

The Effects of Spray Drying Conditions on Water Absorption Index, Water Solubility Index, Solubility and Water Activity (a_w) of Rice Milk Powder

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Cow's milk has been widely consumed as it acts as an important source of protein. It also acts as a wholesome complete food providing all the major nutrients like fat, carbohydrates and proteins. Due to the lactose intolerance in some people in place of cow's milk plant based milk products are becoming more popular due to its nutritional benefits same as that of cow's milk. Broken rice has the nutritional benefits equal to raw rice and it can be processed into various value added products. In this study, the broken rice was used to prepare rice milk with the optimized process parameters. Rice milk was spray dried to enhance its shelf life at different inlet drying air temperatures and feed flow rates. Temperature and feed flow rate were optimized with desirability function which satisfied

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all the responses with required values to obtain optimum conditions for spray drying. The predicted optimum conditions were; T= 138°C, and Q= 35 mL/min. Under these conditions, the response values for water activity, water solubility index and water absorption index were 0.30, 72.8% and 21.7%, respectively.

Keywords: Rice milk; solubility; spray drying; water activity; water absorption index; water solubility index.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is a most important food for the people in the world. In India, rice production area is about 43.78 million ha and annual production is about 117.47 million tonnes [1]. The contribution of Asian region is about 90% of the total rice production in the world out of which China contributes 28.7% and India contributes 19.5%. The states which are producing rice as a major crop in India are West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Bihar, Orissa, Chhattisgarh, Assam, Tamil Nadu and Haryana. The amount of broken rice produced in the rice industry was about 0.97 million tonnes. The cost of the rice is set by the head rice kernels percentage in each unit of rough rice [2]. Low prices of broken rice in India stimulated its utilization in products where the cereal component had usually been derived from other grains. Consequently, a particular interest was given to the possible substitution of processed rice meal for processed corn meal in corn-soy-milk [3]. Broken rice is still under-utilized and is mostly used as raw material for pet foods, rice flour, wine and beer [4].

Broken rice has the nutritional benefits equal to raw rice and it is processed into flour and utilized as a food product [5]. According to Hartmann et al. [6], rice flour is free from gluten therefore; it is an alternative for producing gluten-free products [7]. Rice flour is also hypoallergenic [8]. The rice flour is preferred for baby food and other food products by the food companies because of low risk for people with sensitivities [9]. The price of the broken rice is less when compared to the raw rice; thus, it has become more economical to get flour from the broken rice [10].

A liquid derived from rice generally known as rice milk is suitable substitute for animal milk in the world. The rice milk is the best breakfast food in Southeast Asia, especially in China and Taiwan [11]. Soymilk and other non-dairy milks have long been substitutes for raw milk in the U.S [12]. However, the allergic response that many people have toward soy beverages, the bean-like flavor

and the aftertaste of the soy products have created a demand for rice milk in the U.S. market [13]. The texture, colour and nutritional values of the rice milk makes it a substitute for animal milk and helps in the preparation of various food products including beverages and non-dairy puddings [11].

Spray drying is a method applied to dry a wide variety of food extracts. The resulting powders are conveniently stored, transported and handled. Spray drying is used to produce a wide range of products including heat sensitive materials. It is a powerful tool for delivering cost effective, high quality products [14]. The products produced by spray drying include: pharmaceutical such as antibiotics, analgesics, vaccines, vitamins and catalysts; chemicals, such as, carbides, ferrite, nitrides, tannins, fine organic/inorganic chemicals detergent and dyestuffs; ceramic, including advanced ceramic formulations; and foods such as, milk and milk products, food colour, food supplement, soup mixes, spice and herb extracts, coffee, tea and sweetener. Spray dried food products are appealing, retain nutritional qualities and are convenient to consume [15]. The process is continuous and easily automated which can reduce labour costs [16]. There are less sticking and corrosion problems in spray drying if the material does not contact the equipment walls until it is dry [17].

Spray drying is a dehydration process in which a concentrated solution, suspension, emulsions or pump able paste is sprayed, dried and collected. The particles are dried while they are suspended in the hot drying media. The dried products can be in the form of powder, granules or agglomerates depending on physical and chemical properties of the feed, the drier design and the drying operation [15].

2. MATERIALS AND METHODS

2.1 Spray Drying of Rice Milk

Rice milk obtained from the optimized conditions (TSS: 10-12 °Brix) was subjected to spray drying

at different inlet drying air temperatures (5 levels) and feed flow rates (5 levels) maintaining constant air volume and air flow rate of 60 m³/h. Pilot scale spray dryer (Make: S.M. Scientech, Model: B-290, Capacity: 3 L of water evaporation/h) was utilized for the experiment (Plate 1). The ambient temperature was around 28-32 °C and RH was about 58-65%.

Rice milk powder, thus obtained from different experiments as proposed in the design matrix were analysed for product quality parameters viz., physical and chemical properties. Further, the process conditions were optimized to produce a product with best sensory attributes. Each response variable in the study was analysed statistically using the Design Expert 12.0 software. ANOVA was performed with a significance level of 5%. Optimization was done using response surface methodology with two independent factors: (A) Inlet drying air temperature-120, 130, 140, 150 and 160 °C and (B) Feed flow rate- 15, 20, 25, 30 and 35 mL/min. The response variables optimized were water activity (range), moisture content (range), bulk density, tapped density, WSI and WAI. The prepared spray dried rice milk powder was packed in HDPE (T1P1) and LDPE (T2P2) pouches, and stored under refrigerated (4 °C) and ambient (25 ± 5 °C) conditions.

2.1.1 Independent and dependent variables

2.1.1.1 Independent variables

1. Feed flow rate: 15, 20, 25, 30 and 35 mL/min
2. Inlet drying air temperature: 120, 130, 140, 150 and 160 °C

2.1.1.2 Product Quality Parameters (Dependent variables)

1. Water activity
2. Water Solubility Index (WSI)
3. Water Absorption Index (WAI)

2.2 Determination of Properties of Powder

2.2.1 Water Absorption Index (WAI)

The WAI of rice milk powder was calculated using the method described by Sabhadinde (2014). A sample of 2.5 g was agitated with 25 mL distilled water for 1 hour and centrifuged at 3000 rpm for 10 min. The water was drained from the wet residue for 10 min. The weight of the wet residue was noted.

$$\text{WAI (\%)} = \left(\frac{\text{Weight of wet residue}}{\text{Weight of sample}} \right) \times 100 \quad \dots\dots\dots (1)$$

2.2.2 Water Solubility Index (WSI)

The WSI of the spray dried powder was measured by using method described by Sabhadinde (2014). Spray dried rice milk powder (2.5 g) and distilled water (30 mL) were vigorously mixed in 100 mL centrifuge tube incubated at 37 °C water bath for 30 min and then centrifuged for 20 min at 10000 rpm (11410 g). The supernatant was taken in an empty beaker of known weight and oven dried at temperature 103±2 °C. The WSI (%) was calculated as the percentage of dried supernatant to the amount of original 2.5 g rice milk powder.



Plate 1. Laboratory model pilot scale spray dryer

2.2.3 Solubility

The solubility of powder was measured by adding 2 g of the powder to 50 mL distilled water at 26°C. The mixture was agitated in 100 mL low form glass beaker with a magnetic stirrer (MAKE: REMI, Model: 2MLH) (Plate 2) at 892 rpm using a stirrer bar of size 22 × 7 mm. The time required to dissolve completely was recorded as solubility (Goula et al., 2008).

2.2.4 Water activity (a_w)

Water activity of rice milk powder was determined using a pre-calibrated Water activity meter (Rotronic, Germany) (Plate 3). The sample of known weight was placed in a probe and switch was turned on. The readings of water activity was recorded as displayed on the screen. All experiments were conducted at room temperature of 25±2 °C.

3. RESULTS AND DISCUSSION

3.1 Variation of Water Solubility Index of Rice Milk Powder at Different Air Temperatures and Feed Flow Rates

The data of rice milk powder with respect to water solubility index and water absorption index are shown in Fig. 1 and Fig. 2 respectively. The Water Solubility Index (WSI) of spray dried rice milk powder varied from 66.8 to 89.3%. Increase in WSI values with increase in inlet air temperature were noticed; however decreased WSI with increase in the feed flow rates. Similar results were observed by Ghollasi et al. [18] and Phoungchandang and Sertwasana (2010) for powders obtained by spray drying of ginger juice. The spray dried powder instant properties like

WSI is the ability of powder to dissolve in water with minimum possible time since the powders are intended for rehydration. The spray dried Rice Milk powder wetted quickly and dissolved completely in the water. Hoge Kamp and Schubert, (2003) reported that feed flow rate showed negative effect on WSI values and similar observation was observed in the spray dried rice milk powder.

From the statistical analysis, the F-value of 1073.44 indicates significance of the model. P-values less than 0.0500 indicates that A (Temperature), B (Feed flow rate), AB (interaction effect of temperature and feed flow rate) were significant.

WAI values of rice milk powder decreased at higher spray drying inlet air temperatures. Similar results of the inlet air temperature on residual moisture content, which tends to increase the particle size, is reported by Walton, (2000). The model F-value of 800.51 indicated its significance. Values of Prob > F less than 0.0500 indicate model terms are significant. The inlet air temperature, feed flow rate are significant model terms.

The pH and titrable acidity remained same in both rice milk and spray dried rice milk powder. The ascorbic acid, antioxidant activity and total phenolic content were not present both in the rice milk and rice milk powder. Rice milk powder started to develop stickiness at a moisture content of 6.32% (d.b.), indicating that the spray dried rice milk powder has to be stored in air tight packaging material to avoid moisture absorption. With air tight packaging, rice milk powder could be safely stored for 180 days without quality deterioration.



Plate 2. Magnetic stirrer



Plate 3. Water activity meter

Table 1. ANOVA for water solubility index

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	80360.65	1	80360.65			
Linear vs Mean	404.17	2	202.08	749.45	< 0.0001	
2FI vs Linear	1.56	1	12.40	0.0065		Suggested
Quadratic vs 2FI	0.24	2	0.12	0.92	0.4416	
Cubic vs Quadratic	0.63	2	0.31	5.83	0.0493	Aliased
Residual	0.27	5	0.054			
Total	80767.51	13	6212.89			

Model Summary Statistics

Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	0.52	0.9934	0.9920	0.9838	6.58	
2FI	0.35	0.9972	0.9963	0.9917	3.36	Suggested
Quadratic	0.36	0.9978	0.9962	0.9798	8.23	
Cubic	0.23	0.9993	0.9984	0.9231	31.30	Aliased

Table 2. ANOVA for water absorption index

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	5915.02	1	5915.02			
Linear vs Mean	400.42	2	200.21	679.60	< 0.0001	
2FI vs Linear	1.44	1	1.44	8.61	0.0167	Suggested
Quadratic vs 2FI	0.33	2	0.17	1.00	0.4148	
Cubic vs Quadratic	0.83	2	0.42	6.16	0.0447	Aliased
Residual	0.34	5	0.068			
Total	6318.39	13	486.03			

Model Summary Statistics Std. Adjusted Predicted

Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	0.54	0.9927	0.9912	0.9829	6.91	
2FI	0.41	0.9963	0.9950	0.9888	4.53	Suggested
Quadratic	0.41	0.9971	0.9950	0.9950	0.9733	
Cubic	0.26	0.9992	0.9980	0.9026	39.27	Aliased

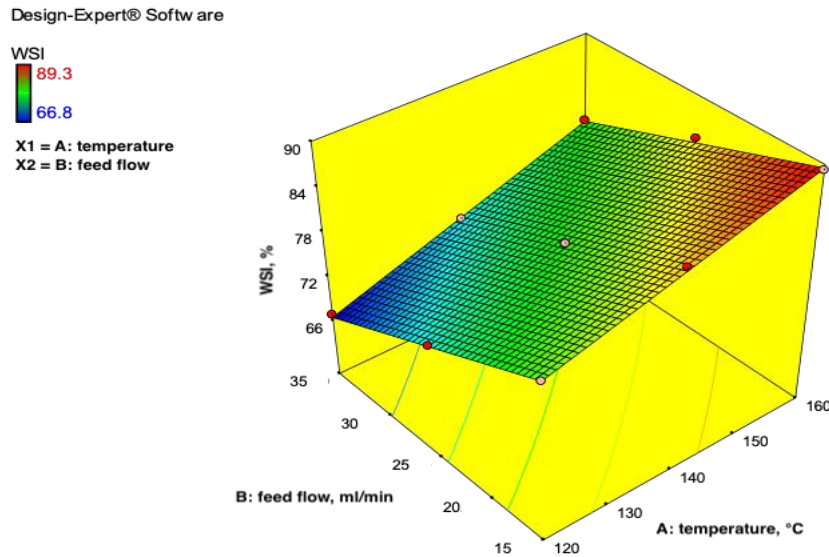


Fig. 1. Variation of water solubility index of rice milk powder with spray drying inlet air temperature and feed flow rate

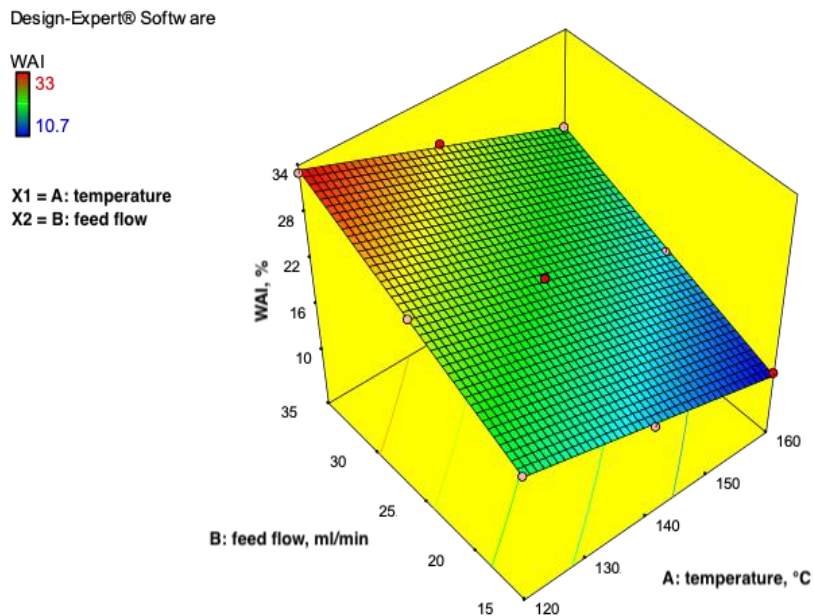


Fig. 2. Variation of water absorption index of rice milk powder with spray drying inlet air temperature and feed flow rate

3.2 Variation of Water Activity of Rice Milk Powder at Different Inlet Air Temperatures and Feed Flow Rates

From the Fig. 3, the water activity of rice milk powder varied from 0.250 to 0.359. Increase in the inlet air temperature lead to decrease in the water activity of the resultant rice milk powder. The water activity low at temperature of 160°C followed by 150, 140, 130, and 120 °C. However, with increase in the feed flow rate, increase in

the water activity of powder was observed. The higher values of water activity were found at 35 mL/min, followed by 30, 25, 20 and 15 mL/min. The lower flow rate results in higher contact time between the drying air and the feed, which in turn helps better evaporation of the water from the feed.

The results on water activity of the spray dried powder were in accordance with results obtained by Adhikari et al. [19]; Chegini and Ghobadian,

[20]; Goula et al., (2008); Zarietard et al. [21]; Avila et al. [22] and Ghollasi et al. [18] for spray dried powders. The model F-value of 615.73 indicated the level of significance. The P-value less than 0.0500 indicate that A (Temperature), B (Feed flow rate) was significant. Pred R² is 0.9800 and Adj R² is 0.9961 [23-26].

3.3 Optimization of Spray Drying Process Variable of Rice Milk Powder

The spray Drying temperature and feed flow rates were optimized with desirability function

which satisfies all the responses with required values to obtain optimum conditions for spray drying as shown in the Fig. 4. The optimized conditions for spray dried rice milk powder were: Inlet air temperature- 138 °C and feed flow rate - 35 ml/min. Under these conditions, the response values were: bulk density - 0.51 (g/mL), tapped density - 0.62 (g/mL), moisture of powder content - 3.8%, water activity- 0.30, Water Solubility Index - 72.8% and Water Absorption Index - 21.7 % and solubility of the sample was 92 s. The RMSE value of 0.490 indicates that the predicted values were close to the observed values.

Table 3. ANOVA for water activity

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob> F
Model	5.592E-003	5	1.118E-003	615.73	< 0.0001	significant
A-temp	3.038E-003	1	3.038E-003	1672.17	< 0.0001	
B-feed flow	2.521E-003	1	2.521E-003	1388.11	< 0.0001	
AB	2.250E-006	1	2.250E-006	1.24	0.3025	
A ²	7.725E-006	1	7.725E-006	4.25	0.0781	
B ²	3.058E-005	1	3.058E-005	16.84	0.0046	
Residual	1.272E-005	7	1.817E-006			
Lack of Fit	1.272E-005	3	4.239E-006			
Pure Error	0.000	4	0.000			
Cor Total	5.605E-003	12				
Std. Dev.	1.348E-003		R-Squared		0.9977	
Mean	0.29		Adj R-Squared		0.9961	
C.V. %	0.46		Pred R-Squared		0.9800	
PRESS	1.119E-004		Adeq Precision		93.924	

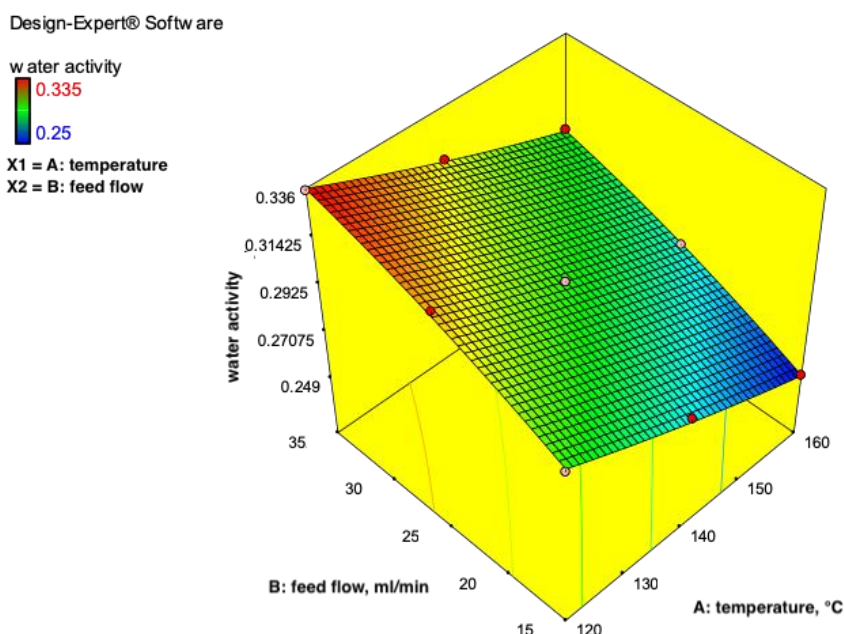


Fig. 3. Variation of water activity of rice milk powder with inlet air temperature and feed flowrate

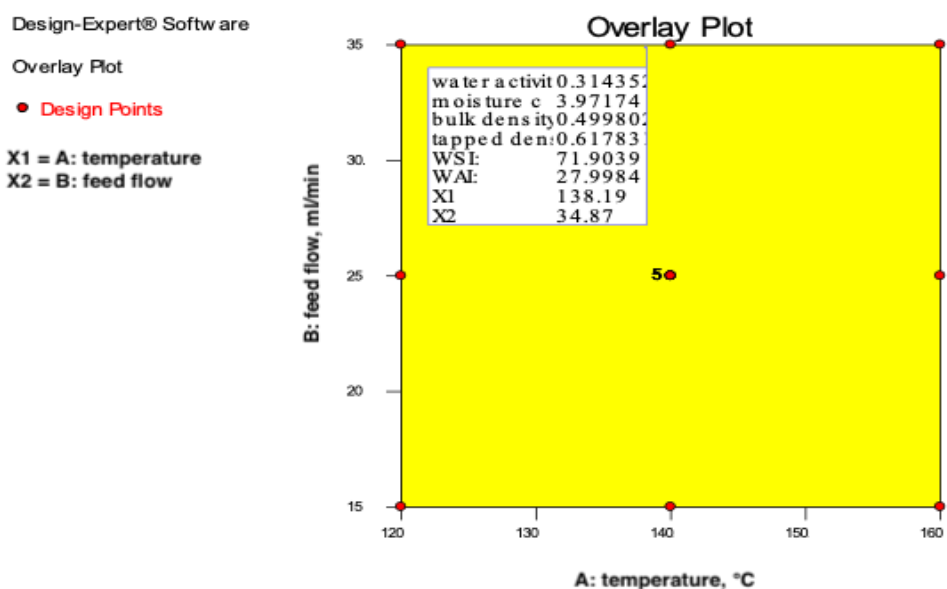


Fig. 4. Optimised spray drying condition for rice milk powder

4. CONCLUSIONS

The rice milk was spray dried at feed flow rates of 15, 20, 25, 30 and 35 mL/min and inlet drying air temperature of 120, 130, 140, 150 and 160 °C. The moisture content of resultant rice milk powders varied from 3.26 to 4.30% (w.b.). The bulk density of the rice milk powder varied from 0.25 to 0.61 g/mL. With increase in inlet drying air temperature, the moisture content, bulk density and tapped density of the spray dried powder decreased. With increase in feed flow rate, the values of the moisture content, bulk density and tapped density of the powder were increased.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX-A

STATISTICAL ANALYSIS OF RICE MILK POWDERBY SPRAY DRYING

Response 1: Water activity

Table 1. ANOVA for Response Surface Quadratic Model Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob> F
Model	5.592E-003	5	1.118E-003	615.73	< 0.0001	significant
A-temp	3.038E-003	1	3.038E-003	1672.17	< 0.0001	
B-feed flow	2.521E-003	1	2.521E-003	1388.11	< 0.0001	
AB	2.250E-006	1	2.250E-006	1.24	0.3025	
A^2	7.725E-006	1	7.725E-006	4.25	0.0781	
B^2	3.058E-005	1	3.058E-005	16.84	0.0046	
Residual	1.272E-005	7	1.817E-006			
Lack of Fit	1.272E-005	3	4.239E-006			
Pure Error	0.000	4	0.000			
Cor Total	5.605E-003	12				

Std. Dev.	1.348E-003	R-Squared	0.9977
Mean	0.29	Adj R-Squared	0.9961
C.V. %	0.46	Pred R-Squared	0.9800
PRESS	1.119E-004	Adeq Precision	93.924

Factor	Coefficient Estimate	df	Standard Error	95% CI		VIF
				Low	High	
Intercept	0.30	1	5.596E-004	0.29	0.30	
A-temp	-0.023	1	5.502E-004	-0.024	-0.021	1.00
B-feed flow	0.020	1	5.502E-004	0.019	0.022	1.00
AB	7.500E-004	1	6.739E-004	-8.435E-004	2.343E-003	1.00
A^2	1.672E-003	1	8.110E-004	-2.453E-004	3.590E-003	1.17
B^2	-3.328E-003	1	8.110E-004	-5.245E-003	-1.410E-003	1.17

Final Equation in Terms of Coded Factors:

$$\text{Wateractivity} = +0.30 - 0.023*A + 0.020*B + 7.500E-004*A*B + 1.672E-003*A^2 - 3.328E-003*B^2$$

Response WSI:

Table 2: ANOVA for WSI

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	80360.65	1	80360.65			
Linear vs Mean	404.17	2	202.08	749.45	< 0.0001	
2FI vs Linear	1.56	1	12.40	0.0065		Suggested
Quadratic vs 2FI	0.24	2	0.12	0.92	0.4416	
Cubic vs Quadratic	0.63	2	0.31	5.83	0.0493	Aliased
Residual	0.27	5	0.054			
Total	80767.51	13	6212.89			

Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	2.70	6	0.45		
2FI	1.13	5	0.23		
Quadratic	0.90	3	0.30		
Cubic	0.27	1	0.27		
Pure Error	0.000	4	0.000		

Model Summary Statistics

Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	0.52	0.9934	0.9920	0.9838	6.58	
2FI	<u>0.35</u>	<u>0.9972</u>	<u>0.9963</u>	<u>0.9917</u>	<u>3.36</u>	Suggested
Quadratic	0.36	0.9978	0.9962	0.9798	8.23	
Cubic	0.23	0.9993	0.9984	0.9231	31.30	Aliased

Response 3 WAI:

Table 3. ANOVA for WAI Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	5915.02	1	5915.02			
Linear vs Mean	400.42	2	200.21	679.60	< 0.0001	
2FI vs Linear	<u>1.44</u>	1	<u>1.44</u>	<u>8.61</u>	<u>0.0167</u>	Suggested
Quadratic vs 2FI	0.33	2	0.17	1.00	0.4148	
Cubic vs Quadratic	0.83	2	0.42	6.16	0.0447	Aliased
Residual	0.34	5	0.068			
Total	6318.39	13	486.03			

Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Linear	2.95	6	0.49		
2FI	1.51	5	0.30		
Quadratic	1.17	3	0.39		
Cubic	0.34	1	0.34		
Pure Error	0.000	4	0.000		

Model Summary Statistics Std. Adjusted Predicted

Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	0.54	0.9927	0.9912	0.9829	6.91	
2FI	<u>0.41</u>	<u>0.9963</u>	<u>0.9950</u>	<u>0.9888</u>	<u>4.53</u>	Suggested
Quadratic	0.41	0.9971	0.9950	0.9950	0.9733	
Cubic	0.26	0.9992	0.9980	0.9026	39.27	Aliased

Final Equation in Terms of Coded Factors:

$$WAI = +21.33 - 5.30 * A + 6.22 * B - 0.60 * A * B$$

Table 4. Constraints imposed on optimization for spray drying

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
temp	is in range	120	160	1	1	3
feed flow	is in range	15	35	1	1	3

Table 5. Solutions for 30 combinations of categoric factor levels for imposed constraints

Solutions Number	temp	feed flow	Desirability	
1	138.19	34.87	1.000	Selected
2	128.89	29.21	1.000	
3	123.81	30.38	1.000	
4	145.22	30.72	1.000	
5	137.45	27.60	1.000	
6	145.38	21.14	1.000	
7	136.13	30.19	1.000	
8	131.93	29.65	1.000	
9	126.37	25.87	1.000	
10	133.44	31.00	1.000	
11	134.14	34.00	1.000	
12	144.13	18.47	1.000	
13	152.11	27.16	1.000	
14	139.00	23.72	1.000	
15	125.32	15.09	1.000	
16	155.51	16.74	1.000	
17	136.83	28.91	1.000	
18	133.21	28.90	1.000	
19	134.10	33.78	1.000	
20	142.54	32.34	1.000	
21	157.91	28.27	1.000	
22	133.86	18.70	1.000	
23	134.55	18.38	1.000	
24	158.40	30.55	1.000	
25	153.02	24.41	1.000	
26	151.77	28.24	1.000	
27	128.02	28.84	1.000	
28	151.89	25.77	1.000	
29	130.36	23.26	1.000	
30	122.15	18.45	1.000	

Table 6. Data statistics

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	temp	138.19	120.00	160.00	0.000	Actual
B	feed flow	34.87	15.00	35.00	0.000	Actual

Table 7. Predicted values for spray dried rice milk powder

Response	Prediction	SE Mean	95% CI low	95% CI high	SE	Pred	
						95% PI low	95% PI high
water activity	0.314351	9.297E-004	0.31	0.32	1.637E-003	0.31	0.32
moisture content	3.97173	9.938E-003	3.95	4.00	0.018	3.93	4.01
bulk density	0.499796	4.964E-003	0.49	0.51	0.011	0.47	0.52
tapped density	0.617824	4.137E-003	0.61	0.63	9.365E-003	0.60	0.64
WSI	71.9043	0.17	71.51	72.30	0.40	71.01	72.80
WAI	27.9979	0.20	27.54	28.45	0.46	26.97	29.03

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