Original Research Article

The Effects of Spray Drying Conditions on Moisture Content, Water activity, Bulk Density and Tapped Density of Rice Milk Powder

Abstract

Cow's milk is usually consumed by the majority of the population and is well thought as a wholesome complete food providing major nutrients like fat, proteins, and carbohydrates. Though milk is considered to be a complete food yet limited availability or near absence of certain minerals such as iron, and vitamins restricts its recommendation as a complete food for infants older than 12 months. To meet this requirement the rice milk was prepared by using the broken rice. Spray drying is a method applied to dry a wide variety of food extracts. The resulting powders are conveniently stored, transported and handled. To increase the shelf life of the rice milk, spray drying of the rice milk was done by using the different inlet temperatures and feed flow rates. An experiment was conducted to study the effects of spray drying conditions on moisture content, bulk density and tapped density of rice milk powder during 2019 at Bapatla, Andhra Pradesh, India. The broken rice was used to prepare rice milk with the optimized process parameters. Temperature and feed flow rate were optimized with desirability function which satisfied all the responses with required values to obtain optimum conditions for spray drying. The predicted optimum conditions were,T=138°C, and Q=35 mlm^{-1}. Under these conditions, the response values for bulk density, moisture content and water activity were 0.51 gml^{-1}, 3.8%, and 0.30.

Keywords: Rice milk, spray drying, bulk density, tapped density

1. Introduction

Cow's milk is usually consumed by the majority of the population and is well thought as a wholesome complete food providing major nutrients like fat, proteins, and carbohydrates (Anonymous, 2016). Besides these macronutrients, milk also contains numerous nutrients (micro & macro) such as calcium, selenium, riboflavin, vitamin B12 and pantothenic acid (vitamin B5) which significantly contributes towards the overall growth and maintenance of the body system (Paul et al., 2019). Though milk is considered to be a complete food yet limited availability or near absence of certain minerals such as iron, and vitamins like folate and some other biomolecules (amino acids) restricts its recommendation as a complete food for infants older than 12 months. To meet this requirement the rice milk was prepared by using the broken rice. The amount of broken rice produced in the rice industry was about 0.97 mt. The cost of the rice is set by the head rice kernels percentage in each unit of rough rice (Van Dalen, 2004). 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 (Paul et al., 2019). Broken rice is still under-utilized and is mostly used as raw material for pet foods, rice flour, wine and beer (Shih et al., 1999,Schucket al., 2005).

Broken rice has the nutritional benefits equal to raw rice and it is processed into flour and utilized as a food product (Kim et al., 2012). According to Hartmann et al. (2006), rice flour is free from gluten therefore, it is an alternative for producing gluten-free products. Rice flour is also hypoallergenic (Marcoa and Rosell, 2008). The rice flour is preferred for baby food and other food products by the food companies because of low risk for people with sensitivities (Gujaral and Rosell, 2004). 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 (Qian and Zhang, 2013).

A liquid derived from rice generally known as rice milk is suitable substitute for animal milk in the world. Recently, consumers have tended toward a plant-based diet which includes cereal, legumes, seeds, nuts, fruits, and vegetables because of varied reasons such as an aversion to animal cruelty, a desire for a healthy lifestyle, and environmental awareness (Janssen et al., 2016,Sebastiani et al., 2019,Aydar et al., 2020). The rice milk is the best breakfast food in Southeast Asia, especially in China and Taiwan (Joshi et al., 2015,Shepherd et al., 1981). Soymilk and other non-dairy milks have long been substitutes for raw milk in the U.S (Aboulfazli et al., 2018). 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. The common steps in the production of all almond, cashew, coconut, hazelnut, peanut, sesame, soy, tiger nut, oat, rice, hemp, and walnut milk substitutes are wet milling, filtration, the addition of ingredients, sterilization, homogenization, aseptic packaging, and cold storage. Gums are used to improve stability, and salt and sweeteners are used for the development of sensory properties (Bernat et al., 2014, Manzoor et al., 2017,Makinde and Adebile, 2018) 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 (Joshi et al., 2015).

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 (Masters, 2002). 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 (Gupta,1978, Masters, 2002). The process is continuous and easily automated which can reduce labour costs (Sharma et al., 2000). There are less sticking and corrosion problems in spray drying if the material does not contact the equipment walls until it is dry (Wang et al., 2015).

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 (Masters, 2002). To increase the shelf life of the rice milk, spray drying of the rice milk was done by using the different inlet temperatures and feed flow rate.

2. Material and Methods

2.1. Spray drying of rice milk

The spray drying of rice milk was conducted in the year 2019.Rice milk obtained from the optimized conditions (TSS: 10–12^{o}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 m^3h^{-1}. Pilot scale spray dryer (Make: S.M. Scientech, Model: B-290, Capacity: 3 L of water evaporationh^{-1}) 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 mlm^{-1}. 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.

Plate 1: Laboratory model pilot scale spray dryer

2.2. Independent and Dependent Variables

The independentvariablesarefeed flow rate and inlet drying air temperatures, the dependent variables are bulk density, tapped density and moisture content.

2.3. Determination of properties of powder

2.3.1. Moisture Content

Moisture analysis has been performed on rice milk samples using an IR Moisture balance(Make: Shimadzu, Model: Mu 63). Moisture content of all rice milk powder samples was determined by subjecting the samples to Infrared heating at 105°C till constant weight (Plate 2).

Plate 2: Infrared moisture analyzer

2.3.2. BulkDensity

The bulk density of rice milk powder was measured by the procedure as described by Goula and Adamopoulos (2010) and Goulaet al. (2008). 2 g of rice milk powder was transferred to a 50 ml measuring cylinder. The Bulk density was measured by dividing the weight of the powder by the volume of the sample in the cylinder

2.3.3. Tapped Density

The tapped density was calculated by manually tapping a container containing the rice milk powder on a rubber mat. It was measured after 250±15 taps from a height of 3±0.2 mm. The tapped density was measured by dividing the weight of the powder by the volume of the sample in the graduated cylinder.

3. Results and Discussion

3.1. Production of rice milk powder by spray drying

Spray drying studies were carried out at Post-Harvest Technology Centre, Bapatla using Pilot Scale Spray Dryer (Make: S.M. Science Tech., India). The maximum capacity of the spray dryer was 1.30 Lh^{-1} with the nozzle fits to 1 mm size. The rice milk was fed at the feed flow rate of 15, 20, 25, 30 and 35 mlm^{-1}. The inlet air temperature was maintained at 120, 130, 140, 150 and 160°C temperature.

3.1.1. Variation in Moisture Content of spray dried rice milk powder at different Inlet Air Temperatures and Feed Flow Rates

The moisture content of the rice milk powder prepared by spray drying is presented in Figure 1. Moisture content of the rice milk powder varied from 3.26–4.30% (w.b.). The moisture content decreased with increase in the inlet air temperature but increased with increase in the feed flow rate. The decrease in moisture content at higher inlet drying air temperature was due to increase in heat transfer rate that helped more moisture removal (Adhikari et al., 2001,Chegini and Ghobadian, 2007,Goulaet al., 2008,Zareifardet al., 2012, Avila et al., 2015,Ghollasi et al., 2018) in spray dried powders. F-value of 657.00 shows that the model was significant. The *p*-values less than 0.0500 indicates A (Temperature), B (Feed flow rate), AB (Interaction between Temperature and Feed flow rate) are significant model terms (Appendix B). The Pred. R^2 was 0.9831, Adj R^2 was 0.9964 and Adeq precision ratio was 96.373 indicating goodness of fit.

Table 1: ANOVA for Moisture Content

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F-value	Prob> F significant	
Model	0.68	5	0.14	657.00	< 0.0001	significant
A-temp	0.27	1	0.27	1294.91	< 0.0001	
B-feed flow	0.41	1	0.41	1953.81	< 0.0001	
AB	4.225E-	1	4.225E-	20.35	0.0028	

	003		003		
A^2	1.324E-003	1	1.324E-003	6.38	0.0395
B^2	3.027E-003	1	3.027E-003	14.58	0.0066
Residual	1.453E-003	7	2.076E-004		
Lack of Fit	1.453E-003	3	4.844E-004		
Pure Error	0.000	4	0.000		
Cor Total	0.68	12			

Std. Dev.	0.014	R-Squared	0.9979
Mean	3.72	Adj R-Squared	0.9964
C.V. %	0.39	Pred R-Squared	0.9831
PRESS	0.012	Adeq Precision	96.373

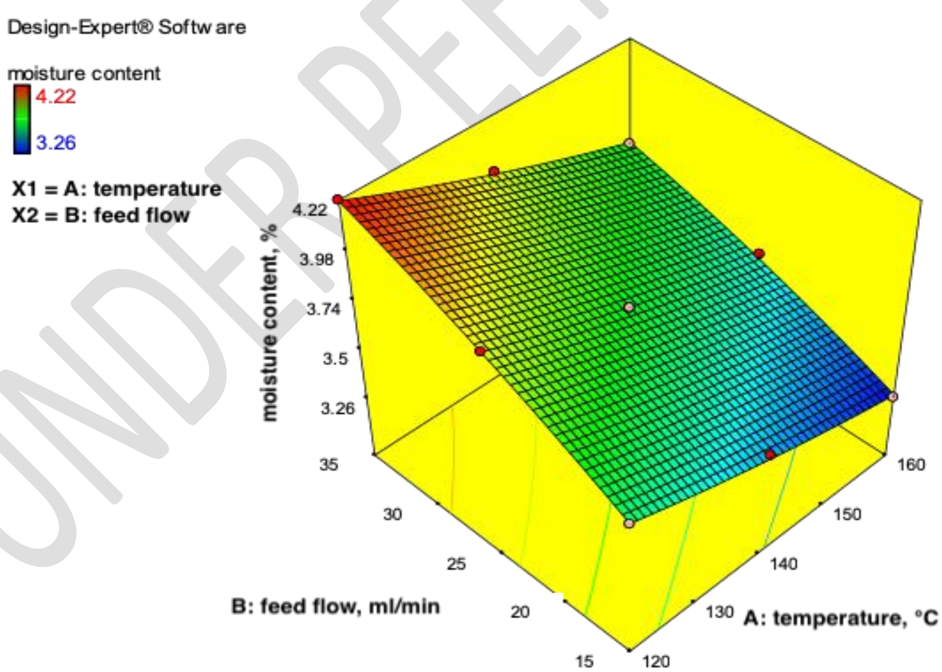

Figure 1: Variation of moisture content of rice milk powder with spray drying inlet air temperature and feed flow rate

3.1.2. Variation of Water Activity of rice milk powder at different Inlet Air Temperatures and Feed Flow Rates

From the Figure 2, the water activity of rice milk powder varied from 0.250–0.359. 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 (Appendix B). 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 m^{-1}, followed by 30, 25, 20 and 15 mlm^{-1}. 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. (2001),Chegini and Ghobadian(2007),Goulaet al. (2008),Zariefardet al. (2012), Avila et al. (2015) and Ghollasi et al. (2018) 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 (Appendix B). Pred R^2 is 0.9800 and Adj R^2 is 0.9961.

Table 2: 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

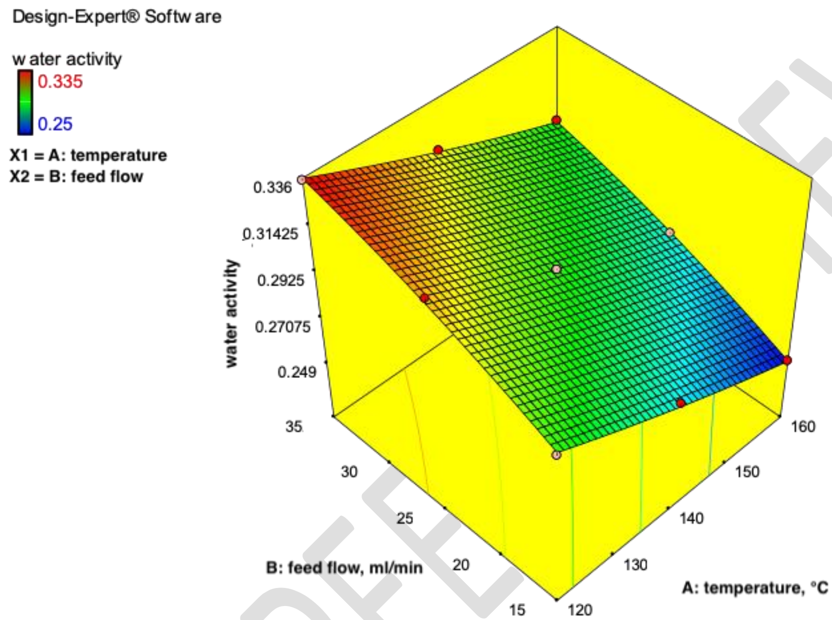

Figure 2:Variation of water activity of rice milk powder with inlet air temperature and feed flowrate

3.1.3. Variation of Bulk and Tapped Density of rice milk powder at different Inlet Air Temperatures and Feed Flow Rates

The spray dried rice milk powder characterization with reference to bulk density, tapped density and particle density is shown in Figures 3 and4.The bulk density of the rice milk powder varied from 0.25–0.61 gml^{-1}. Increase in inlet air temperature, the bulk density of the powder decreased and the negative effect was observed for feed flow rate with respect to bulk density. Ghollasi et al. (2018) reported that the decrease in bulk density and particle density was observed with increase in the drying air temperature. According to Chegini and Ghobadian (2007), the increase in moisture content tend to increase the bulk density as the bulking weight increases with presence of water, which was considerably denser than the dry solid. The trend was same with tapped density of the rice milk powder which varied from 0.35–0.73 gml^{-1}. Chegini and Ghobadian (2007), Samborskaet al. (2015), Zareifardet al. (2012), Goula and Adamopoulos (2010) also reported similar results for spray dried powders. The model F-value of 400.66 indicates its significanance. *p*-values less than 0.0500 indicate that the A (Temperature), B (Feed flow rate) are significant.

Table 3: ANOVA for Bulk Density

Source	Sum of Squares	df	Mean Square	F-value	*p*-value	Prob> F
Model	0.082	2	0.041	400.66	< 0.0001	significant
A-temp	0.047	1	0.047	457.03	< 0.0001	
B-feed flow	0.035	1	0.035	344.28	< 0.0001	
Residual	1.024E-003	10	1.024E-004			
Lack of Fit	1.024E-003	6	1.707E-004			
Pure Error	0.000	4	0.000			
Cor Total	0.083	12				

Std. Dev.	0.010	R-Squared	0.9877
Mean	0.42	Adj R-Squared	0.9852
C.V. %	2.43	Pred R-Squared	0.9725
PRESS	2.282E-003	Adeq Precision	67.873

Table 4: ANOVA for Tapped Density

Source	Sum of Squares	df	Mean Square	F Value	*p*-value Prob > F	
Mean vs Total	3.47	1	3.47			
Linear vs Mean	0.096	2	0.048	379.35	< 0.0001	
2FI vs Linear	6.250E-	1	6.250E-004	8.85	0.0156	Sugges

	004					ted
Quadratic vs 2FI	2.442E-004	2	1.221E-004	2.19	0.1831	
Cubic vs Quadratic	2.833E-004	2	1.417E-004	6.57	0.0399	Aliased
Residual	1.078E-004	5	2.155E-005			
Total	3.57	13	0.27			

Table 5: Model Summary Statistics Std. AdjustedPredicted

Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	0.011	0.9870	0.9844	0.9692	2.988E-003	
2FI	8.401E-003	0.9934	0.9913	0.9820	1.745E-003	Suggested
Quadratic	7.475E-003	0.9960	0.9931	0.9626	3.619E-003	
Cubic	4.642E-003	0.9989	0.9973	0.8707	0.013	Aliased

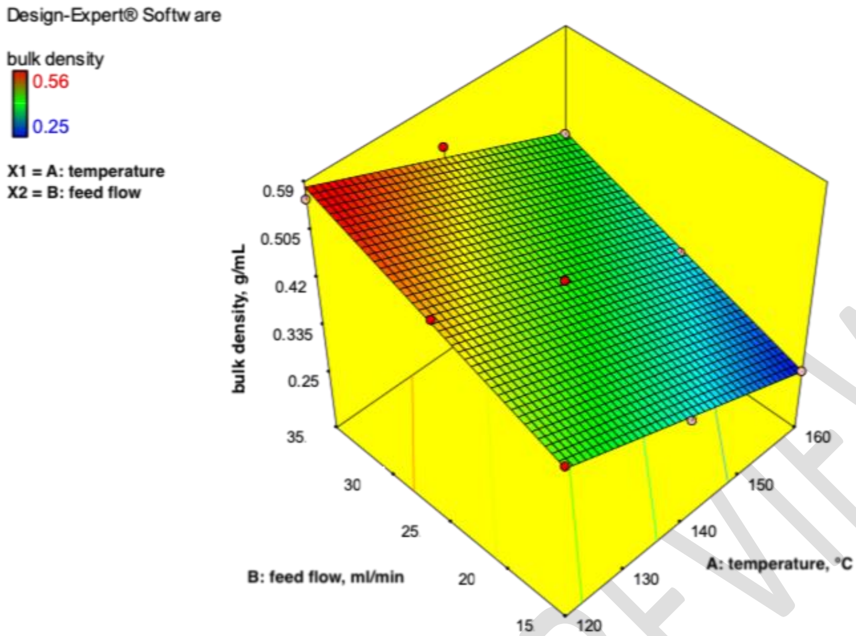

Figure 3:Variation of bulk density with inlet air temperatures and feed flowrate

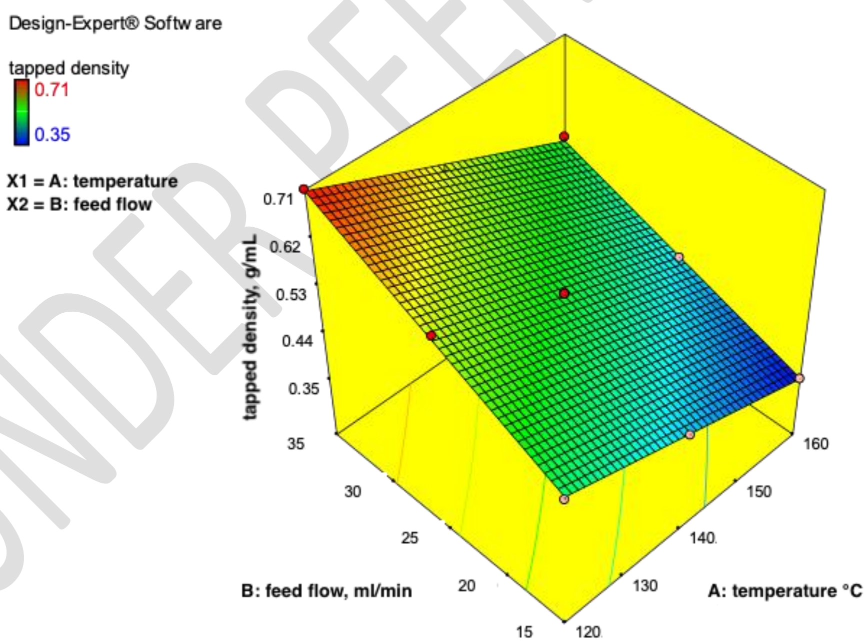

Figure 4:Variation of tapped density with inlet air temperature and feed flow rate.

4. Conclusions

The rice milk was spray dried at feed flow rates of 15, 20, 25, 30 and 35 mlm^{-1} and inlet drying air temperature of 120, 130, 140, 150 and 160°C. With increase in inlet drying air temperature, the moisture content, bulk 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.

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