Original Research Article

The effects of Spray Drying Conditions on Water Absorption Index, Water Solubility Index, Solubility and Water activity (a_w) of rice milk powder

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 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.

KEY WORDS: rice milk, solubility, spray drying, water activity, water absorption index, water solubility index

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 (FAO, 2019). 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 (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 (Shepherd *et al*., 1981). 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).

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 (Quinones et al., 2015). 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. The rice milk is the best breakfast food in Southeast Asia, especially in China and Taiwan (Joshi *et al.*, 2015). Soymilk and other non-dairy milks have long been substitutes for raw milk in the U.S (Ikya *et al*., 2013). 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 (Hassan *et al*., 2005). 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, 1991). 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 (Masters, 1972). 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 (Gupta, 1978).

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, 1972).

MATERIAL AND METHODS

SPRAY DRYING OF RICE MILK

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^3/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 3). 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.

Plate 1. Laboratory model pilot scale spray dryer

Independent and Dependent Variables

I. 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

II. Product Quality Parameters (Dependent variables)

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

DETERMINATION OF PROPERTIES OF POWDER

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.

WAI (%) = (Weight of wet residue/ Weight of sample) × 100……….……… (1)

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 2 Infra Red moisture analyzer

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) 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).

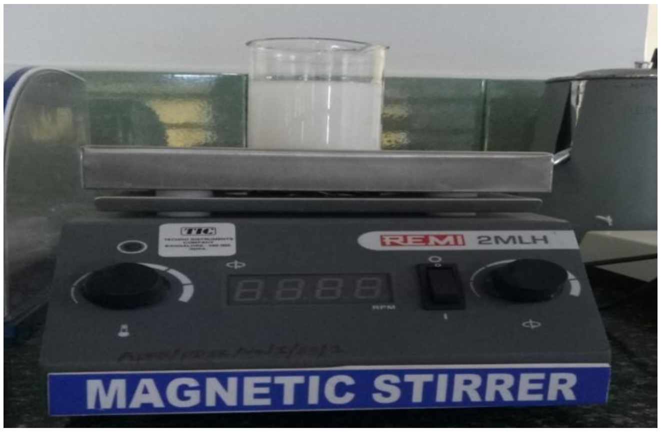

Plate 3 Magnetic stirrer

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.

Plate 4 Water activity meter

RESULTS AND DISCUSSION

Variation of Water Solubiliy 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 Figure.1. 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*. (2018) andPhoungchandang 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. Hogekamp 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.

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. AdjustedPredicted

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

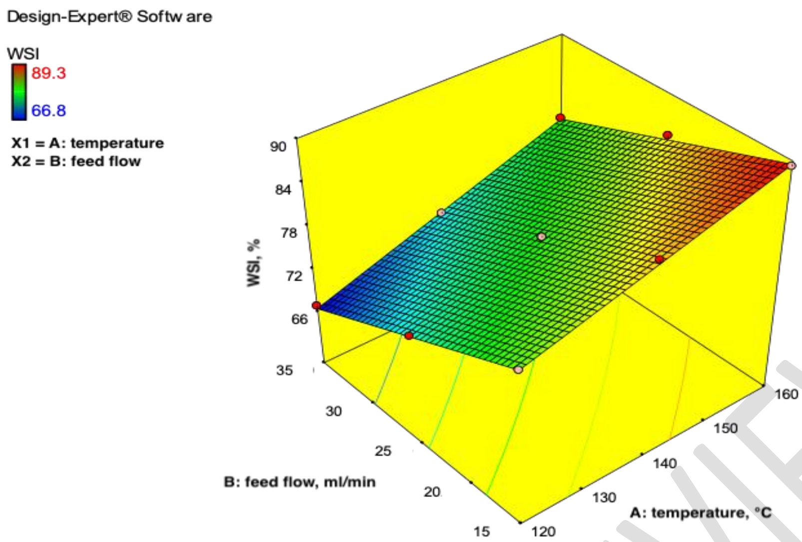

Figure 1. Variation of Water Solubility Indexof Rice Milk Powder with spray drying inlet air temperature and feed flow rate

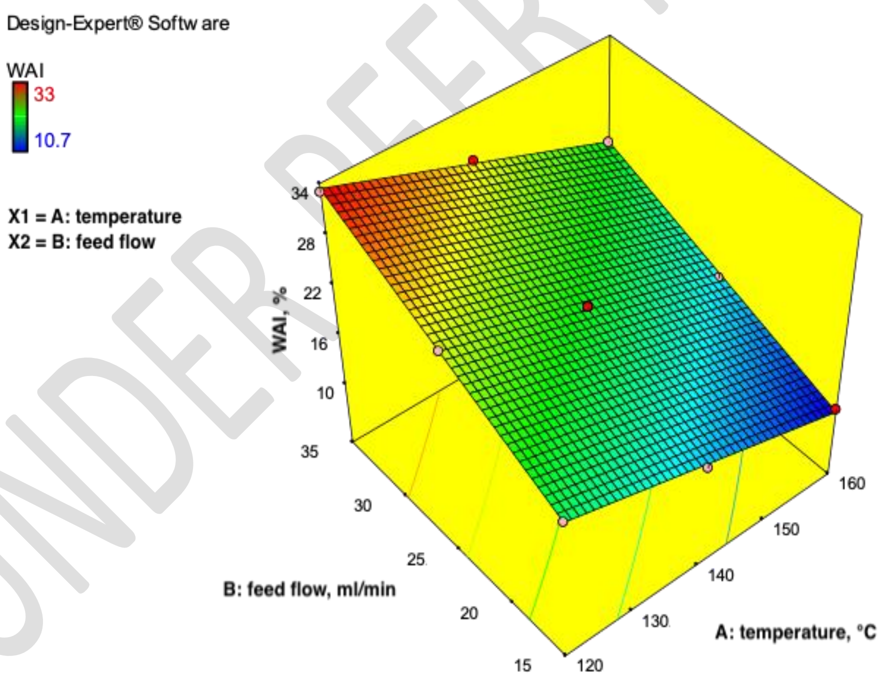

Figure 2.Variation of Water Absorption Indexof Rice Milk Powder with spray drying inlet air temperature and feed flow rate

WAI values of rice milk powder decreased at hogher 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 significanance. 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 absoprtion. With air tight packaging, rice milk powder could be safely stored for 180 days without quality deterioration.

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 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 (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/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*. (2003); Chegini and Ghobadian, (2007); Goula *et al*., (2008); Zariefard *et al*. (2012); Avila *et al*. (2015) andGhollasi *et al*. (2018) for spray dried powders. The model F-value of 615.73 indicated the level of significanance. 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 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

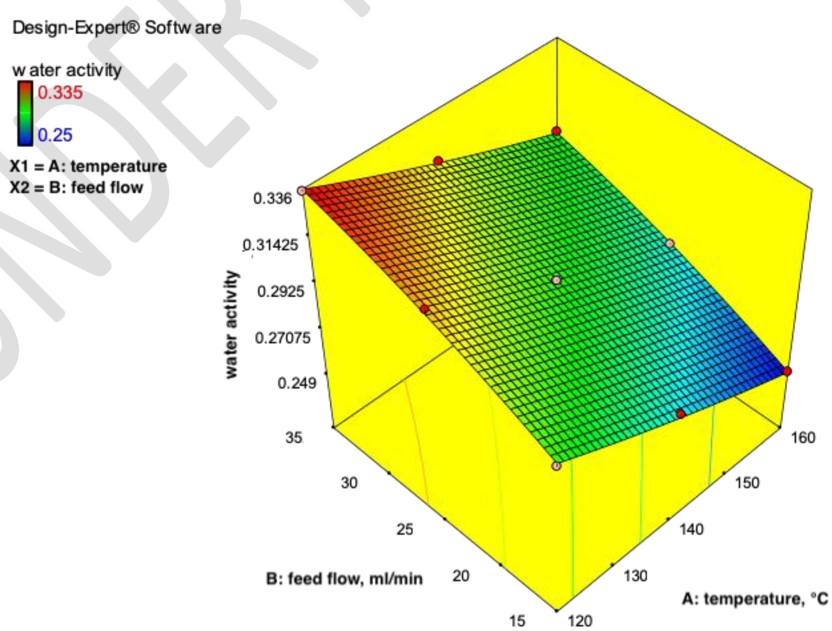

Figure 3 **Variation of water activity of rice milk powder with inlet air temperature and feed flowrate**

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. 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.

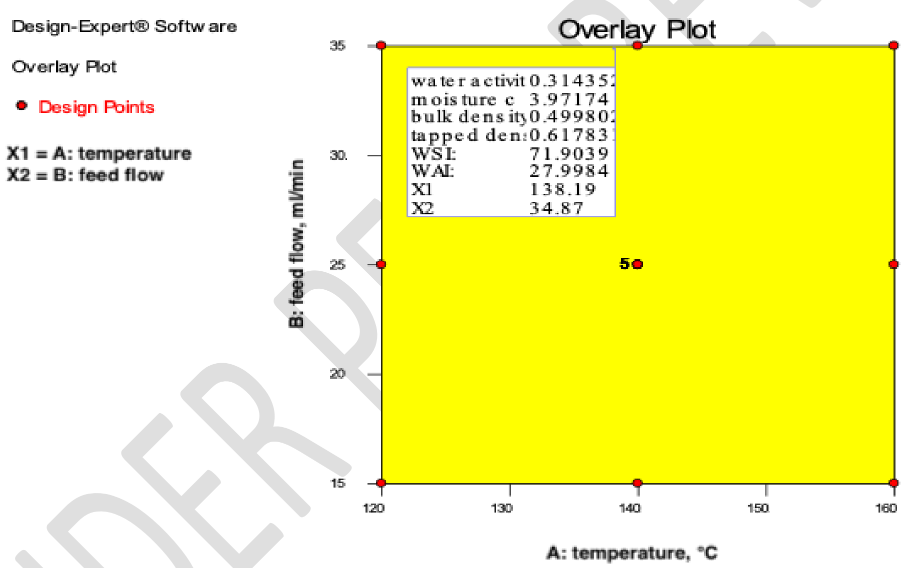

Figure 4 Optimised spray dryingcondition for rice milk powder

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.

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