Selected Bioactive Attributes of Spray-Dried Ripe Red Banana (*Musa acuminata*) Powder as Affected by Dryer's Operational parameters

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ABSTRACT: Red banana is rich in bioactive compounds and nutrients but deteriorate rapidly due to its abundant moisture content. To enhance its stability and health benefits, processing it into a more stable form is essential. Spray drying is an operational technique for producing fruit powders with improved stability and convenience. This study examines the impact of some spray dryer's operational parameters on the bioactive attributes of spray-dried ripe red banana powder. The effects of inlet air temperature (150-180 °C), feed pump speed (20-50 rpm), and maltodextrin concentration (25-40%) on the stability of total phenolic content (TPC), total flavonoid content (TFC), vitamin C, and β-carotene were analysed. Results showed satisfactory retention of bioactive compounds, with highest values of 132.20 mg/100 g, 45.99 mg/100 g, 18.87 mg/100 g, and 0.065 mg/100 g for TPC, TFC, vitamin C and β-carotene respectively. These values were obtained at operational parameters of 180 ºC IAT, 35 rpm FPS, 25% MDC for TPC; 150ºC IAT, 20 rpm FPS, 32.5% MDC for TFC; 165 ºC IAT, 20 rpm FPS, 25% MDC for vitamin C and 165 ºC IAT, 35 rpm FPS, 32.5% MDC for β-carotene. These findings underscore the importance of selecting suitable spray dryer parameters to preserve bioactive compounds, offering valuable insights for the food industry in developing functional ingredients with enhanced nutritional properties.

KEYWORDS: Red banana, operational parameters, maltodextrin, ascorbic acid, β-carotene.

I. INTRODUCTION

Red banana, also known as red dacca (Musa acuminata Colla AAA "Red") (Maseko et al., 2024) is regarded as one of the most important tropical fruits widely cultivated in numerous tropical regions (Pavethra et al., 2024). However, there are up to 1000 varieties of banana, such as giant and dwarf Cavendish, Barangan, Gold finger, red, Pisang and Saba banana, red banana has gained significant attention as a food resource due to its exceptional bioactive qualities, nutritional profile, and health-promoting properties (Elangovan and Natarajan, 2021). This fruit is abundant in carbohydrates (such as glucose, fructose, and sucrose), dietary fibres, and organic acids (primarily citric, succinic, and malic acids). It is also rich in vitamins (including A, B1, B2, and particularly vitamin C) and essential minerals like magnesium, potassium, manganese, calcium and iron (Kumari et al., 2023; Vicent, 2024). Additionally, red banana is a potent source of bioactive compounds, which include phenols and flavonoids, contributing to its association with various health benefits. Consumption of banana in general and particularly red banana has been linked to digestive health, protection against cancer, gastrointestinal disorders, inflammatory and cardiovascular diseases (Afzal et al., 2022; Chowdhury et al., 2024; Van Tai et al., 2024).

Due to their natural sweetness and firm texture, red bananas are widely appreciated in both fresh and cooked applications. They can be consumed raw, blended into smoothies and yoghurts, or used as toppings for breakfast dishes and desserts (Mishra et al., 2016; Shini et al., 2024). However, its high sugar and moisture content make it highly perishable, leading to rapid physical deterioration and appearance changes within days of harvest, especially when ripe. Consequently, the commercialization of red bananas is restricted, predominantly catering to local markets. This limits its potential applications on a larger scale, such as in the food or pharmaceutical industries (Costa et al., 2023; Ferreira and Freitas, 2019). To address these limitations, preservation methods that retain the fruit's nutritional and bioactive attributes while extending its shelf life are essential.

Drying has emerged as a practical technique for reducing the moisture content of fruits and other biomaterials, thereby inhibiting microbial growth and enzymatic or chemical reactions. This process extends shelf life and makes transportation and storage easier (Adepoju et al., 2021; Adepoju and Osunde, 2017; Vargas et al., 2022). Various drying methods have been investigated for bananas, including solar drying (Elangovan and Natarajan, 2021), hot air drying (Mishra et al., 2016; Sonawane et al., 2021), forced convective drying (Taheri-Garavand et al., 2017); freeze-drying (Monteiro et al., 2016), Pulse vacuum drying (Zhou et al., 2022); foam mat drying (Marzlan et al., 2020; Noordia et al., 2020; Van Tai

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et al., 2024) and spray drying (Barooah et al., 2018; Wong et al., 2018), each offering distinct benefits and limitations. Among these, spray drying has shown considerable potential for red banana processing due to its success in producing powdered forms of diverse feedstock (Chávez-Rodríguez et al., 2013).

Spray drying is a leading industrial technique for producing powdered foods and microencapsulated food ingredients. The process involves atomizing a fluid feed material through a hot medium, usually air, resulting in the rapid development of powder particles (Darroca et al., 2024; Ferreira et al., 2022). This method offers several advantages, such as minimal heat exposure, efficient moisture removal, consistent powder volume reduction, improved solubility of the resulting powder, and enhanced organoleptic properties (Acosta-Vega et al., 2023; Gawałek, 2021; Ledri et al., 2024; Santos et al., 2021). Various fruits have been successfully processed to powders using spray drying, including oranges (Sidlagatta et al., 2020), watermelon (Asnawi et al., 2022; Shi et al., 2018), tamarind (Cynthia et al., 2015; Muzaffar and Kumar, 2017), mango (Kongpichitchoke et al., 2021), mangosteen (Setyawati et al., 2020), pineapple (Sharma et al., 2023; Wong et al., 2015), guava (Shishir et al., 2014) and banana (Harish et al., 2017; Wong et al., 2018). This study aimed to investigate the effects of operational parameters (inlet air temperature, feed pump speed, and maltodextrin concentration) on total phenolics, total flavonoids, β-carotene, and ascorbic acid.

II. MATERIALS AND METHODS

A. Materials

Fully ripe red banana fruits (ripeness level 4 as shown in the red banana ripening chart in Figure 1) used in this study were procured from a popular agricultural produce market located in Ganmo (8°29′00″ N, 4°35′00″ E), Ilorin in Kwara State, south-western Nigeria. Laboratory-scale spray dryer used was situated at the Food Processing Laboratory, Nigerian Stored Products Research Institute (NSPRI), Ilorin. Maltodextrin (carrier agent) was purchased from Special Ingredients Ltd, Foxwood Industrial Park, Chesterfield, S41 9RN, United Kingdom, Pectinase enzyme was bought from North Mountain Supply, Mildred, PA, USA and Folin-Ciocalteau's reagent, gallic acid and all chemical used were of analytical grade and were obtained from Sigma-Aldrich, Germany and BDH, England

1 – Unripe; 2 – Early Ripening; 3 – Partially Ripe; 4 – Fully Ripe; 5 – Overripe. Source: Morelli & Kader (2024)

Figure 1: Red Banana Ripening Chart

B. Methods

1. Feedstock preparation

The banana fruits were washed, drained, peeled and cut into small pieces directly into a manual food chopper and processed until a mashed pulp was obtained. The pulp was immediately treated with pectinase enzyme by using the method of Chang *et al.* (2020) with modifications, to obtain banana juice. Maltodextrin (25-40%) was added directly to the extracted banana juice according to the experimental design and this mixture is considered to be the feedstock for the spray drying process.

2. Spray drying of feedstock

A laboratory-scale co-current spray dryer (Xiamen Ollital, China) shown in Figure 2 was utilized to produce red banana powder. A peristaltic pump dispersed the feedstock into the dryer following the experimental design. The process conditions, including inlet air temperature (150-180°C), feed pump speed (20-50 rpm), and maltodextrin concentration (25-40%), were adjusted accordingly. The spray-dried banana powders were collected from the product vessel, cyclone, and cylindrical sections after each experimental run by gently brushing the chamber walls. The collected powders were then immediately stored separately in airtight pouches at room temperature (20-25°C) for further analysis.

Figure 2: Laboratory-Scale Spray Dryer

3. Experimental design

The experiment was designed using Response Surface Methodology (RSM) of the Design Expert 13.0 software (Statease Inc., Minneapolis, MN, USA). Box-Behnken design with five replicates at the centre point was used for spray drying of ripe banana juice. This particular design was chosen because it was reported to have better predictive precision in the centre of the factor space (Bazaria and Kumar, 2018). Three independent variables namely, inlet air temperature (150, 165 and 180°C), feed pump speed (20, 35 and 50 rpm) and maltodextrin concentration (DE 17) concentration (25, 32.5 and 40%) were considered to develop predictive models for different responses. Seventeen (17) runs of the experiment were conducted including the central point. To evaluate the effects of process conditions on the responses, the quadratic polynomial Equation (1) was fitted to the empirical data. The designed experiment is presented in Table 1.

$$Y = B_O + \sum_{i=1}^{n} B_i\, x_i + \sum_{i=1}^{n} B_{ii}\, x_i^2 + \sum_{i=1}^{n} \sum_{j=1}^{n} B_{ij}\, x_{ij} \quad (1)$$

Table 1: Experimental Design for Spray Drying of Red Banana Powder

Run	IAT (ºC)	FPS (rpm)	MDC (%)
1	165	35	32.5
2	165	50	25
3	165	35	32.5
4	165	20	40
5	180	50	32.5
6	165	35	32.5
7	150	35	25
8	165	35	32.5
9	165	20	25
10	150	35	40
11	180	35	25
12	165	35	32.5
13	180	35	40
14	150	50	32.5
15	150	20	32.5
16	180	20	32.5
17	165	50	40

IAT - Inlet Air Temperature; FPS - Feed Pump Speed; MDC - Maltodextrin Concentration

C. Analysis of Bioactive Attributes of the Banana Powder

The following bioactive attributes of the spray-dried banana powder were determined:

1. Determination of Total Phenolic Content (TPC)

Total phenolic content was measured using the Folin–Ciocalteau method with gallic acid as the standard following the method of Riya *et al.* (2023) with modifications. Spectrophotometric readings were taken at 650 nm using a UV-visible spectrophotometer (1902PC Searchtech Instrument, England). The results were expressed in milligrams of gallic acid/100 g of sample.

2. Determination of Total Flavonoid Content (TFC)

The total flavonoid content was determined using the aluminium chloride colorimetric assay method outlined by Riya *et al.* (2023) with modifications, with quercetin as the standard. Spectrophotometric readings were performed at 450 nm using a UV-visible spectrophotometer (1902PC Searchtech Instrument, England). The results were reported in milligrams of quercetin/100 g of sample.

3. Determination of ascorbic acid content

The determination of ascorbic acid (or vitamin C) content was determined using the titration method, involving the reduction of standardized 2,6-dichloroindophenol in the presence of oxalic acid as described by Hussain *et al.* (2024). The results were expressed in milligrams of ascorbic acid/100 g of sample.

4. Determination of β-carotene content

The β-carotene content in the spray-dried banana powder samples was analysed using the solvent extraction method described by Arebo *et al.* (2023). The absorbance of the extracted sample was measured at 450 nm using a UV-Vis spectrophotometer. The β-carotene concentration was then determined based on a calibration curve generated from standard analytical-grade β-carotene solutions.

D. Statistical Analysis

Design Expert 13.0, (Stat-ease Inc., Minneapolis, USA) was used to correlate the relationship between the independent variables (inlet air temperature, feed pump speed and maltodextrin concentration) and the responses (total phenolic contents, total flavonoid contents, vitamin C, and β-carotene). Analysis of variance (ANOVA), along with coefficient of determination R^2 and adjusted R^2 were used to assess the quality, accuracy and adequacy of the models. Lack of fit tests were used to determine the appropriateness of the fit. The F-values and R^2 values of the responses were calculated as a function of variables. The 3-D surface plots were generated to study the interactive effect of independent variables on the responses by keeping two factors constant and varying the other factor.

III. RESULTS AND DISCUSSION

The effects of spray drying operational parameters on the bioactive attributes of red banana powder is presented in Table 2.

A. Effect of Operational parameters on Total Phenolic Content (TPC) of the Banana Powder

Phenolic compounds are essential secondary metabolites that are relatively high in bananas compared to other fruits. They have been associated with health benefits that include the prevention of several cardiovascular diseases (Anyasi *et al.*, 2018). Banana juice dried at inlet air temperature of 180ºC, feed pump speed of 35 rpm and maltodextrin concentration of 25 % has the highest TPC of 132.20 mg/100 g while the lowest value of 77.18 mg/100 g was observed at a temperature of 180ºC, feed pump speed of 35 rpm and maltodextrin concentration of 40%.

The ANOVA results (Table 3) showed F- and p-values of 3349.81 and <0.000, indicating that, the quadratic model is statistically significant and explains most of the variations in TPC. All linear, interaction and quadratic terms are significant ($p<0.0001$), and this implied that the operational parameters contribute meaningfully to the model. The p-value for lack of fit is greater than 0.05 (0.0613), implying that the lack of fit is not significant. This shows that the model adequately fits the experimental data. The high R^2 (0.9998) and adjusted R^2

Table 2: Bioactive Properties of the Banana Powder as Affected by Process Parameter

Run	IAT (ºC)	FPS (rpm)	MDC (%)	TPC (mg/100g)	TFC (mg/100g)	Vitamin C (mg/100g)	β-Carotene (mg/100g)
1	165	35	32.5	89.711	25.119	9.574	0.065
2	165	50	25.0	128.543	26.174	12.637	0.045
3	165	35	32.5	89.411	25.111	9.589	0.064
4	165	20	40.0	117.758	29.794	14.680	0.041
5	180	50	32.5	90.630	26.607	9.318	0.048
6	165	35	32.5	89.468	25.107	9.543	0.064
7	150	35	25.0	88.045	33.298	17.012	0.034
8	165	35	32.5	89.197	24.912	9.572	0.065
9	165	20	25.0	114.577	31.253	18.868	0.047
10	150	35	40.0	115.909	31.355	13.851	0.049
11	180	35	25.0	132.203	23.700	12.064	0.063
12	165	35	32.5	89.197	24.912	9.572	0.065
13	180	35	40.0	77.183	17.491	12.162	0.036
14	150	50	32.5	86.527	24.675	12.034	0.043
15	150	20	32.5	92.328	45.990	16.260	0.040
16	180	20	32.5	91.378	20.144	12.252	0.051
17	165	50	40.0	98.334	19.676	13.672	0.043
RBJ				270.938	60.935	22.440	0.083

RBJ – Red Banana Juice

(0.9995) values indicated that the quadratic model explains 99.98% of the variability in the TPC. The minimal difference between R^2 and Adjusted R^2 implies a well-fitted model with no overfitting. The predicted R^2 (0.9969) is in reasonable agreement with the adjusted R^2, suggesting strong predictive ability of the model. The exceptionally high ratio (191.174) indicated a very strong signal and confirmed the model's reliability for navigating the design space. Equation (2) showed the quadratic model for TPC.

$$TPC = 84.40 + 1.07A - 1.50B - 6.77C + 1.26AB - 20.72AC - 8.35BC - 5.32A^2 + 6.14B^2 + 19.26C^2 \quad (2)$$

The coefficients indicate the magnitude and direction of each factor's effect. For example, the inlet air temperature (A) has a linear effect on the TPC and a positive coefficient of +1.07 suggests that an increase in IAT slightly enhances TPC within the studied range. This could be due to various mechanisms explained in literatures such as possible polymerization of polyphenols at high temperatures leading to an increase in TPC, formation of new phenolics and cleaving of ester bonds from phenolics-containing compounds, thereby releasing free phenolics (Huynh *et al.*, 2023; Zhang *et al.*, 2020). However, a negative quadratic coefficient (−5.32) indicates that very high IAT lead to a decline in TPC, which may be due to thermal degradation of heat-sensitive phenolic compounds.

Feed pump speed (B) has a linear effect with a negative coefficient (−1.50) and this shows that increasing FPS reduces TPC. This is probably due to less residence time in the drying chamber, resulting in incomplete evaporation and lower encapsulation of phenolic compounds. A similar observation was noted in studies on the spray drying of mango juice (Pham *et al.*, 2022). Other authors noted that increasing FPS results in shorter residence time, which can lead to lower TPC due to insufficient drying (Silva *et al.*, 2024). However, a positive coefficient (+6.14) of the quadratic effect (B^2) implies that moderate FPS can improve TPC, balancing efficient drying and encapsulation. Maltodextrin Concentration (C) has a strong negative coefficient (−6.77) on the TPC, and this indicates that higher MDC significantly decreases TPC. It was also noted that the highest value of TPC was obtained at the lowest MD concentration within the design matrix (25%). This observation is in tandem with previous studies that established a dilution effect of TPC at higher carrier concentrations (Leyva-Porras *et al.*, 2021; Tan *et al.*, 2021; Wirivutthikorn, 2024).

However, a very large positive coefficient (+19.26) of the quadratic effect of maltodextrin concentration (C^2) suggests that at optimal levels, MDC can protect phenolic from degradation during spray drying by acting as a stabilizing agent. The most significant interaction (−20.72) occurs with the interactive effects of inlet air temperature and maltodextrin concentration, and this indicates that the combination of high IAT and high MDC leads to substantial TPC reduction. This reflects the dual effect of heat-induced degradation and excessive dilution of phenolic compounds in the banana juice powder. A negative interaction (−8.35) which shows that higher MDC combined with faster FPS reduces TPC was also noted. This may likely results due to inadequate encapsulation

Table 3: Analysis of variance (ANOVA) of quadratic model for TPC and TFC

		TPC				TFC			
Source	df	Sum of squares	Mean square	F Value	P value	Sum of squares	Mean square	F Value	P value
Model	9	4240.25	471.14	3349.81	< 0.0001	671.88	74.65	5602.84	< 0.0001
A-IAT	1	9.21	9.21	65.48	< 0.0001	280.56	280.56	21056.54	< 0.0001
B-FPS	1	18.02	18.02	128.13	< 0.0001	112.88	112.88	8471.40	< 0.0001
C-MDC	1	366.99	366.99	2609.32	< 0.0001	32.44	32.44	2434.65	< 0.0001
AB	1	6.38	6.38	45.38	0.0003	192.92	192.92	14478.49	< 0.0001
AC	1	1717.44	1717.44	12211.03	< 0.0001	4.55	4.55	341.36	< 0.0001
BC	1	278.72	278.72	1981.69	< 0.0001	6.35	6.35	476.53	< 0.0001
A^2	1	119.37	119.37	848.71	< 0.0001	17.33	17.33	1300.99	< 0.0001
B^2	1	158.92	158.92	1129.94	< 0.0001	22.13	22.13	1660.91	< 0.0001
C^2	1	1562.34	1562.34	11108.25	< 0.0001	1.52	1.52	113.95	< 0.0001
Residual	7	0.9845	0.1406			0.0933	0.0133		
Lack of Fit	3	0.8004	0.2668	5.80	0.0613	0.0452	0.0151	1.25	0.4021
Pure Error	4	0.1841	0.0460			0.0481	0.0120		
Cor Total	16	4241.23				671.98			
		$R^2 = 0.9998$ Adjusted $R^2 = 0.9995$ Predicted $R^2 = 0.9969$ Adeq Precision = 191.1738				$R^2 = 0.9999$ Adjusted $R^2 = 0.9997$ Predicted $R^2 = 0.9988$ Adeq Precision = 322.1247			

at high flow rates and excessive carrier content. A smaller but significant positive interaction (+1.26) indicates that the combined optimisation of IAT and FPS can enhance TPC, provided these are within optimal ranges. 3D surface curves showing the interactive effects of the operational parameters on TPC of banana powders are shown in Figure 3

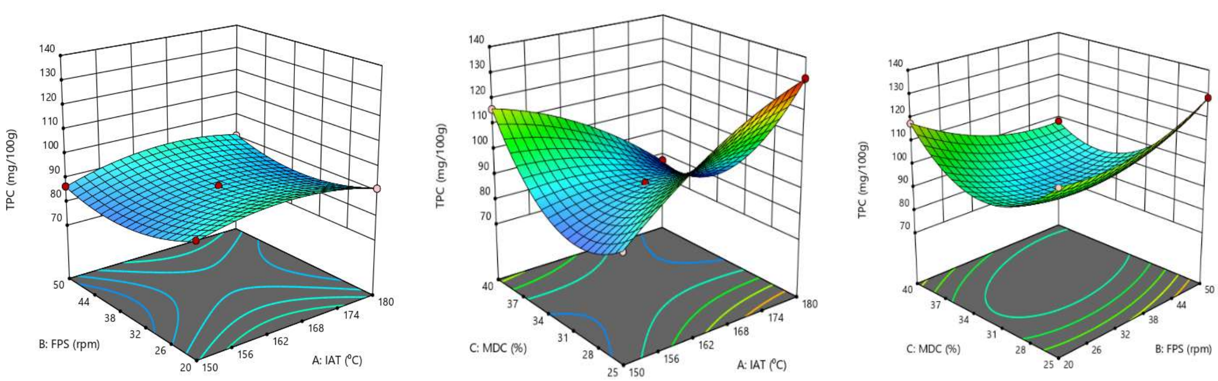

Figure 3: Interactive effects of the operational parameters on TPC of banana powders as depicted by 3D plots

The TPC values recorded in this study are higher than the range (29.91-71.46 mg/100g) obtained by Alam *et al.* (2023) for banana flour dried with freeze drying and other methods. Several studies have also reported lower or similar values of TPC for different spray-dried fruit powder. Notably, 105 mg/100g for bilberry juice powder (Halahlah *et al.*, 2023); 116.90-218.50 mg/100g cantaloupe powder (Tan *et al.*, 2021); 116.87 mg/100 for blackcurrant powder (Archaina *et al.*, 2018); 5.9-10.8 mg/g for strawberry juice powder (Leyva-Porras *et al.*, 2021) and 50.36-78.30 mg/g for palmyrah fruit powder (Sangeetha *et al.*, 2023). TPC ranging from 61.28-96.11 mg/100 g was also obtained for lemon juice powders (Rohini *et al.*, 2024). However, Khoza *et al.* (2021) reported higher range of values (298.73-524.87 mg/100g) for different cultivars of green banana flour. This is possibly because of differences in the stage of ripening, the growth conditions and other environmental practices. Moreover, the extent of maturity has been reported to substantially affect the total phenolic content in banana powder (Khoza *et al.*, 2021). It was reported that over-ripe banana flour had 52% less phenolic content than green banana flour (GBF), while ripe banana flour had 15-45% less phenolic content than GBF (Anyasi *et al.*, 2018). Additionally, Huynh *et al.* (2023) recorded a TPC of 1011-1268 mg/100 g for spray-dried lime powder. Furthermore, phenolic compounds are of interest in the food industry due to their antimicrobial, anticarcinogenic, antitumorigenic and antioxidant properties (Ferreira *et al.*, 2022). With the value of TPC obtained in this study, the banana powder produced has the potential for being used as a raw ingredient in functional foods.

B. *Effect of Operational parameters on Total Flavonoid Content (TFC) of the Banana Powder*

Flavonoids are potent antioxidants, neutralizing free radicals and preventing oxidative stress. They help in lowering the risks of chronic diseases such as cardiovascular issues and neurodegenerative disorders and have been reported to have anticancer, anti-inflammatory, antidiabetic and antimicrobial properties (Raman *et al.*, 2020; Silva *et al.*, 2024). The highest TFC of 45.99 mg/100 g for the spray-dried banana powder was observed in experimental run 15 with 150ºC IAT, 20 rpm FPS and 32.5% MDC while the lowest value of 17.49 mg/100 g was obtained at 180ºC IAT, 35 rpm FPS and 40% MDC.

The results obtained in this study corroborate previous reports in literature that lower IAT helps to preserve heat-sensitive flavonoids, minimizing thermal degradation. Studies confirmed that temperatures around 140-160°C optimise flavonoid retention in banana and other fruit powders (Demircan *et al.*, 2023; Hadree *et al.*, 2023; Sharma *et al.*, 2023). Moreover, lower FPS allowed sufficient drying time without overheating, reducing oxidative and thermal damage to flavonoids and other bioactive compounds in fruit powders, leading to higher retention of phenolic compounds (Chang *et al.*, 2021; Singh and Hathan, 2017). In addition, a moderate maltodextrin concentration balances the protection of flavonoids during spray drying without excessively diluting the juice. Studies suggest that maltodextrin levels around 25-35% provide effective encapsulation without significant dilution of active compounds (Lee *et al.*, 2013; Wirivutthikorn, 2024).

All factors (linear, quadratic and interaction) showed significant effects on TFC ($p < 0.0001$) as shown in the ANOVA in Table 3. Equation (3) showed the quadratic model used to evaluate the impact of the operational parameters on TFC. The 3D surface plots illustrating the relationships between the operational parameters and TFC are presented in Figure 4.

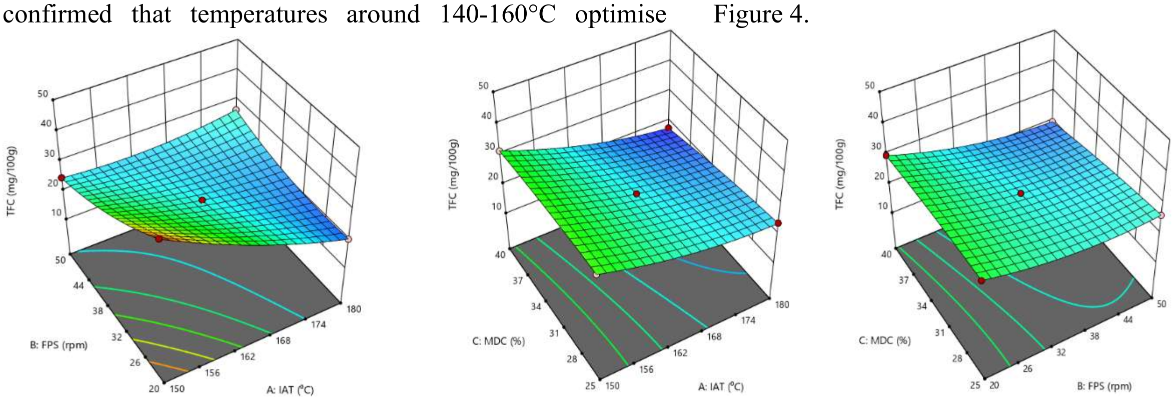

Figure 4: Response surface plots showing the interactive effects of the operational parameters on TFC of the banana powders

The lowest TFC of 17.49 mg/100 g was obtained at process conditions, 180°C IAT, 35 rpm FPS, 40% MDC. This observation is in line with some research stating that high inlet air temperature causes thermal degradation of flavonoids, which are sensitive to heat. The present findings were consistent with the results obtained for spray-dried Japanese apricot (Kim *et al.*, 2023) and chokeberry powder (Gawałek and Domian, 2020).

$$TFC = 25.03 - 5.92A - 3.76B - 2.01C + 6.94AB - 1.07AC - 1.26BC + 2.03A^2 + 2.29B^2 - 0.60C^2 \quad (3)$$

Studies highlight that temperatures above 170°C lead to significant losses in flavonoid content due to oxidation and breakdown (Feszterová *et al.*, 2023; Kuck and Noreña, 2016). Higher feed rates result in insufficient drying, leading to uneven moisture content, which can accelerate degradation processes during and after drying, compromise powder quality and bioactive retention (Pham *et al.*, 2022). Further, high MDC dilute the flavonoid content in the final powder. While carriers protect bioactives during drying, excessive amounts lower the apparent concentration of bioactives in the powder, causing a reduction in TPC (Tran *et al.*, 2023). The interaction between these parameters (inlet air temperature, feed pump speed, and maltodextrin concentration) can significantly affect the total flavonoid content. For instance, a combination of lower IAT with appropriate FPS can enhance flavonoid retention as seen in the model equation. The findings in this study align with recent literature emphasizing the importance of optimizing spray drying parameters to preserve bioactive compounds (Huynh *et al.*, 2023). The significant influence of IAT, FPS, and MDC on TFC corroborates broader trends in food processing research, highlighting spray drying as a reliable technique for producing nutrient-rich banana powder.

Several studies have reported different values for TFC for varieties of spray-dried fruit powders. A range of 15.25-25.94 mg/100 g was obtained for cantaloupe powder (Tan *et al.*, 2021), 56.34-98.85 mg/100 g for lemon juice powders (Rohini *et al.*, 2024). Saikia *et al.*, (2015) noted 34.16 mg/100 g for khasi mandarin, 16.93 mg/100 g for carambola, 14.59 mg/100 g for pineapple and 2.41 mg/100 g for watermelon powders respectively.

C. *Effect of Operational parameters on* Ascorbic Acid *Contents of the Banana Powder*

Ascorbic acid (vitamin C) is a potent antioxidant that functions as a preservative in foods by preventing browning and other oxidative reactions, acting as a free radical scavenger. It plays a crucial role in various physiological processes, including immune system support, prevention of mucosal bleeding, and regulation of blood glucose levels (García-Chacón *et al.*, 2024; Silva *et al.*, 2024). It is also one of the important nutrient in humans' diet due to the inability of the human body to synthesize it (Muniz *et al.*, 2020). The ascorbic acid in banana juice was 22.44 mg/100 g while the one found in the banana powder ranged from 9.32-18.87 mg/100 g, indicating a significant influence of the process parameters. The highest obtainable value of ascorbic acid for the powder in this study was close to those observed for the juice, indicating a lesser effect of the spray drying process on this bioactive compound. The ANOVA of the quadratic model (Table 4) revealed that IAT (A), FPS (B), and MDC (C) significantly affect vitamin C retention, both individually and through interactions. The model's F-value (27599.48) and $p < 0.0001$ indicate that it is highly significant. This suggests that the independent variables (IAT, FPS, and MDC) and their interactions significantly influence vitamin C retention. The R^2 value of 1.0000 implied that the model, demonstrating excellent fit, explains the variability in vitamin C retention. The adjusted R^2 (0.9999) and predicted R^2 (0.9997) showed strong agreement between predicted and observed values, with a difference of less than 0.2, confirming the model's reliability. The lack of fit is not significant, indicating the model adequately captures the data without random noise interference. The robustness of the model to navigate the design space is indicated by the high value of adequate precision (529.6759). The model equation fitted for vitamin C is presented in Equation (4).

$$Ascorbic\ acid = 9.57 - 1.67A - 1.80B - 0.78C + 0.32AB + 0.82AC + 1.31BC + 0.85A^2 + 2.04B^2 + 3.35C^2 \quad (4)$$

Negative Coefficient (−1.67) of IAT indicated that vitamin C retention decreased with increase in temperature. This observation is in alignment with previous studies on spray-dried powder, which stated that elevated IATs negatively influence vitamin C retention due to thermal degradation and possible oxidation (Huynh *et al.*, 2023; Khwanpruk *et al.*, 2018; Lee *et al.*, 2013; Pham *et al.*, 2022). A study on sweet orange juice powder reported that vitamin C retention was higher at lower inlet air temperatures, with significant degradation observed as temperatures increased (Sidlagatta *et al.*, 2020). Similar behaviour of vitamin C with respect to the process temperatures was reported for pineapple powder (Cardona *et al.*, 2023). Thermal degradation of heat-sensitive vitamin C can also occur through the conversion of ascorbic acid to dehydroascorbic acid, which further degrades into inactive compounds (Sarkar *et al.*, 2023).

The negative coefficient (−1.80) of the FPS implied that higher feed pump speeds reduced vitamin C retention (Huynh *et al.*, 2023). Faster flow rates caused uneven drying, leading to incomplete evaporation and dripping of the banana juice directly into the waste collection chamber of the spray dryer. Feed pump speed affects the residence time of the feed in the drying chamber, thereby influencing vitamin C retention. A study on cupuassu powder found that an inlet air temperature of 130°C and a feed flow rate of 30 mL/min produced high-quality spray-dried powder, suggesting that moderate FPSs can enhance vitamin C retention by reducing exposure to heat (Acosta-Vega *et al.*, 2023).

However, a contrary observation was reported by Muzaffar *et al.* (2016) that higher feed pump speed showed a positive effect on the vitamin C content of pomegranate powder as a result of slower heat and the mass transfer. The negative coefficient (−0.78) for MDC implied that higher concentration of maltodextrin leads to a decrease in vitamin C retention due to dilution effect, that is, increasing MDC reduced the effective concentration of vitamin C in the feed mixture, leading to lower measured retention.

Table 4: Analysis of variance (ANOVA) of quadratic model for Vitamin C and β-carotene

		Vitamin C				β-carotene			
Source	df	Sum of squares	Mean square	F Value	p-value	Sum of Squares	Mean Square	F-value	p-value
Model	9	136.65	15.18	27599.48	< 0.0001	0.0658	0.0073	166.43	< 0.0001
A-IAT	1	22.31	22.31	40557.49	< 0.0001	0.0000	0.0000	1.03	0.3429
B-FPS	1	25.92	25.92	47116.54	< 0.0001	0.0105	0.0105	238.91	< 0.0001
C-MDC	1	4.83	4.83	8777.53	< 0.0001	0.0050	0.0050	113.04	< 0.0001
AB	1	0.4173	0.4173	758.60	< 0.0001	0.0007	0.0007	16.79	0.0046
AC	1	2.66	2.66	4826.51	< 0.0001	0.0001	0.0001	1.89	0.2121
BC	1	6.82	6.82	12399.50	< 0.0001	0.0284	0.0284	647.40	< 0.0001
A^2	1	3.06	3.06	5554.68	< 0.0001	0.0060	0.0060	136.55	< 0.0001
B^2	1	17.59	17.59	31973.40	< 0.0001	0.0075	0.0075	170.55	< 0.0001
C^2	1	47.27	47.27	85916.10	< 0.0001	0.0081	0.0081	183.82	< 0.0001
Residual	7	0.0039	0.0006			0.0003	0.0000		
Lack of Fit	3	0.0027	0.0009	3.28	0.1408	0.0002	0.0001	2.36	0.2123
Pure Error	4	0.0011	0.0003			0.0001	0.0000		
Cor Total	16	136.66				0.0020			
$R^2 = 1.0000$						$R^2 = 0.9981$			
Adjusted $R^2 = 0.9999$						Adjusted $R^2 = 0.9957$			
Predicted $R^2 = 0.9997$						Predicted $R^2 = 0.9766$			
Adeq Precision = 529.6759						Adeq Precision = 55.2570			

While maltodextrin served as a protective carrier, too much MDC can alter particle structure, reducing encapsulation efficiency. In addition, maltodextrin attracts moisture due to its hygroscopic nature, and excess moisture can accelerate vitamin C degradation through hydrolysis and oxidation. A contrary observation was reported by Mohanty *et al.* (2021) that increase in additive concentration led to increased vitamin C content in palm powder. The authors stated that vitamin C was well encapsulated and less affected on exposure to a higher temperature with increased additive concentration. Ribeiro *et al.* (2019) also reported a similar trend.

The interaction effects of AB (IAT×FPS) with a positive coefficient (+0.32) on vitamin C retention means that while both high IAT and FPS individually decrease Vitamin C, their combined effect is less severe than expected. This is because high flow rates may shorten drying time, partially offsetting the damage from high temperatures. Likewise, the interactive effects of IAT and MDC (AC) showed that higher MDC combined with increased drying temperature (IAT) improves vitamin C retention, suggesting that maltodextrin provides some thermal protection at moderate levels by forming a protective layer around vitamin C, reducing direct exposure to heat. However, excessive MDC at high temperatures may increase viscosity of the feed, leading to incomplete drying and degradation.

Moreover, Higher MDC and increased FPS (BC with coefficient +1.31) enhanced retention as maltodextrin acts as a protective carrier when applied with optimised feed rates in spray drying. A high feed pump speed prevents overheating, which helps maintain Vitamin C stability. The nonlinear (quadratic) effects of IAT on vitamin C retention showed that its degradation accelerates at extreme temperatures, but a moderate temperature range were less harmful. In addition, very high or very low feed pump speeds were detrimental to vitamin C and a moderate FPS was observed to balance uniform drying and minimize exposure time. Likewise, the quadratic effect of MDC suggested that both very low and very high MDC levels reduce vitamin C retention. However, a contrary view was reported by for spray-dried umbu powder where the authors observed vitamin C retention at high maltodextrin concentration (Muniz *et al.*, 2020). The response surface plots for vitamin C are depicted in Figures 5.

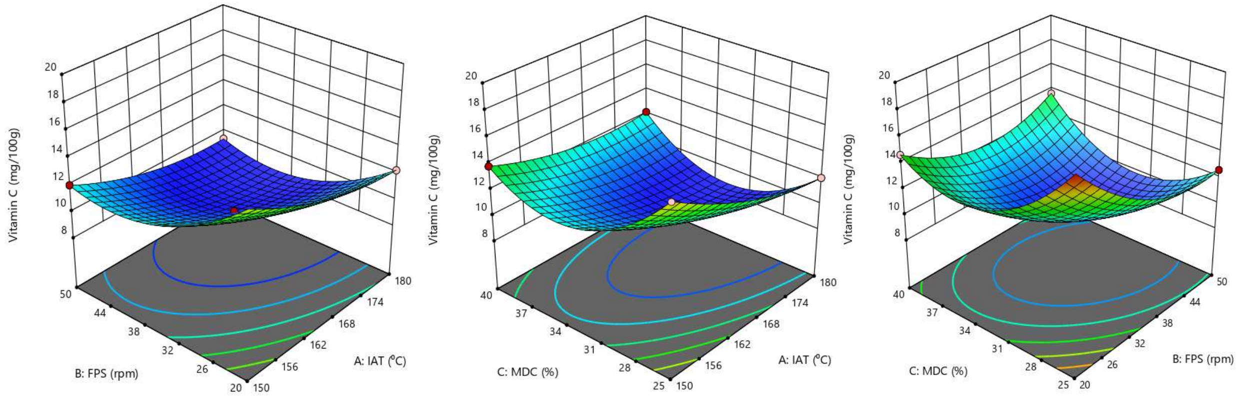

Figure 5: Response surface plots showing the interactive effects of the operational parameters on vitamin C of banana powders

Several authors have reported varying values for vitamin C/ascorbic acid retention in spray-dried fruit powders. An increase in ascorbic acid from 33.32-97.62 mg/100 g was recorded for muskmelon powder (Vennila *et al.*, 2020). In another study, mean values of vitamin C for pineapple powder were reported to fluctuate between 5.9 and 39.1 mg/100 g (Cardona *et al.*, 2023). Vitamin C of 5.2% and 10.5% for ripe and unripe spray-dried banana powder were reported by Harish *et al.* (2017). A decrease in vitamin C content of spray-dried mango from 21.13 mg/100 g to 13.44±0.63 g/100 g was also noted for mango powder (Pham *et al.*, 2022)

D. *Effect of operational parameters on β-carotene contents of the banana powder*

β-carotene is a precursor of vitamin A, essential for vision and immune function. It helps to reduce inflammatory responses and aids in the regulation of cell signalling in the human body. Lebaka *et al.* (2021) reported that high concentrations of β-carotene coupled with other phytochemicals have the potential of preventing leukaemia and progression of certain cancers in the body. Retention during spray drying enhances the nutritional value of the powder for use in fortified foods. The values of β-carotene obtained in this study for spray-dried red banana powder was in the range of 0.034-0.065 mg/100 g.

The ANOVA and model fit for the β-carotene contents of banana juice powders are presented in Table 4. The high F-value (166.43) and very low p-value (<0.0001) indicate that the model is highly significant, and the operational parameters evaluated have a strong influence on the β-carotene contents. The model's R^2 (0.9953) and adjusted R^2 (0.9894) show excellent predictive accuracy and agreement with the observed values. The parameters feed pump speed (FPS), maltodextrin concentration (MDC), and their quadratic terms (B^2, C^2) are significant contributors to β-carotene retention (p 0.05). The model shows a non-significant lack of fit (p=0.2123), indicating that it adequately captures the variability in the data. The predicted R^2 of 0.9498 is in reasonable agreement with the adjusted R^2 (0.9894) with a difference of less than 0.2. Adequate precision, which measures the signal-to-noise ratio is 53.982 and this showed that the model could be used to navigate the design space.

Figures 6 illustrates the 3D surface plots showing the influence of the operational parameters on the β-carotene contents of the banana juice powder. The second order polynomial equation

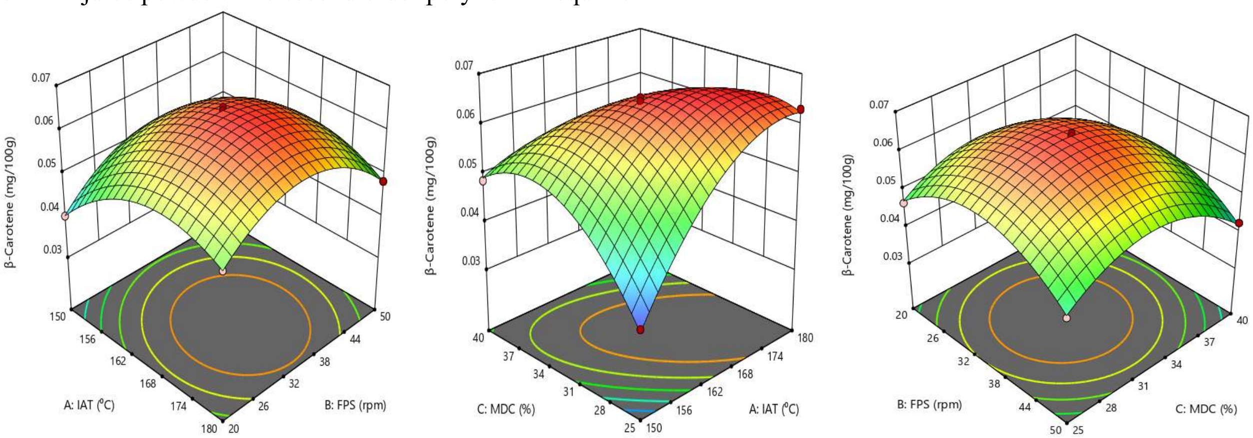

Figure 6: Response surface plots showing the interactive effects of the operational parameters on β-carotene of banana powders

showing the relationship between operational parameters and β-carotene contents is written as Equation (5).

$$\beta\text{-}carotene = 0.052 + 0.036B + 0.025C + 0.084BC - 0.038A^2 + 0.042B^2 + 0.044C^2 \quad (5)$$

In this study, it was observed that though IAT was not a primary driver of β-carotene retention (as shown in the insignificance of temperature in the ANOVA), it still influenced drying kinetics and if it is excessively high, it can degrade β-carotene due to thermal sensitivity. Several studies have highlighted that the β-carotene content of spray-dried fruit/food powders declined with an increase in inlet air temperature due to thermal and oxidative degradation (Arebo *et al.*, 2023; Deshmukh *et al.*, 2017; Pui *et al.*, 2020; Thumthanaruk *et al.*, 2021). However, Hadree *et al.* (2023) alluded to a study that suggested that spray drying at high temperatures produced a large number of small powder particles, which helped to protect β-carotene from oxidation.

A controlled feed pump speed ensures proper atomization and minimizes exposure to temperatures, reducing thermal degradation of β-carotene. It was observed from this study that higher feed pump speed resulted in insufficient contact time between feed droplets and hot air, and led to less efficient heat and mass transfer. A similar observation was reported by Arebo *et al.* (2023). On the other hand, very low FPS resulted in burnt powders, which adhered to the wall of the drying chamber. In both scenarios, the retention of β-carotene was not satisfactory. Therefore, for better β-carotene retention, a moderate FPS coupled with other operational parameters should be selected. Anisuzzaman *et al.* (2022) noted in their review on spray drying of tomatoes that increased feed flow rates, which are a function of the feed pump speed, lower yield, as some feed will not be atomised but drip directly into the waste collection bottle of the dryer, thereby lowering the β-carotene contents and other nutrients in the powder. Similar observations were noted in this study.

MDC positively correlates with β-carotene retention. Maltodextrin acts as a carrier and encapsulating agent, forming a protective matrix around β-carotene molecules. This minimizes oxidative and thermal degradation during spray drying. The interaction term FPS×MDC (BC) has the highest impact, as indicated by the F-value (647.40). This suggested that a moderate combination of MDC with FPS enhanced β-carotene retention by balancing thermal exposure and matrix protection. A synergistic interaction which prevented stickiness (from low MDC), and incomplete drying (from high FPS) was observed. Research consistently supports the protective role of carrier agents like maltodextrin in carotenoid-rich powders (Chang *et al.*, 2018; García-Chacón *et al.*, 2024). Encapsulation through maltodextrin not only protects β-carotene during drying but also enhances the powder's shelf stability by reducing oxidative degradation.

Pertiwi *et al.* (2020) reported a negative relationship between maltodextrin and β-carotene of overripe canistel powder, where increased maltodextrin addition led to reduced β-carotene retention in the powder. They stated that the increase in maltodextrin influenced the β-carotene content due to the dilution of pigment. They recorded predicted and validated values of β-carotene as 2.65 mg/kg and 0.63 mg/kg for the powder. A similar trend was observed in this study with the quadratic terms of MDC indicating diminishing returns beyond optimal levels, connoting that excessive maltodextrin could dilute the active compounds and reduce the powders' β-carotene contents. The β-carotene contents of the banana powder were observed to be lower after spray drying. The β-carotene content of the juice was 0.083 mg/100 g while those of the powder ranged between 0.034-0.065 mg/100 g. A similar observation was reported for kuini powder where the β-carotene content reduced from 14.12 µg/g (1.412 mg/100 g) in the juice to 5.54 µg/g (0.554 mg/100 g) after spray drying (Chng *et al.*, 2020). The β-carotene contents of the developed banana powder in this study are lower than those reported for carrot waste extract (Šeregelj *et al.*, 2021) and muskmelon powder (Vennila *et al.*, 2020). The red banana powder with retained β-carotene can be used as a supplementary, nutrient-dense ingredient for fortified foods, smoothies, or health supplements.

IV. CONCLUSION

This study highlighted the effects of spray dryer operational parameters on the retention of bioactive compounds in red banana powder. The findings demonstrated that the studied operational parameters had varying effects on the retention of total phenolics, flavonoids, vitamin C, and β-carotene. The results underscored the significance of carefully selecting drying conditions to enhance the bioactive properties of the dried powder. The ripe red banana powder produced is recommended as a functional ingredient in food formulations. Overall, this research provides valuable insights for the food industry in developing stable, nutrient-rich fruit powders for health-conscious consumers.

AUTHOR CONTRIBUTIONS

A. L. Adepoju: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **J. A. Adeyanju:** Supervision, Writing – review & editing. **A. O. Abioye:** Supervision, Writing – review & editing.

REFERENCES

Acosta-Vega, L.; Martínez-Suárez, J. F.; Sánchez-Garzón, F. S.; Hernández-Carrión, M. and Nerio, L. S. (2023). Optimization of the encapsulation process of Cupuassu (Theobroma grandiflorum) pulp by spray drying as an alternative for the valorization of Amazonian fruits. *LWT*, *184*, 1-10.

Adepoju, L. A. and Osunde, Z. D. (2017). Effect of pretreatments and drying methods on some qualities of dried mango (Mangifera indica) fruit. *Agricultural Engineering International: CIGR Journal*, *19*(1), 187-194.

Adepoju, L. A.; Osunde, Z. D. and Falua, K. J. (2021). Changes in Proximate Composition, Vitamin C and β-Carotene Contents of Oven Dried Pawpaw (Carica papaya) Fruit as Influenced by Pretreatment Methods. *FUOYE Journal of Engineering and Technology*, *6*(1), 10-14.

Afzal, M. F.; Khalid, W.; Akram, S.; Khalid, M. A.; Zubair, M.; Kauser, S.; Abdelsamea Mohamedahmed, K.; Aziz, A. and Anusha Siddiqui, S. (2022). Bioactive profile and functional food applications of banana in food sectors and health: a review. *International Journal of Food Properties*, *25*(1), 2286-2300.

Alam, M.; Biswas, M.; Hasan, M. M.; Hossain, M. F.; Zahid, M. A.; Al-Reza, M. S. and Islam, T. (2023). Quality attributes of the developed banana flour: Effects of drying methods. *Heliyon*, *9*(7), 1-17

Anisuzzaman, S. M.; Joseph, C. G.; Nga, J. L. H. and Ismail, F. N. (2022). Effect of Carrier Agents and Operational Parameters on the Physical Quality of Spray-Dried Tomato Powder: A Review. In *ASEAN Journal of Chemical Engineering*, *22*(2), 228-247.

Anyasi, T. A.; Jideani, A. I. O. and Mchau, G. R. A. (2018). Phenolics and essential mineral profile of organic acid pretreated unripe banana flour. *Food Research International*, *104*, 100-109.

Archaina, D.; Leiva, G.; Salvatori, D. and Schebor, C. (2018). Physical and functional properties of spray-dried powders from blackcurrant juice and extracts obtained from the waste of juice processing. *Food Science and Technology International*, *24*(1), 78-86.

Arebo, M. A.; Feyisa, J. D.; Tafa, K. D. and Satheesh, N. (2023). Optimization of spray-drying parameter for production of better quality orange fleshed sweet potato (Ipomoea batatas L.) powder: Selected physiochemical, morphological, and structural properties. *Heliyon*, *9*(1), 1-14.

Asnawi, S.; Wan Mohd, F.; Wan, A.; Sharifah, H.; Mohd, R.; Shahar, A.; Fariz, M. W.; Azman, W.; Hafiza, S. and Ramli, M. (2022). Effect of Different Drying Processing Method on the Physicochemical Properties of Watermelon Powder. *Advances in Agricultural and Food Research Journal*, *3*(2), 1-11.

Barooah, N.; Das, P.; Barooah, M. S.; Seth, D. K. and **Dutta, P. (2018).** Storage Studies on Spray-dried Ripe Banana Powder Produced by Response Surface Methodology. *International Journal of Current Microbiology and Applied Sciences*, *7*(06), 1922-1933.

Bazaria, B. and Kumar, P. (2018). Optimization of spray drying parameters for beetroot juice powder using response surface methodology (RSM). *Journal of the Saudi Society of Agricultural Sciences*, *17*(4), 408-415.

Cardona, L. M. M.; Cortés-Rodríguez, M. and Castellanos-Galeano, F. J. J. (2023). Pineapple powder quality: Effect of the feedstock solution composition, homogenization and spray drying process. *Revista Mexicana de Ingeniería Química*, *22*(2), 1-14. https://doi.org/10.24275/rmiq/Alim2993

Chang, L. S.; Eau Yong, S. M. and Pui, L. P. (2021). Production of spray-dried "terung asam" (Solanum lasiocarpum dunal) powder. *Walailak Journal of Science and Technology*, *18*(1), 1–11.

Chang, L. S.; Karim, R.; Mohammed, S. and Ghazali, H. M. (2018). Production and characterization of enzyme-treated spray-dried soursop (Annona muricata L.) powder. *Journal of Food Process Engineering*, *12688*, 1-12.

Chang, L. S.; Tan, Y. L. and Pui, L. P. (2020). Production of spray-dried enzyme-liquefied papaya (Carica papaya L.) powder. *Brazilian Journal of Food Technology*, *23*, 1–16.

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

Chng, Y. V. G.; Chang, L. S. and Pui, L. P. (2020). Effects of maltodextrin concentration and inlet temperature on the physicochemical properties of spray-dried kuini powder. *Asia-Pacific Journal of Molecular Biology and Biotechnology*, *28*(4), 117-131.

Chowdhury, M. R.; Morshed, S.; Salma Amin, U.; Hossain, T.; Humayun Kober, A. K. M. and Humayun Kober, M. (2024). Effects of Adding Banana Juice on the Physical, Chemical, and Microbiological Quality of Yogurt. *J Mod Agric Biotechnol*, *3*(1), 1-7.

Costa, R. S.; Oliveira, R. F.; Henry, F. C.; Mello, W. A. O. and Gaspar, C. R. (2023). Development of prebiotic yogurt with addition of green-banana biomass (Musa spp.). *Anais Da Academia Brasileira de Ciencias*, *95*(1), 1-19.

Cynthia, S. J., Don Bosco, J. and Bhol, S. (2015). Physical and Structural Properties of Spray-dried Tamarind (Tamarindus indica L.) Pulp Extract Powder with Encapsulating Hydrocolloids. *International Journal of Food Properties*, *18*(8), 1793-1800.

Darroca, R. M. F.; Lopez, M. J. A.; Thuy, N. M.; Giau, T. N.; Hao, H. V. and Tai, N. V. (2024). Development and characterization of butterfly pea (Clitoria ternatea L.) flower juice from spray-dried powder. *International Journal of Chemical and Biochemical Sciences*, *25*(19), 357-365.

Demircan, B.; Velioglu, Y. S. and GiuFPSè, A. M. (2023). Bergamot juice powder with high bioactive properties: Spray-drying for the preservation of antioxidant activity and ultrasound-assisted extraction for enhanced phenolic compound extraction. *Journal of Food Science*, *88*(9), 3694-3713.

Deshmukh, Y.; Sharma, H. K. and Kumar, N. (2017). Modeling of physicochemical and functional parameters of pumpkin (Cucurbita pepo) powder using response surface methodology. *International Food Research Journal*, *24*(5), 2071-2081.

Elangovan, E. and Natarajan, S. K. (2021). Experimental research of drying characteristic of red banana in a single slope direct solar dryer based on natural and forced convection. *Food Technology and Biotechnology*, *59*(2), 137-146.

Ferreira, L. M. de M. C.; Pereira, R. R.; Carvalho-Guimarães, F. B.; Remígio, M. S. N.; Barbosa, W. L. R.; Ribeiro-Costa, R. M. and Silva-Júnior, J. O. C. (2022). Microencapsulation by Spray Drying and Antioxidant Activity of Phenolic Compounds from Tucuma Coproduct (Astrocaryum vulgare Mart.) Almonds. *Polymers*, *14*(14), 1-20.

Ferreira, T. H. B. and Freitas, M. L. F. (2019). Production, physical, chemical and sensory evaluation of dried banana (Musa Cavendish). *Emirates Journal of Food and Agriculture*, *31*(2), 102-108.

Feszterová, M.; Kowalska, M. and Mišiaková, M. (2023). Stability of Vitamin C Content in Plant and Vegetable Juices under Different Storing Conditions. *Applied Sciences (Switzerland)*, *13*(19), 1-23.

García-Chacón, J. M.; Rodríguez-Pulido, F. J.; Heredia, F. J.; González-Miret, M. L. and Osorio, C. (2024). Characterization and bioaccessibility assessment of bioactive compounds from camu-camu (Myrciaria dubia) powders and their food applications. *Food Research International*, *176,* 1-12.

Gawałek, J. (2021). Effect of spray dryer scale size on the properties of dried beetroot juice. *Molecules*, *26*(21), 1-9.

Gawałek, J. and Domian, E. (2020). Tapioca dextrin as an alternative carrier in the spray drying of fruit juices-a case study of chokeberry powder. *Foods*, *9*(8), 1-15.

Hadree, J.; Shahidi, F.; Mohebbi, M. and Abbaspour, M. (2023). Evaluation of Effects of Spray Drying Conditions on Physicochemical Properties of Pomegranate Juice Powder Enriched with Pomegranate Peel Phenolic Compounds: Modeling and Optimization by RSM. *Foods*, *12*(10), 1-21.

Halahlah, A.; Räikkönen, H.; Piironen, V.; Valoppi, F.; Mikkonen, K. S. and Ho, T. M. (2023). Wood hemicelluloses as sustainable wall materials to protect bioactive compounds during spray drying of bilberries. *Powder Technology*, *415*, 1-13.

Harish, N.; Vandana, K.; Dhanusha Sree, K. V. and Kalpana, D. (2017). Feasible Studies on Production of Banana Powder. *International Journal of Agricultural Science and Research*, *7*(4), 413-420. www.tjprc.org

Hussain, A.; Kausar, T.; Siddique, T.; Kabir, K.; An, Q. U.; Rukhsar, F.; Gorsi, F. I.; Yaqub, S.; Kauser, S.; Rehman, A.; Najam, A.; Haroon, H.; Rafiu, A.; Korma, S. A. and Mahdi, A. A. (2024). Physiological and biochemical variations of naturally ripened mango (Mangifera Indica L.) with synthetic calcium carbide and ethylene. *Scientific Reports*, *14*(1), 1-12.

Huynh, T. D.; Kha, C. T.; Nguyen, V. A.; Nguyen, T. D.; Ha, T. M. L. and Ngo, H. H. (2023). Spray drying conditions of lime juice prepared by freeze-concentration. *IOP Conference Series: Earth and Environmental Science*, *1155*(1), 1-11.

Khoza, M.; Kayitesi, E. and Dlamini, B. C. (2021). Physicochemical Characteristics, Microstructure and Health Promoting Properties of Green Banana Flour. *Foods*, *10*(2894), 1–15.

Khwanpruk, K.; Akkaraphenphan, C.; Wattananukit, P.; Kaewket, W. and Chusai, S. (2018). Effect of drying air condition and feed composition on the properties of orange juice spray-dried powder. *MATEC Web of Conferences*, *192*, 1-4.

Kim, J. H.; Kim, J. H. and Eun, J. B. (2023). Optimization of spray drying process of Japanese apricot (Prunus mume Sieb. et Zucc.) juice powder using nondigestible maltodextrin by response surface methodology (RSM). *Journal of Food Science and Technology*, *60*(3), 868-878.

Kongpichitchoke, T.; Gnoumou, E.; Noomhorm, A. and Hsien, C. H. (2021). Study on Factors Affecting Physicochemical Properties of Spray-dried Mango Powder Using Taguchi Experimental Design Approach. *International Journal of Eco-Innovation in Science and Engineering*, *2*(1), 7-13.

Kuck, L. S. and Noreña, C. P. Z. (2016). Microencapsulation of grape (Vitis labrusca var. Bordo) skin phenolic extract using gum Arabic, polydextrose, and partially hydrolyzed guar gum as encapsulating agents. *Food Chemistry*, *194*, 569-576.

Kumari, P.; Gaur, S. S. and Tiwari, R. K. (2023). Banana and its by-products: A comprehensive review on its nutritional composition and pharmacological benefits. *EFood*, *4*(5), 1-23.

Lebaka, V. R.; Wee, Y. J.; Ye, W. and Korivi, M. (2021). Nutritional composition and bioactive compounds in three different parts of mango fruit. *International Journal of Environmental Research and Public Health*, *18*(2), 1-20).

Ledri, S. A.; Milani, J. M.; Shahidi, S. A. and Golkar, A. (2024). Comparative analysis of freeze drying and spray drying methods for encapsulation of chlorophyll with maltodextrin and whey protein isolate. *Food Chemistry*, *21*, 1-10.

Lee, K. H., Wu, T. Y. and Siow, L. F. (2013). Spray drying of red (Hylocereus polyrhizus) and white (Hylocereus undatus) dragon fruit juices: Physicochemical and antioxidant properties of the powder. *International Journal of Food Science and Technology*, *48*(11), 2391-2399.

Leyva-Porras, C.; Saavedra-Leos, M. Z.; López-Martinez, L. A.; Espinosa-Solis, V.; Terán-Figueroa, Y.; Toxqui-Terán, A. and Compeán-Martínez, I. (2021). Strawberry juice powders: Effect of spray-drying conditions on the microencapsulation of bioactive components and physicochemical properties. *Molecules*, *26*(18), 1-14.

Marzlan, A. A.; Muhialdin, B. J. and Hussin, A. S. M. (2020). Production of banana cake premix from banana (musa acuminata colla) by-products via foam mat drying process. *Malaysian Journal of Medicine and Health Sciences*, *16*(6), 150-158.

Maseko, K. H.; Regnier, T.; Meiring, B.; Wokadala, O. C. and Anyasi, T. A. (2024). Musa species variation, production, and the application of its processed flour: A review. *Scientia Horticulturae*, *325*, 1-16.

Mishra, A. A.; Shukla, R. N.; Kumar, A. and Gautam, A. K. (2016). Effect of drying temperature and packaging material on quality and shelf-life of dried banana powder. *International Journal of Processing and Post-Harvest Technology*, *7*(1), 47-52.

Mohanty, S.; Mishra, S. and Pradhan, R. C. (2021). Development and process optimization of spray-dried powder from enzymatically extracted ripe palm (borassus flabellifer) juice. *Journal of Microbiology, Biotechnology and Food Sciences*, *10*(6), 1-8.

Monteiro, R. L.; Carciofi, B. A. M. and Laurindo, J. B. (2016). A microwave multi-flash drying process for producing crispy bananas. *Journal of Food Engineering*, *178*, 1-11.

Morelli, K. L. and Kader A. A. (2024). Recommendations for Maintaining Postharvest Quality Access at https://postharvest.ucdavis.edu/produce-facts-sheets/banana-specialty (Accessed on December 6, 2024).

Muniz, T.; Araujo, H.; Paiva, E. G.; Bezerra de Oliveira, I.; Martins, M. E. D.; Cavalcanti-Mata, M.; Lisboa, H. M. and Pasquali, M. A. B. (2020). Preservation of vitamin C and phenolic compounds from Umbu(spondias tuberosa arr. Cam.) via spray drying. *3*, 54-67.

Muzaffar, K.; Dinkarrao, B. V. and Kumar, P. (2016). Optimization of spray drying conditions for production of quality pomegranate juice powder. *Cogent Food* and *Agriculture*, *2*(1), 1-9.

Muzaffar, K. and Kumar, P. (2017). Spray Drying of Tamarind Pulp: Effect of Process Parameters Using Protein as Carrier Agent. *Journal of Food Processing and Preservation*, *41*(2), 1-11.

Noordia, A.; Mustar, Y. S. and Kusnanik, N. W. (2020). Foam mat drying of banana juice: varieties of ripe banana analysis and egg albumen foam. *Food Science and Technology*, *40*(2), 465-468.

Pavethra, A.; Sebastian, K.; Manjula, B. S.; Satheeshan, K. N. and Thinakaran, J. (2024). Response of postharvest treatments on shelf life, biochemical and microbial quality of banana variety Red Banana. *Journal of Applied Horticulture*, *26*(2), 136-140.

Pertiwi, S. R. R.; Sunarya, R.; Rohmayanti, T. and Aminullah (2020). Optimization on formulation of foamed overripe canistel powder using response surface methodology. *Revista Brasileira de Fruticultura*, *42*(3), 1-11.

Pham, T. V.; Nguyen, M. T. P.; Do, L. V.; Truong, M. N.; Vo, A. N.; Van, K. C. and Le, T. D. (2022). Effect of operational conditions on physicochemical profiles of spray-dried powder of mango (Mangifera indica L.) juice from Tu Quy variety in Vietnam. *Food Research*, *6*(3), 342-349.

Pui, L. P.; Karim, R.; Yusof, Y. A.; Wong, C. W. and Ghazali, H. M. (2020). Anti-caking agent effects on the properties of spray-dried 'cempedak' fruit powder. *Pertanika Journal of Tropical Agricultural Science*, *43*(4), 621-635.

Raman, R. K.; Santhalakshmy, S.; John, S.; Bosco, D. and Ganguly, S. (2020). Phytochemical properties of spray-dried jamun juice powder as affected by encapsulating agents. *Journal of Pharmacognosy and Phytochemistry*, *9*(3), 599-602.

Ribeiro, C. M. C. M.; Magliano, L. C. dos S. A.; de Costa, M. M. A.; Bezerra, T. K. A.; da Silva, F. L. H. and Maciel, M. I. S. (2019). Optimization of the spray drying process conditions for acerola and seriguela juice mix. *Food Science and Technology)*, *39*, 48-55.

Riya, P.; Kumar, S. S. and Giridhar, P. (2023). Phytoconstituents, GC-MS Characterization of Omega Fatty Acids, and Antioxidant Potential of Less-Known Plant Rivina humilis L. *ACS Omega*, *8*(31), 28519-28530.

Rohini, C.; Kanchana, S.; Geetha, P. S.; Mini, M. L. and Arul Arasu, P. (2024). Optimize the process for encapsulated spray-dried Lemon juice powder to enhance the Vitamin C. *World Journal of Advanced Research and Reviews*, *21*(1), 2064-2072.

Saikia, S.; Mahnot, N. K. and Mahanta, C. L. (2015). Effect of Spray Drying of Four Fruit Juices on Physicochemical, Phytochemical and Antioxidant Properties. *Journal of Food Processing and Preservation*, *39*(6), 1656-1664.

Sangeetha, S.; Thuraisingam, S.; Jayawardane, J. A. E. C. and Srivijeindran, S. (2023). A novel approach to the formulation of an encapsulated bioactive powder from palmyrah (Borassus flabellifer L) fruit pulp for nutraceutical applications. *Food Chemistry Advances*, *3*. 1-9.

Santos, P. D. de F.; Rubio, F. T. V.; Balieiro, J. C. de C.; Thomazini, M. and Favaro-Trindade, C. S. (2021). Application of spray drying for production of microparticles containing the carotenoid-rich tucumã oil (Astrocaryum vulgare Mart.). *Lwt*, *143,* 1-8.

Sarkar, A.; Hossain, M. W.; Alam, M.; Biswas, R.; Roy, M. and Haque, M. I. (2023). Drying conditions and varietal impacts on physicochemical, antioxidant and functional properties of onion powder. *Journal of Agriculture and Food Research*, *12*, 1-14.

Šeregelj, V.; Ćetković, G.; Čanadanović-Brunet,

J.; Šaponjac, V. T.; Vulić, J.; Lević, S.; Nedović, V.; Brandolini, A. and Hidalgo, A. (2021). Encapsulation of carrot waste extract by freeze and spray drying techniques: An optimization study. *Lwt*, *138*, 1-38.

Setyawati, D. M.; Mardliyati, E.; Rahman, S. and Wijaya, A. F. (2020). Spray drying of mangosteen (Garcinia mangostana L.) juice and analysis of antioxidant activity and total phenolic content. *IOP Conference Series: Materials Science and Engineering*, *796*(1), 1-8.

Sharma, R.; Nath, P. C. and Seth, D. (2023). Optimization of spray-drying conditions using response surface methodology, physico-chemical characterization and shelf-life estimation of pineapple powder. *Sustainable Food Technology*, *1*(5), 750-761.

Shi, Y.; Wang, J.; Wang, Y.; Zhang, H.; Ma, Y.; Zhao, X. and Zhang, C. (2018). Inlet temperature affects spray drying quality of watermelon powder. *Czech Journal of Food Sciences*, *36*(4), 316-323.

Shini, V. S.; Billu, A.; Suvachan, A. and Nisha, P. (2024). Exploring the nutritional, physicochemical and hypoglycemic properties of green banana flours from unexploited banana cultivars of southern India. *Sustainable Food Technology*, *2*(4), 1113-1127.

Shishir, M. R. I.; Taip, F. S.; Aziz, N. A. and Talib, R. A. (2014). Physical Properties of Spray-dried Pink Guava (Psidium Guajava) Powder. *Agriculture and Agricultural Science Procedia*, *2*, 74-81.

Sidlagatta, V.; Chilukuri, S. V. V.; Devana, B. R.; Dasi, S. D. and Rangaswamy, L. (2020). Effect of Maltodextrin Concentration and Inlet Air Temperature on Properties of Spray-dried Powder from Reverse Osmosis Concentrated Sweet Orange Juice. *Brazilian Archives of Biology and Technology*, *63*, 1-14.

Silva, N. C.; Andrade, G. B. and Barrozo, M. A. S. (2024). Spray-Dried Jaboticaba Powder as Food Resource. *Resources*, *13*(102), 1-17.

Singh, B. and Hathan, B. S. (2017). Process optimization of spray drying of beetroot Juice. *Journal of Food Science and Technology*, *54*(8), 2241-2250.

Sonawane, A.; Pathak, S. S. and Pradhan, R. C. (2021). Effect of drying on physical and flow properties of banana powder. *Carpathian Journal of Food Science and Technology*, *13*(3), 173-184.

Taheri-Garavand, A.; Karimi, F.; Karimi, M.; Lotfi, V. and Khoobbakht, G. (2017). Hybrid response surface methodology – artificial neural network optimization of drying process of banana slices in a forced convective dryer. *Food Science and Technology International 0*(0), 1-15.

Tan, S. L.; Sulaiman, R.; Rukayadi, Y. and Ramli, N. S. (2021). Physical, chemical, microbiological properties and shelf life kinetic of spray-dried cantaloupe juice powder during storage. *Lwt*, *140*, 1-44.

Thumthanaruk, B.; Laohakunjit, N.; and Chism, G. W. (2021). Characterization of spray-dried Gac aril extract and estimated shelf life of β-carotene and lycopene. *PeerJ*, *9*, 1-16. https://doi.org/10.7717/peerj.11134

Tran, N. T. Y.; Le, T. T. T.; Nghia, N. H.; Nhu, D. B.; Huynh, L. B.; Nguyen, T. X. T.; Huynh, P. X. and Dao, T. P. (2023). Developing mango powders by foam mat drying technology. *Food Science and Nutrition*, *11*, 1-9.

Van Tai, N.; Van Hao, H.; Han, T. T. N.; Giau, T. N.; Thuy, N. M. and Van Thanh, N. (2024). Effect of foaming conditions and drying temperatures on total polyphenol content and drying rate of foam-mat dried banana powder: Modeling and optimization study. *Journal of Agriculture and Food Research*, *18*, 1-11.

Vargas, L.; Kapoor, R.; Nemzer, B. and Feng, H. (2022). Application of different drying methods for evaluation of phytochemical content and physical properties of broccoli, kale, and spinach. *Lwt*, *155*, 1-10.

Vennila, P.; John Kennedy, Z.; Preetha, P. and Pandidurai, G. (2020). Studies on formulation and evaluation of muskmelon fruit powder incorporated ready-to-use products. *Journal of Pharmacognosy and Phytochemistry*, *9*(3), 1768-1771.

Vicent, V. (2024). Influence of banana powder on proximate composition, physicochemical and rheological properties of soy yoghurt. *Applied Food Research*, *4*(2), 1-8.

Wirivutthikorn, W. (2024). Development of Spray Drying of Powdered Oolong Tea Incorporated with Chinese Jujube Beverage. *Current Research in Nutrition and Food Science Journal*, *12*(2), 802-813.

Wong, C. W.; Teoh, C. Y. and Putri, C. E. (2018). Effect of enzymatic processing, inlet temperature, and maltodextrin concentration on the rheological and physicochemical properties of spray-dried banana (Musa acuminata) powder. *Journal of Food Processing and Preservation*, *42*(2), 1-9.

Wong, C. W. W.; Pui, L. P. and Ng, J. M. L. (2015). Production of spray-dried Sarawak pineapple (Ananas comosus) powder from enzyme liquefied puree. *International Food Research Journal*, *22*(4), 1631-1636.

Zhang, C.; Khoo, S. L. A.; Swedlund, P.; Ogawa, Y.; Shan, Y. and Quek, S. Y. (2020). Fabrication of spray-dried microcapsules|containing noni juice using blends of maltodextrin and gum acacia: physicochemical properties of powders and bioaccessibility of bioactives during in vitro digestion. *Foods*, *9*(9), 1-17.

Zhou, Y. H., Pei, Y. P., Sutar, P. P., Liu, D. H., Deng, L. Z., Duan, X., Liu, Z. L., and **Xiao, H. W. (2022).** Pulsed vacuum drying of banana: Effects of ripeness on drying kinetics and physicochemical properties and related mechanism. *LWT*, *161*, 1-9.