	8.47	390	—
	50	392.62	8.95	360	7.69
	60	397.67	8.57	330	15.38
	70	389.86	8.85	300	23.08
1.0	40	399.33	6.71	420	—
	50	394.71	5.95	390	7.14
	60	392.05	6.52	330	21.43
	70	390.19	6.67	300	28.57
1.5	40	394.71	6.19	390	—
	50	382.19	6.90	360	7.69
	60	389.71	6.52	300	23.08
	70	380.76	7.14	270	30.77

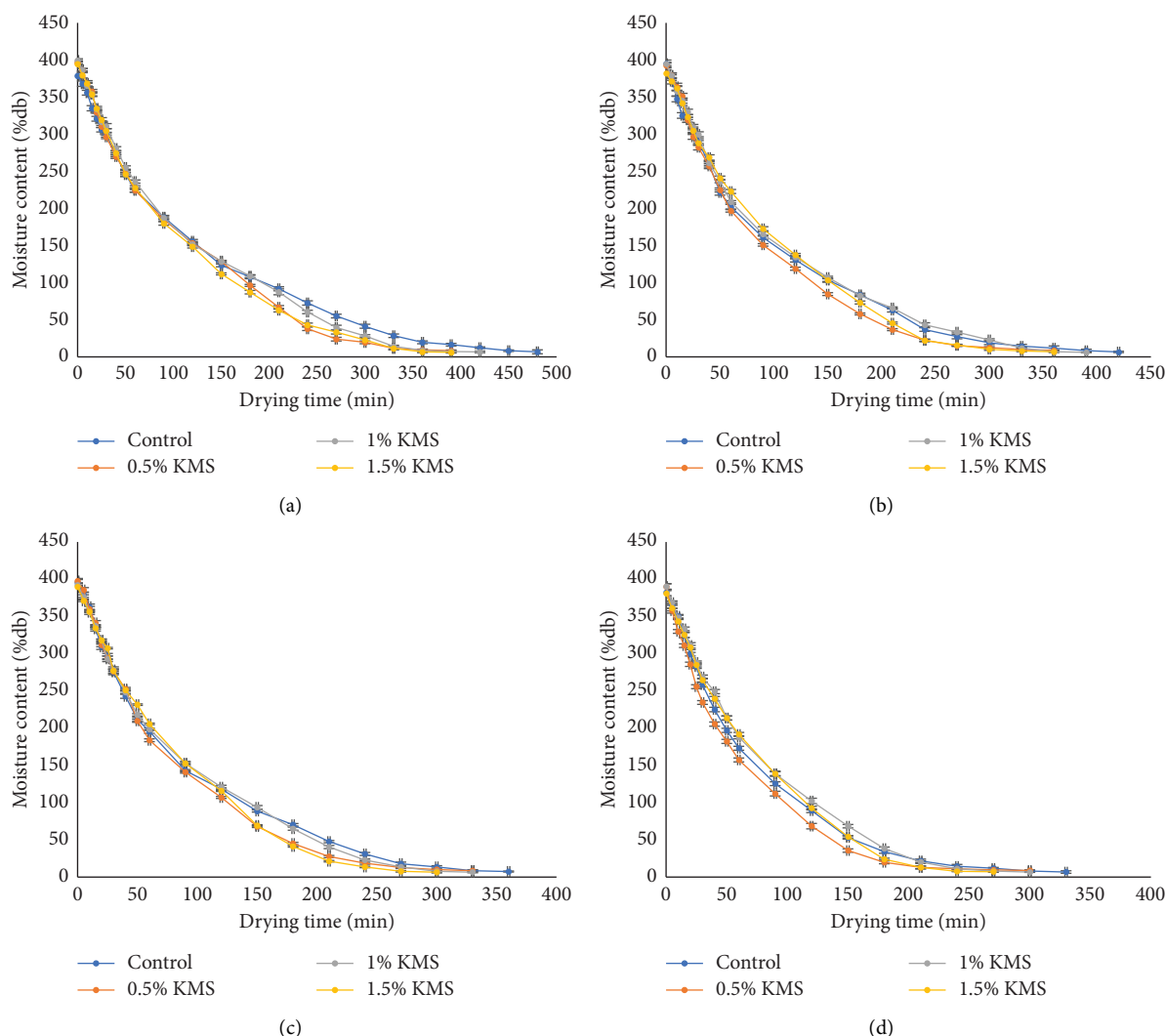


FIGURE 6: Variation in the moisture content with drying time for various pretreatments of green banana slices at (a) 40, (b) 50, (c) 60, and (d) 70°C drying air temperatures.

Expert Software was used to do many response improvements. The drying duration, color, water activity, and rehydration ratio were all standardized across four temperature levels (A) and four pretreatment levels (B).

3.2.1. Regression Analysis of the Responses. Table 3 displays the observed results for all 16 drying trials. The experiments were replicated thrice, and average values were represented. These observed data were utilized to investigate the impact of several independent factors on the drying of green banana slices. For the observed results, second-order multiple regression models were created.

3.2.2. Effect of Process Parameters on the Drying Time of Green Banana Slices. The time required to dry control and treat green banana slices was found to be between 480 and 270 min. Table 4 shows the ANOVA for the effect of temperature and pretreatment on the drying time. The anticipated model was chosen due to an insignificant lack of fit.

The model F value of 49.96 suggests that the chosen model is significant. p values < 0.05 suggest that model terms are significant. The important model terms in this example are A, B, AB^2 , and B^3 . Values above 0.1 indicate that the model's terms are irrelevant.

When compared to the pure error, the F value of 0.47 indicates that the lack of fit is not significant. A non-significant lack of fit is required since it indicates that the model is fit to link the expected and observed values and that the number of experimental permutations generated in the experiment design is sufficient to determine the effect of independent factors on the drying time. Table 5 shows the findings of the second-order cubic model for the effect of process variables on the drying time. The projected R^2 of 0.8500 is similar to the updated R^2 of 0.9514, indicating that both the model and the data are sufficient. As a consequence, the model is handy for exploring the design area.

Equation (5) was generated using the step-down regression technique, and terms with F values less than one were deleted [45].

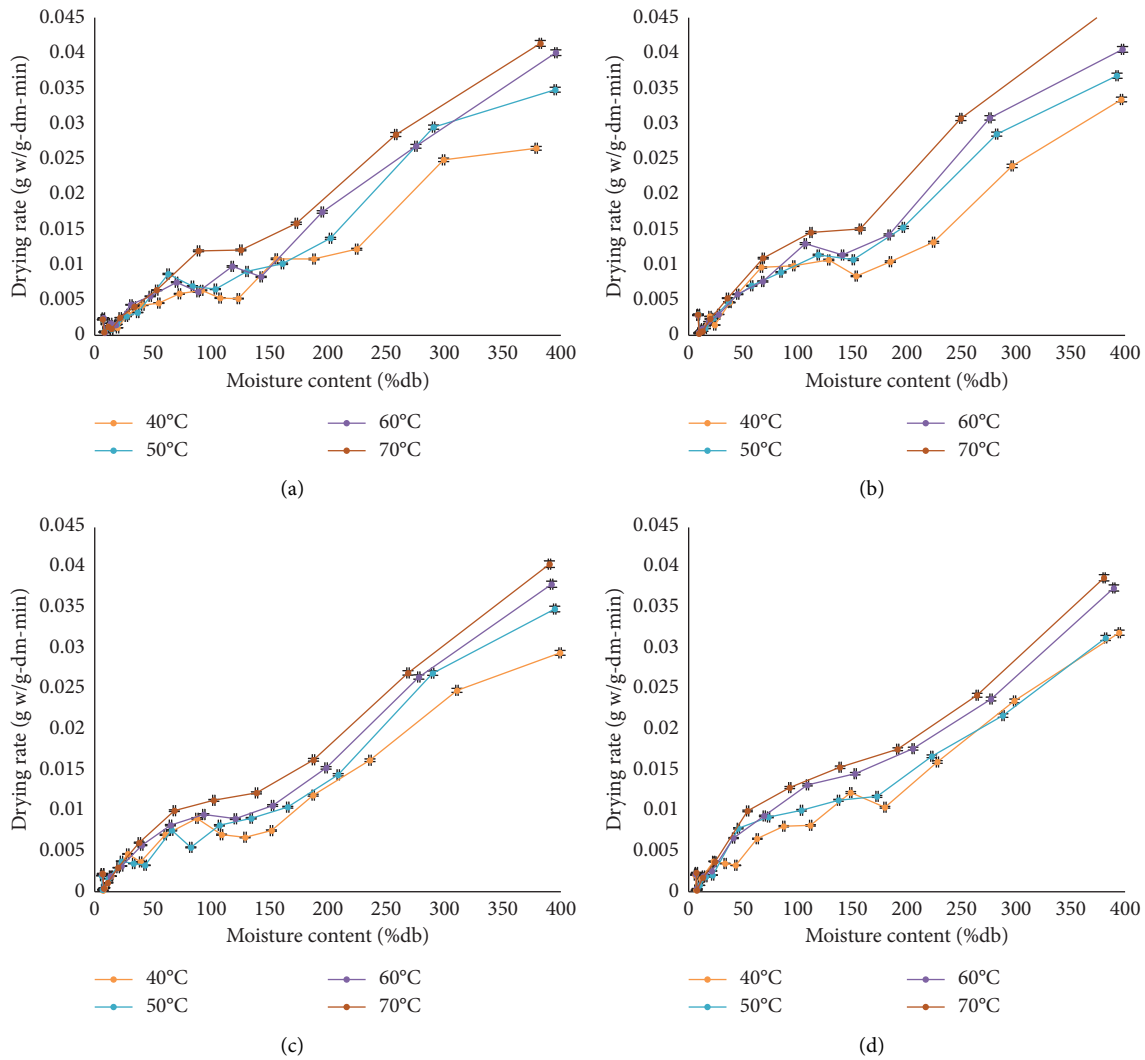


FIGURE 7: Variation in the drying rate with moisture content at different air temperatures for (a) untreated (control) and KMS-treated green banana slices, i.e., (b) 0.5% KMS, (c) 1.0% KMS, and (d) 1.5% KMS.

The final equation of actual factors is given by

$$\text{Drying time} = 680.78 - 5.13T - 625.74P + 5.28TP + 720.62P^2 - 2.91TP^2 - 246P^3, \quad (5)$$

where T = temperature, °C, and P = pretreatment, % KMS.

The influence of temperature, pretreatment, and their interactions on the drying time is shown in equation (5). The linear positive terms demonstrated that when pretreatment was lowered, the drying time increased. The linear negative term suggested that drying time reduced as temperature increased.

The response surface and contour plots were created as a function of two independent parameters (temperature and pretreatment) to simulate the combined effect of the two independent variables on the response. The drying time decreases as the drying air temperature rises, as shown in Figure 8(a). Control samples needed longer drying times. When the percentage KMS was increased from 0.5 to 1.0 and

1.5, the drying time increased in comparison to the drying time needed for banana slices treated with 0.5% KMS.

3.2.3. Effect of Process Parameter on the Color (L^* Value) of Green Banana Slices. The color (L^* value) of untreated and pretreated green banana slice samples ranged from 56.26 to 81.79. The values for ΔE (color difference) were found to be in the range of 1.30–16.20. From Table 3, it can be observed that the control samples are having higher ΔE (color difference) values as compared to others. At lower temperatures, ΔE values might be more due to the fact that the effect of drying time taken by the samples is more as compared to that of the other samples. A similar effect of temperature on the color difference for basil leaves was observed by [46]. Engin reported that long drying time increases color difference in dried foods [47]. Pretreated green banana slices dried at higher temperatures have low color difference values. Table 5 shows the ANOVA for the influence of temperature and pretreatment on the color (L^* value) of

TABLE 3: The I optimal design matrix with measured values of responses for green banana slices.

Run	Independent variables			Dependent variables					
	A	B	Temperature (°C)	Pretreatment, % KMS	Drying time (min)	Color (L^* value)	ΔE	Water activity	Rehydration ratio
1	1	1	70	1.5	270	70.54	2.50	0.314	2.53
2	-0.33	1	50	1.5	360	71.26	1.41	0.349	2.25
3	1	-0.33	70	0.5	300	68.12	4.52	0.302	2.81
4	0.33	-1	60	0	360	60.21	12.13	0.386	2.28
5	1	0.33	70	1.5	270	71.00	2.60	0.319	2.60
6	-0.33	0.33	50	1	390	78.52	6.48	0.341	2.41
7	1	-0.33	70	0	330	56.26	16.20	0.332	2.39
8	-1	0.33	40	1	420	80.44	8.46	0.370	2.26
9	-1	0.33	40	1	420	81.79	9.83	0.368	2.24
10	-1	-1	40	0	480	65.26	7.81	0.412	2.03
11	-0.33	1	50	1.5	330	74.18	2.21	0.356	2.28
12	0.33	-0.33	60	0.5	330	73.19	1.34	0.321	2.74
13	-0.33	-0.33	50	0.5	360	75.56	3.66	0.357	2.39
14	0.33	-0.33	60	0.5	300	73.21	1.30	0.315	2.76
15	-1	-0.33	40	0.5	390	79.54	7.60	0.365	2.07
16	0.33	-0.33	60	0.5	330	73.60	1.66	0.320	2.69

TABLE 4: ANOVA of drying air temperature and pretreatment on the drying time of green banana slices.

S. V.	SS	df	MS	F-value	p value	F-value (1%)	Test
Pretreatment	7875	3	2625	9.545	0.003709	6.99	*
Temperature	38,025	3	12,675	46.09	8.7×10^{-6}	6.99	*
Error	2475	9	275				
Total	48,375	15					

*Significant at 1% level.

dried banana slices. The model was picked because of a little lack of fit.

The selected algorithm's F value of 142.51 indicates that it is significant. Significant model terms have p values < 0.05 . In this case, the important model terms are A, B, AB, and B^2 . Values above 0.1 indicate that the model's terms are useless. When compared to pure error, the lack of fit has an F -value of 1.33, suggesting that it is not statistically significant. A high F -value for the lack of fit indicates that noise is 38.46% likely to be the reason. A nonsignificant lack of fit is required since it indicates that the model is fit to link the anticipated and observed values and that the number of experimental possibilities generated by the experiment design is adequate to determine the effect of independent parameters on color (L^* values).

Table 5 also includes statistics for the second order cubic model for color effect. Based on the high coefficient of determination ($R^2 = 0.9811$), the suggested color model explained 98.11% of total variation. The anticipated R^2 (0.9354) is nearly identical to the modified R^2 (0.9742), indicating that the model and data are adequate. As a result, the model may be utilized to explore the design space. The final equation (equation (6)) of actual factors is given by

$$\text{Color} = 80.46 - 0.35T + 27.39P + 0.143TxP - 18.71P^2, \quad (6)$$

where T = temperature, °C, and P = pretreatment, % KMS.

The color (L^* value) is influenced by temperature, pretreatment, and their interactions, as illustrated in equation (6). When all other variables are maintained constant, the coefficient of the regression equation is the expected change in response per unit change in the factor value. The coefficients were adjusted around the average using the factor settings.

The response surface and contour plots were created as a function of two independent variables in order to duplicate the combined effect of the two independent factors on the response. Figure 8(b) depicts the combined impact of temperature and pretreatment on the color values (L^*) of green banana slices. It shows that when the temperature of the drying air was reduced, the color improved. When compared to treated samples, the color (L^* values) of untreated samples was found to be low. When the percentage KMS treatment was increased from 0.5 to 1, the L^* values grew from 68.12 to 81.79, but when the percentage KMS was increased from 1 to 1.5, the L^* values declined from 81.79 to 70.54. Similar results were reported by [48] for dried banana slices.

3.2.4. Effect of Process Parameter on the Water Activity of Green Banana Slices. The water activity plays an important role in the storage of any fruits and vegetables [49]. The water activity of the dried product should be less as it directly affects the shelf life of processed/dried food products [50]. A higher water activity results in microbial growth in dried

TABLE 5: ANOVA for the effect of process parameters on the drying of green banana slices.

Sr. no.	Source	Drying time			Color (L^* value)			Water activity (a_w)			Rehydration ratio		
		Square mean	F-value	p value	Square mean	F-value	p value	Square mean	F-value	p value	Square mean	F-value	p value
1	Model	8009.53	49.96	0.0001**	181.54	142.51	0.0001**	0.0019	63.18	0.0001**	0.1237	41.27	0.0001**
2	A-temperature (T)	3554.12	22.17	0.0011**	105.08	82.48	0.0001**	0.0013	41.93	0.0002**	0.1377	45.94	0.0001**
3	B-pretreatment (P)	1884.89	11.76	0.0075**	230.76	181.14	0.0001**	0.0017	54.85	0.0001**	0.0459	15.32	0.0045*
4	AB	415.54	2.59	0.11419ns	12.05	9.46	0.0105*	0	1.46	0.2616ns	0	0.0119	0.9157ns
5	A ²	—	—	—	—	—	—	5.3×10^{-06}	0.1742	0.6874ns	0.0024	0.8066	0.3954ns
6	B ²	31.49	0.1964	0.6681ns	293.62	230.49	0.0001**	0.0038	123.76	0.0001**	0.2126	70.92	0.0001**
7	A ² B	—	—	—	—	—	—	0.0008	24.95	0.0011*	—	—	—
8	AB ²	743.88	4.64	0.0596*	—	—	—	—	—	—	0.0407	13.58	0.0062*
9	A ³	—	—	—	—	—	—	0.0002	6.32	0.0361*	0.0187	6.25	0.0369*
10	B ³	3957.55	24.69	0.0008**	—	—	—	—	—	—	—	—	—
11	Residual	160.31	—	—	1.27	—	—	0	—	—	0.003	—	—
12	Lack of fit	98.2	0.47	0.7593ns	1.44	1.33	0.3846ns	0.0001	5.17	0.0543ns	0.0061	5.35	0.0511ns
13	Pure error	210	—	—	1.08	—	—	0	—	—	0.0011	—	—
14	Std. dev.	12.66	—	—	1.13	—	—	0.0055	—	—	0.00548	—	—
15	Mean	352.5	—	—	72.04	—	—	0.3454	—	—	2.42	—	—
16	C.V.	3.59	—	—	1.57	—	—	1.6	—	—	2.26	—	—
17	R ²	0.9709	—	—	0.9811	—	—	0.9822	—	—	0.9731	—	—
18	Adjusted R ²	0.9514	—	—	0.9742	—	—	0.9667	—	—	0.9495	—	—
19	Predicted R ²	0.85	—	—	0.9354	—	—	0.8482	—	—	0.6792	—	—
20	Adeq. precision	24.5569	—	—	39.77	—	—	29.37	—	—	22.07	—	—

Abbreviation: ns, nonsignificant.

*Significant at 5% level.

**Highly significant at 1% level.

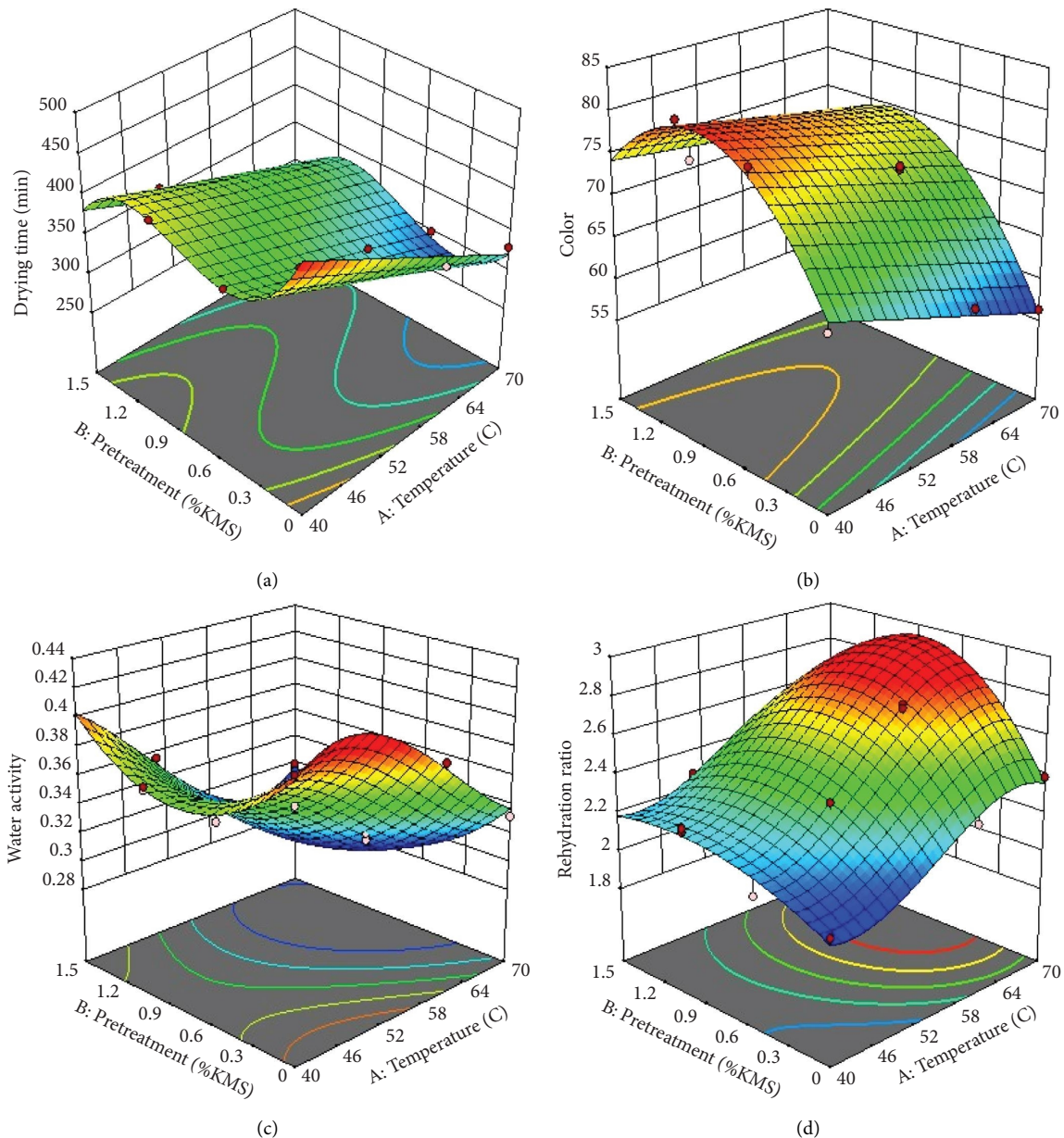


FIGURE 8: Combined effect of process parameters (temperature and pretreatment) on dependent variables of green banana slices, i.e., (a) drying time, (b) color (L^* value), (c) water activity, and (d) rehydration ratio.

products. This is important in any product formulation. The water activity varied from 0.302 to 0.412 for the dried control and treated green banana slices. Table 5 shows the statistical analysis (ANOVA). The chosen model's significance is indicated by its model F value of 63.18. p values of less than 0.05 are considered significant for model terms. In this case, the key model terms are A, B, B^2 , A^2B , and A^3 .

The F value of 5.17 indicates that the lack of fit is low in comparison to the pure error. A nonsignificant lack of fit is required because it indicates that the model is fit to relate the predicted and observed values of water activity and that the number of experimental combinations generated in the experiment design is adequate to determine the effect of independent parameters on water activity.

Table 5 also displays data from the second-order cubic model for the impact of process variables on water activity. According to the high coefficient of determination ($R^2 = 0.9822$), the built model of water activity in dried green banana slices adequately described 98.22% of total variation. The predicted R^2 (0.8482) is close to the adjusted R^2 (0.9667), suggesting that the difference between the two is less than 0.2, implying that the model and data are appropriate. The accuracy of 29.37 indicates that the signal is appropriate. As a result, the model may be used to investigate the design options for aquatic activities.

The final equation (equation (7)) of real components is as follows:

$$\begin{aligned} \text{water activity} = & -1.0635 + 0.08T + 0.4409P - 0.021TP \\ & - 0.0014T^2 + 0.074P^2 + 0.00019T^2P \\ & + 7.46 \times 10^{-6}T^3, \end{aligned} \quad (7)$$

where T =temperature, °C, and P =pretreatment, % KMS.

Equation (7) depicts how temperature, pretreatment, and their interactions affect the water activity of dried banana slices. In an orthogonal design, the constant or intercept represents the average response of all runs.

The response surface and contour plots were generated as a function of two independent variables (temperature and pretreatment) in order to duplicate the combined effect of the two independent factors on response. Figure 8(c) shows how temperature and pretreatment affect the water activity of dried green banana slices. As drying air temperature increased, the water activity (a_w) decreased. The authors of [33] showed similar results for banana slices. Control samples had the highest water activity after drying as compared to treated samples. The water activity (a_w) was found to be the lowest at all temperatures in 0.5% KMS-treated samples, but as the percentage KMS increased from 0.5 to 1.5, the water activity (a_w) increased.

3.2.5. Effect of Process Parameters on the Rehydration Ratio of Green Banana Slices. The rehydration ratio of green banana slices from control and treatment groups was determined to be 2.03–2.81. The authors of [14] reported similar range for dried control and pretreated green banana slices in sun drying. Table 5 uses ANOVA to illustrate the influence of temperature and pretreatments on the rehydration ratio. The chosen model's F value of 41.27 suggests that it is significant. Significant model terms have p values less than 0.05. In this scenario, the key model terms are A , B , B^2 , and AB^2 .

The F value for the lack of fit appears 5.35, indicating that the lack of fit is insignificant when compared to the pure mistake. A nonsignificant lack of fit is necessary because it implies that the model is fit to connect anticipated and observed values and that the number of experimental possibilities created in the experiment design is adequate to identify the influence of independent factors on the rehydration ratio.

Table 5 also shows the fit statistics for the second-order cubic model's effect on the rehydration ratio of dried banana slices. According to the high coefficient of determination ($R^2 = 0.9731$), the rehydration ratio model accurately represented 97.31% of the entire variance. The measured ratio of 22.07 indicated an adequate signal in this circumstance. As a consequence, the model may be used to explore the design space and predict the rehydration ratio of dried banana slices.

The acquired data were fitted using a second-order polynomial multiple regression equation to characterize the effect of temperature, A , and pretreatment, B , on the rehydration ratio. The final real factor equation (Equation (8)) may be found by

$$\begin{aligned} \text{Rehydration ratio} = & 10.88 - 0.5338T - 0.9P + 0.033TP \\ & + 0.01033T^2 + 0.6777P^2 \\ & - 0.02186TP^2 - 0.000063T^3, \end{aligned} \quad (8)$$

where T =temperature, °C, and P =pretreatment, % KMS.

The response surface and contour plots as functions of two independent variables were created to investigate the combined effect of the two independent factors on the response. Figure 8(d) shows that as the drying air temperature increased, so did the rehydration ratio. Untreated samples had a lower rehydration ratio than pretreated samples. In the case of pretreatment, the rehydration ratio increased as the percentage of KMS increased.

The authors of [51] reported that water absorption was higher at temperatures, resulting in faster water diffusion through the substance due to swelling and plasticization of cell membranes for apple slices. Similar results were also reported by [30] for culinary banana slices [42], for *carbada* bananas [52], and for apple slices.

3.3. Optimization and Experimental Validation of Drying of Green Banana Slices. Numerical optimization studies were used to anticipate the optimal level of process parameters for a certain set of variables that produced the desired results. Desirable targets were selected for each variable and response, and different weights were assigned to each target to change the shape of its unique desirability characteristic [32]. For mathematical optimization of process parameters, the desirability for maximum function was assigned to all process parameters (temperature and pretreatment) and four responses (drying time, color (L^*) value, water activity, and rehydration ratio), as shown in Table 6.

The constraints' optimization criteria were addressed. The optimal solution has a drying air temperature of 60.62°C, a pretreatment (% KMS) of 0.786, a drying time of 346.28 min, a color (L^* value) of 76.23, a water activity (a_w) of 0.299, a rehydration ratio of 2.81, and a desirability of 0.927. In actuality, it is impossible to maintain optimum processing conditions, and there was significant variation in responses. To get the optimum results, the process temperature was adjusted to 60°C and the pretreatment was set to 0.8%. Figure 9's contour plot reveals a similar overlaid point for all replies.

3.4. Verification of the Model. The optimal condition was validated experimentally in order to test and compare expected values with experimental outcomes. For experiment validation, the first of the top three software-generated solutions with the highest attractiveness was picked. The experiment was conducted under ideal conditions (temperature, 61°C; pretreatment, 0.8% KMS) to evaluate the model's accuracy. A similar drying temperature and pretreatment level are found significant for mango slices [53] and Russian olive fruit [50].

TABLE 6: Goal and importance of processing variables and responses.

Parameter	Goal	Lower limit	Upper limit	Importance
A: Temperature	In the range	40	70	3
B: Pretreatment	In the range	0	1.5	3
Drying time	Minimize	270	480	3
Color (L^* value)	Maximize	56.26	81.79	3
Water activity	Minimize	0.302	0.412	3
Rehydration ratio	Maximize	2.03	2.81	3

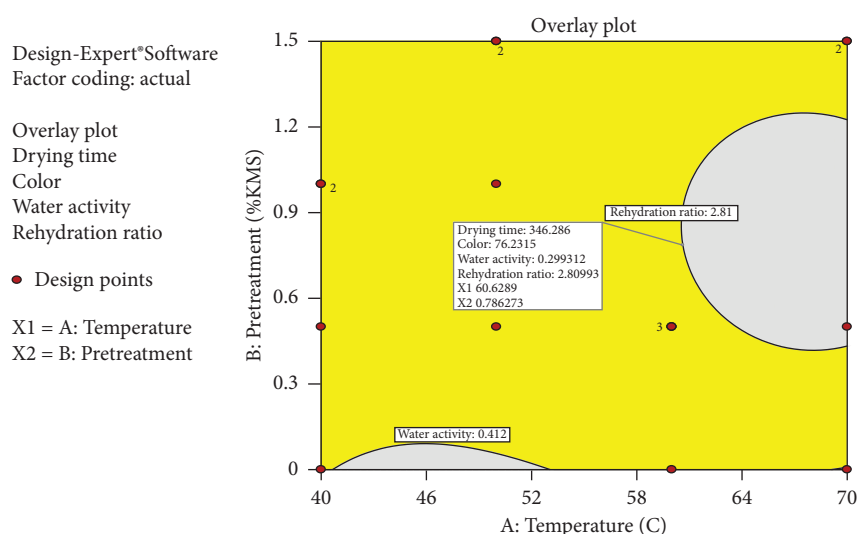


FIGURE 9: Superimposed contour plot for the drying time, color, water activity, and rehydration ratio.

TABLE 7: Final optimized results for the production of dried green banana slices.

Parameter	Temperature (°C)	Pretreatment, % KMS	Drying time	Color (L^* value)	Water activity	Rehydration ratio
Theoretical	60.62	0.786	346.28	76.23	0.299	2.81
Experimental	61	0.8	360	78.41	0.294	2.97

A validation test of the ideal conditions was carried out to confirm the regression equation's validity and accuracy more thoroughly [23]. Considering the results obtained theoretically, practical operations were carried out for temperature 61°C and pretreatment 0.8% KMS, which resulted in a drying time of 360 min, a color (L^*) of 78.41, the water activity as 0.294, and the rehydration ratio as 2.97. The experimental values were very close to the predicted one.

Table 7 shows that the experimental results were substantially equal to the expected values. The experimental data for the answers were found to be in close agreement with the solution produced via RSM.

As a result, it is possible to conclude that the model equations are quite adequate for accessing the performance of all four responses (drying time, color (L^* value), water activity, and rehydration ratio).

4. Conclusions

The study investigated the drying characteristics and optimization of process parameters for green banana slices using RSM. Un-pretreated and 0.5%, 1%, and 1.5% KMS pretreated green banana slices, cut to a thickness of 4 ± 0.5 mm, were dried in a tray dryer at temperatures of 40°C, 50°C, 60°C, and 70°C, respectively. The results showed that the samples treated with 0.5% KMS dried more rapidly than the control samples. The entire drying process took place in a decreasing amount of time. Temperature was noted to have an impact on color values; nevertheless, samples treated with 1% KMS demonstrated better color preservation. It was discovered that green banana slices needed between 270 and 480 min to dry. The pretreated samples demonstrated lower water activity, while those pretreated with 0.5% KMS showed acceptable rehydration ratios with good color preservation.

and low water activity. The study revealed that drying temperature affected drying time, while pretreatment had an effect on quality parameters. In the current investigation, process parameter optimization was done using the Design Expert Software. Theoretical optimization produced the best results at a drying temperature of 60.62°C and a pretreatment of 0.786% KMS, leading to a drying time of 346.28 min, a color (L^*) value of 76.23, a rehydration ratio of 2.81, and a water activity of 0.299. The experiment demonstrated that the actual findings closely aligned with the theoretical results. Since it was difficult to maintain a temperature of 60.62°C with a pretreatment of 0.786% KMS, it is advised to dry green banana slices at 61°C with a 0.8% KMS treatment to produce high-quality dried green banana slices. Future recommendations include increasing the size of banana slices to study the impact of slice size on drying kinetics and to evaluate the effect on nutrient quality.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization: K.P.D., S.K.J., and P.B.P.; methodology: K.P.D.; validation: K.P.D., S.K.J., and P.B.P.; formal analysis: K.P.D., S.K.J., S.J., and P.B.P.; investigation: K.P.D.; resources: S.K.J.; data curation: K.P.D.; writing—original draft: K.P.D.; writing—review and editing: S.K.J., S.J., and P.B.P.; visualization: S.J. and P.B.P.; supervision: S.K.J.

Funding

No funding was received for this research.

References

- [1] J. Vishala and G. Singh, "A Review on Product Development Through Pulp and Peel of Banana," *Plant Arch* 21, no. 1 (2021): 693–698, <https://doi.org/10.51470/plantarchives.2021.v21.s1.104>.
- [2] L. A. Espinoza-Espinoza, C. E. Juárez-Ojeda, L. A. Ruiz-Flores, L. A. Moreno-Quispe, M. S. Anaya-Palacios, and H. Cárdenas-Quintana, "Influence of Convection Drying With Hot Air on the Physicochemical and Phytochemical Properties of Green Banana Flour (Musa Cavendish)," *Frontiers in Sustainable Food Systems* 7 (2023): <https://doi.org/10.3389/fsufs.2023.1204349>.
- [3] M. Al-Dairi, P. B. Pathare, R. Al-Yahyai, H. Jayasuriya, and Z. Al-Attabi, "Postharvest Quality, Technologies, and Strategies to Reduce Losses along the Supply Chain of Banana: A Review," *Trends in Food Science & Technology* 134 (2023): 177–191, <https://doi.org/10.1016/j.tifs.2023.03.003>.
- [4] M. Al-Dairi, P. B. Pathare, R. Al-Yahyai, and A. Al-Mahdouri, "Effect on Physiological Properties of Banana Fruit Based on Pendulum Impact Test and Storage," *Current Research in Food Science* 7 (2023): 100640, <https://doi.org/10.1016/j.crf.2023.100640>.
- [5] S. K. Nanda, R. K. Vishwakarma, H. V. L. Bathla, and C. P. Rai Anil, "Harvest and Post Harvest Losses of Major Crops and Livestock Produce in India" (2012).
- [6] A. Amini Khoozani, J. Birch, and A. E. D. A. Bekhit, "Production, Application and Health Effects of Banana Pulp and Peel Flour in the Food Industry," *Journal of Food Science and Technology* 56, no. 2 (2019): 548–559, <https://doi.org/10.1007/s13197-018-03562-z>.
- [7] B. Singh, J. P. Singh, A. Kaur, and N. Singh, "Bioactive Compounds in Banana and Their Associated Health Benefits—A Review," *Food Chemistry* 206 (2016): 1–11, <https://doi.org/10.1016/j.foodchem.2016.03.033>.
- [8] A. S. A. Olalekan, *Banana Drying Kinetics* (Intech, 2016).
- [9] K. Dhake, S. K. Jain, S. Jagtap, and P. Pathare, "Effect of Pretreatment and Temperature on Drying Characteristics and Quality of Green Banana Peel," *AgriEngineering* 5, no. 4 (2023): 2064–2078, <https://doi.org/10.3390/agriengineering5040127>.
- [10] R. Kumar, O. P. Pandey, S. K. Dhiman, and P. Kumar, "Influence of Blanching and Drying Air Temperature on Drying Kinetics of Banana Slices," *Journal of Biosystems Engineering* 46, no. 4 (2021): 375–385, <https://doi.org/10.1007/s42853-021-00114-w>.
- [11] A. K. Sahoo, A. M. Sonkamble, S. R. Patil, R. K. Bhoyar, and J. N. Papade, "Effect of Drying Methods on Consumer Acceptability of Banana Powder," *Asian Journal of Dairy and Food Research* 34, no. 1 (2015): 63, <https://doi.org/10.5958/0976-0563.2015.00013.5>.
- [12] P. S. Kumar, E. Nambi, K. N. Shiva, et al., "Thin Layer Drying Kinetics of Banana Var. Monthan (ABB): Influence of Convective Drying on Nutritional Quality, Microstructure, Thermal Properties, Color, and Sensory Characteristics," *Journal of Food Process Engineering* 42, no. 4 (2019): 1–12, <https://doi.org/10.1111/jfpe.13020>.
- [13] S. Teeta, S. Mali, W. Pharanat, M. Narissara, and Y. Poratoso, "Effects of Using Green Banana Flour as a Substitute for Wheat Flour on the Production of Chiffon Cakes," *Food Agricultural Sciences and Technology (FAST)* 9 (2023): 66–78.
- [14] G. G. Abd El-Wahhab, H. A. A. Sayed, M. A. Abdelhamid, et al., "Effect of Pre-Treatments on the Qualities of Banana Dried by Two Different Drying Methods," *Sustainability* 15, no. 20 (2023): 15112, <https://doi.org/10.3390/su152015112>.
- [15] Y. Yuan, L. Tan, Y. Xu, Y. Yuan, and J. Dong, "Optimization of Combined Drying for Lettuce Using Response Surface Methodology," *Journal of Food Processing and Preservation* 40, no. 5 (2016): 1027–1037, <https://doi.org/10.1111/jfpp.12683>.
- [16] S. Tüfekçi and S. G. Özkal, "The Optimization of Hybrid (Microwave–Conventional) Drying of Sweet Potato Using Response Surface Methodology (RSM)," *Foods* 12, no. 16 (2023): 3003, <https://doi.org/10.3390/foods12163003>.
- [17] R. Rahmawati, D. Hunaefi, I. Basriman, D. Saputra, A. A. Apriliyani, and B. S. L. Jenie, "Optimization of Temperature and Drying Time of Indigenous Cocktail Yeast Mold Culture Using Response Surface Methodology (RSM)," *Food Research* 4, no. 2 (2019): 389–395, [https://doi.org/10.26656/fr.2017.4\(2\).247](https://doi.org/10.26656/fr.2017.4(2).247).
- [18] Ijeoma, "The Effect of Different Pre-Treatments on the Functional Properties of Unripe Mature Green Horn Plantain Flour (Musa Paradisiaca)," *Natural Products* 10 (2014): 37–43, <https://doi.org/10.1201/noe0824727857.ch232>.
- [19] S. Venkateshamamba, R. Krishnaveni, A. Lavanya, and T. Vyshnavi, "Study on Effect of Quality of Green Banana Flour Using Different Drying Techniques," *The Pharma Innovation Journal* 6 (2017): 1–7.

- [20] F. Ajuebor, T. J. Afolabi, and S. E. Agarry, "Optimization of Convective Hot Air Drying of Plantain Slices Using Response Surface Methodology," *The International Journal Of Science & Technology* 5 (2017): 182–189.
- [21] R. P. Farias, R. S. Gomez, W. P. Silva, et al., "Heat and Mass Transfer, and Volume Variations in Banana Slices during Convective Hot Air Drying: An Experimental Analysis," *Agriculture* 10 (2020): 423–514, <https://doi.org/10.3390/agriculture10100423>.
- [22] B. M. A. Amer, M. M. Azam, and A. G. Saad, "Monitoring Temperature Profile and Drying Kinetics of Thin-Layer Banana Slices Under Controlled Forced Convection Conditions," *Processes* 11, no. 6 (2023): 1771, <https://doi.org/10.3390/pr11061771>.
- [23] D. Wang, M. Ma, Z. Zhao, et al., "American Ginseng Slice Drying and Optimization: Effect of Different Drying Methods on Drying Kinetics and Physicochemical Properties," *Processes* 12, no. 6 (2024): 1226, <https://doi.org/10.3390/pr12061226>.
- [24] AOAC International *Official Methods of Analysis of the Association of Official Analytical Chemists International*, 20th edition (Rockville, MD, USA: AOAC International, 2016).
- [25] A. Vega-Galvez, E. Uribe, A. Pasten, et al., "Comprehensive Evaluation of the Bioactive Composition and Neuroprotective and Antimicrobial Properties of Vacuum-Dried Broccoli (Brassica Oleracea Var. Italica) Powder and Its Antioxidants," *Molecules* 28, no. 2 (2023): 766, <https://doi.org/10.3390/molecules28020766>.
- [26] M. Kamble, A. Singh, S. V. Singh, A. Chinchkar, and S. Pareek, "Optimization of Convective Tray-Drying Process Parameters for Green Banana Slices Using Response Surface Methodology and Its Characterization," *Journal of Food Quality* 2022 (2022): 1–17, <https://doi.org/10.1155/2022/8208572>.
- [27] Q. Cai, Z. Li, W. Geng, et al., "Optimization of Hot Air Drying Technology for Bamboo Shoots by Response Surface Methodology," *Food Science and Technology* 43 (2023): 2–10, <https://doi.org/10.5327/fst.128422>.
- [28] S. H. Miraei Ashtiani, B. Sturm, and A. Nasirahmadi, "Effects of Hot-Air and Hybrid Hot Air-Microwave Drying on Drying Kinetics and Textural Quality of Nectarine Slices," *Heat and Mass Transfer* 54, no. 4 (2018): 915–927, <https://doi.org/10.1007/s00231-017-2187-0>.
- [29] P. S. Madamba, "The Response Surface Methodology: An Application to Optimize Dehydration Operations of Selected Agricultural Crops," *LWT-Food Science and Technology* 35, no. 7 (2002): 584–592, <https://doi.org/10.1006/fstl.2002.0914>.
- [30] P. Khawas, K. K. Dash, A. J. Das, and S. C. Deka, "Drying Characteristics and Assessment of Physicochemical and Microstructural Properties of Dried Culinary Banana Slices," *International Journal of Food Engineering* 11, no. 5 (2015): 667–678, <https://doi.org/10.1515/ijfe-2015-0094>.
- [31] I. C. Ekeke, N. A. C. K. F. L. N. P., and A. J. C., "Statistical Modelling of Drying Characteristics of Unripe Plantain (Musa Paradisiaca) Slices," *International Journal of Engineering and Management Research* 9, no. 4 (2019): 30–39, <https://doi.org/10.31033/ijemr.9.4.6>.
- [32] P. S. Kumar, A. Saravanan, N. Sheeba, and S. Uma, "Structural, Functional Characterization and Physicochemical Properties of Green Banana Flour from Dessert and Plantain Bananas (Musa Spp.)," *LWT-Food Science and Technology* 116 (2019): 108524, <https://doi.org/10.1016/j.lwt.2019.108524>.
- [33] L. L. Macedo, W. C. Vimercati, C. da Silva Araújo, S. H. Saraiva, and L. J. Q. Teixeira, "Effect of Drying Air Temperature on Drying Kinetics and Physicochemical Characteristics of Dried Banana," *Journal of Food Process Engineering* 43, no. 9 (2020): 1–10, <https://doi.org/10.1111/jfpe.13451>.
- [34] B. T. Olawoye, O. Kadiri, and T. R. Babalola, "Modelling of Thin-Layer Drying Characteristic of Unripe Cardaba Banana (Musa ABB) Slices," *Cogent Food & Agriculture* 3, no. 1 (2017): 1290013, <https://doi.org/10.1080/23311932.2017.1290013>.
- [35] T. O. Olurin, A. O. Adelekan, and W. A. Olosunde, "Mathematical Modelling of Drying Characteristics of Blanched Field Pumpkin (Cucurbita Pepo L) Slices," *Agricultural Engineering International: CIGR Journal* 14 (2012): 246–254.
- [36] X. D. Song, A. S. Mujumdar, C. L. Law, et al., "Effect of Drying Air Temperature on Drying Kinetics, Colour, Carotenoid Content, Antioxidant Capacity and Oxidation of Fat for Lotus Pollen," *Drying Technology* (2019): 1–14.
- [37] M. Al-Amin, M. Hossain, and A. Iqbal, "Effect of Pre-Treatments and Drying Methods on Dehydration and Rehydration Characteristics of Carrot," *Universal Journal of Food and Nutrition Science* 3, no. 2 (2015): 23–28, <https://doi.org/10.13189/ujfns.2015.030201>.
- [38] M. M. Nasiru, J. D. Raj, and K. C. Yadav, "Effect of Potassium Metabisulphite and Temperature on Hot Air Drying of Dasherri Mango Slices" (2019).
- [39] R. P. Kingsly, R. K. Goyal, M. R. Manikantan, and S. M. Ilyas, "Effects of Pretreatments and Drying Air Temperature on Drying Behaviour of Peach Slice," *International Journal of Food Science and Technology* 42, no. 1 (2007): 65–69, <https://doi.org/10.1111/j.1365-2621.2006.01210.x>.
- [40] I. Ayim, E. A. Amankwah, and K. A. Dzisi, "Effect of Pre-treatment and Temperature on the Air Drying of French and False Horn Plantain Slices," *Journal of Animal and Plant Sciences* 13 (2012): 1771–1780.
- [41] P. Jeet, G. Immanuel, and O. Prakash, "Effects of Blanching on the Dehydration Characteristics of Unripe Banana Slices Dried at Different Temperature," *Agricultural Engineering International: CIGR Journal* 17 (2015): 168–175.
- [42] K. A. Taiwo and R. T. Babalola, "Studies on the Drying Kinetics and Rehydration Capacities of Cardaba Banana Compared to Plantain Slices," *Open Agriculture* 3, no. 1 (2018): 57–71, <https://doi.org/10.1515/opag-2018-0007>.
- [43] I. Doymaz, "Evaluation of Mathematical Models for Prediction of Thin-Layer Drying of Banana Slices," *International Journal of Food Properties* 13, no. 3 (2010): 486–497, <https://doi.org/10.1080/10942910802650424>.
- [44] A. Fawohunre, B. Adewumi, D. Ou, and O. Sobukola, "Fittingmodel for the Thin Layer Drying of Plantain (Musa Acuminata)," *American Journal of Engineering Research (AJER)* 8 (2019): 160–166.
- [45] S. Wongcharee and V. Aravinthan, "Application of Mesoporous Magnetic Nanosorbent Developed from Macadamia Nut Shell Residues for the Removal of Recalcitrant Melanoidin and Its Fractions," *Separation Science and Technology* 55, no. 9 (2020): 1636–1649, <https://doi.org/10.1080/01496395.2019.1606015>.
- [46] A. Al-Hamdani, H. Jayasuriya, P. B. Pathare, and Z. Al-Attabi, "Drying Characteristics and Quality Analysis of Medicinal Herbs Dried by an Indirect Solar Dryer," *Foods* 11, no. 24 (2022): 4103, <https://doi.org/10.3390/foods11244103>.
- [47] D. Engin, "Effect of Drying Temperature on Color and Desorption Characteristics of Oyster Mushroom," *Food Science and Technology* 40, no. 1 (2020): 187–193, <https://doi.org/10.1590/fst.37118>.

- [48] T. A. Anyasi, A. I. O. Jideani, and G. R. A. McHau, "Effect of Organic Acid Pretreatment on Some Physical, Functional and Antioxidant Properties of Flour Obtained from Three Unripe Banana Cultivars," *Food Chemistry* 172 (2015): 515–522, <https://doi.org/10.1016/j.foodchem.2014.09.120>.
- [49] A. Vega-Gálvez, L. S. Gomez-Perez, K. S. Ah-Hen, et al., "Convective Hot Air Drying of Red Cabbage (*Brassica Oleracea* Var. *Capitata Rubra*): Mathematical Modeling, Energy Consumption and Microstructure," *Processes* 12, no. 3 (2024): 509, <https://doi.org/10.3390/pr12030509>.
- [50] S. Mahmoodi, F. Moradinezhad, S. Moodi, H. Amini, and M. Khayyat, "Effects of Potassium Metabisulfite Pre-Treatment and Different Drying Temperatures on Some Chemical Properties and Color Retention of Russian Olive (*Elaeagnus Angustifolia*) Fruit," *Journal of Horticulture and Postharvest Research* 1 (2018): 49–62, <https://doi.org/10.22077/jhpr.2018.1177.1004>.
- [51] K. A. Taiwo, A. Angersbach, and D. Knorr, "Influence of High Intensity Electric Field Pulses and Osmotic Dehydration on the Rehydration Characteristics of Apple Slices at Different Temperatures," *Journal of Food Engineering* 52, no. 2 (2002): 185–192, [https://doi.org/10.1016/S0260-8774\(01\)00102-9](https://doi.org/10.1016/S0260-8774(01)00102-9).
- [52] A. Vega-Gálvez, K. Ah-Hen, M. Chacana, et al., "Effect of Temperature and Air Velocity on Drying Kinetics, Antioxidant Capacity, Total Phenolic Content, Colour, Texture and Microstructure of Apple (Var. Granny Smith) Slices," *Food Chemistry* 132, no. 1 (2012): 51–59, <https://doi.org/10.1016/j.foodchem.2011.10.029>.
- [53] D. B. Singh and R. K. Goyal, "Effect of Pre-Treatments and Drying Temperatures on the Quality of Dehydrated Mango Slices," *Indian Journal of Horticulture* 69 (2012): 586–890.



DSPACE

<https://dspace.org/>

Optimization of drying parameters for pretreated green banana slices using response surface methodology

Dhake, Kushal; Jain, Sanjay K.; Jagtap, Sandeep; Pathare, Pankaj B.

2025-02-22

Wiley

<https://doi.org/10.1155/jfq/3959937>

Dhake KP, Jain SK, Jagtap S, Pathare PB. (2025) Optimization of drying parameters for pretreated green banana slices using response surface methodology. Journal of Food Quality, Volume 2025, February 2025, Article number 3959937