

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 of 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 in 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 the desirability function which satisfied all the responses with the required values to obtain optimum conditions for spray drying. The predicted optimum conditions were $T=138^{\circ}\text{C}$ and $Q=35 \text{ MLM}^{-1}$. 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, food extracts

1. Introduction

“Cow's milk is usually consumed by the majority of the population and is well thought of 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”. (Paul et al., 2019). 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, 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, Schuckel et al., 2005).

“Broken rice has 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). “Rice flour is preferred for baby food and other food products by food companies because of the 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 a suitable substitute for animal milk around 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). 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 milk have long been substitutes for raw milk in the U.S (Aboufazli 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, color 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 pharmaceuticals 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 color, 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 labor costs” (Sharma et al., 2000). “There are fewer 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 pumpable 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 the 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 different inlet temperatures and feed flow rates.

The objective of the present study is to determine the effects of spray drying conditions on moisture content, water activity, bulk density, and tapped density of rice milk powder.

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°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 airflow rate of $60 \text{ m}^3\text{h}^{-1}$. A pilot scale spray dryer (Make: S.M. Scientech, Model: B-290, Capacity: $3 \text{ L of water evaporation}^{-1}$) was utilized for the experiment (Figure 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 was analyzed for product quality parameters viz., physical and chemical properties. Further, the process conditions were optimized to produce a product with the best sensory attributes. Each response variable in the study was analyzed 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 ($25 \pm 5^\circ\text{C}$) conditions.



Figure 1: Laboratory model pilot scale spray dryer

2.2. *Independent and Dependent Variables*

The independent variables are feed 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). The moisture content of all rice milk powder samples was determined by subjecting the samples to Infrared heating at 105°C till constant weight (Figure 2).



Figure 2: Infrared moisture analyzer

2.3.2. *BulkDensity*

The bulk density of rice milk powder was measured by the procedure described by Goula and Adamopoulos (2010) and Goula et 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 fitting 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 3. The moisture content of the rice milk powder varied from 3.26–4.30% (w.b.). The moisture content decreased with an increase in the inlet air temperature but increased with an increase in the feed flow rate. The decrease in moisture content at higher inlet drying air temperature was due to an increase in heat transfer rate that helped more moisture removal (Adhikari et al., 2001, Chegini and Ghobadian, 2007, Goula et al., 2008, Zareifardet al., 2012, Avila et al., 2015, Ghollasi et al., 2018) in spray dried powders. An 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), and 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> significant	F
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-	1	1.324E-	6.38	0.0395
	003		003		
B ²	3.027E-	1	3.027E-	14.58	0.0066
	003		003		
Residual	1.453E-	7	2.076E-		
	003		004		
Lack of Fit	1.453E-	3	4.844E-		
	003		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

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moisture content



X1 = A: temperature
X2 = B: feed flow

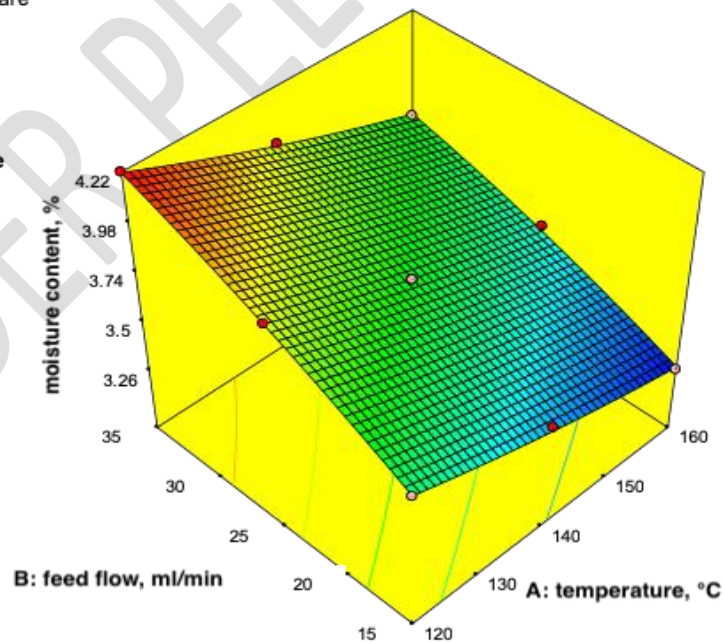


Figure3: Variation of moisture content of rice milk powder with spray drying inlet air temperature and feed flow rate

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

From Figure 4, the water activity of rice milk powder varied from 0.250–0.359. An increase in the inlet air temperature leads to a decrease in the water activity of the resultant rice milk powder. The water activity is low at a temperature of 160°C followed by 150, 140, 130, and 120°C (Appendix B). However, with an increase in the feed flow rate, an 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. A *p*-value less than 0.0500 indicate that A (Temperature), and B (Feed flow rate) was significant (Appendix B). Pred R² is 0.9800 and Adj R² is 0.9961.

Table 2: ANOVA for Water Activity

Source	Sum of Squares	df	Mean Square	F-value	<i>p</i> -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

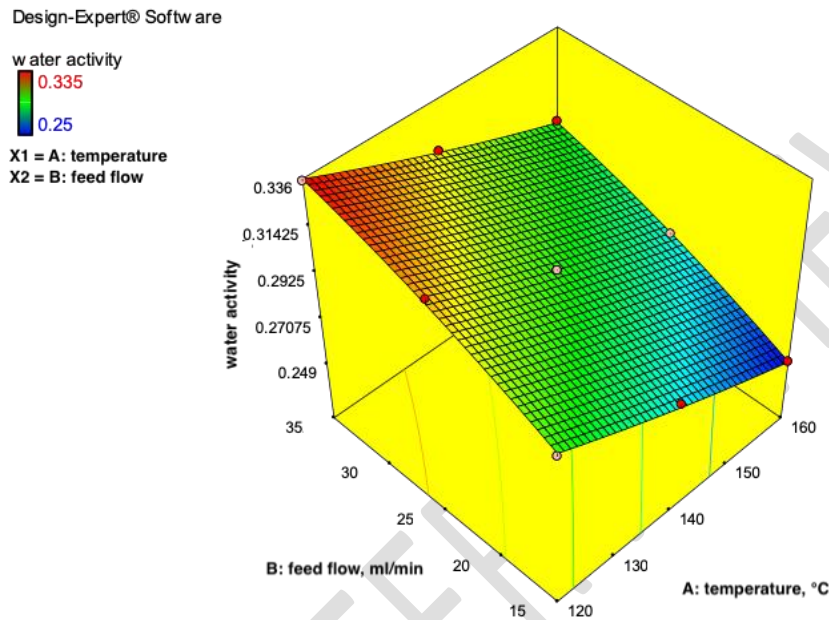


Figure 4: Variation of water activity of rice milk powder with inlet air temperature and feed flowrate

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 5 and 6. 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 a negative effect was observed for feed flow rate with respect to bulk density. Ghollasi et al. (2018) reported that a decrease in bulk density and particle density was observed with an 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 the presence of water, which was considerably denser than the dry solid. The trend was the same with a 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), and Goula and Adamopoulos (2010) also reported similar results for spray-dried powders. The model F-value of 400.66 indicates its significance. p -values less than 0.0500 indicate that the A (Temperature), and 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-004	1	6.250E-004	8.85	0.0156	Suggested

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. Adjusted Predicted

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

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bulk density
0.56
0.25

X1 = A: temperature
X2 = B: feed flow

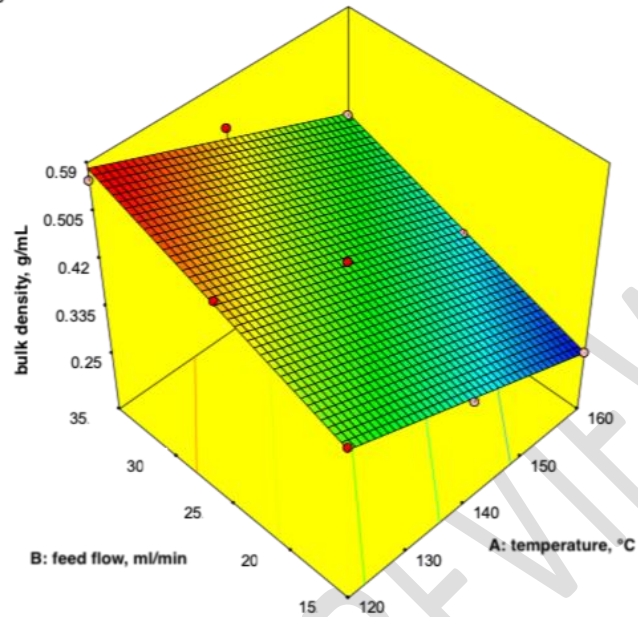


Figure 5: Variation of bulk density with inlet air temperatures and feed flowrate

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tapped density
0.71
0.35

X1 = A: temperature
X2 = B: feed flow

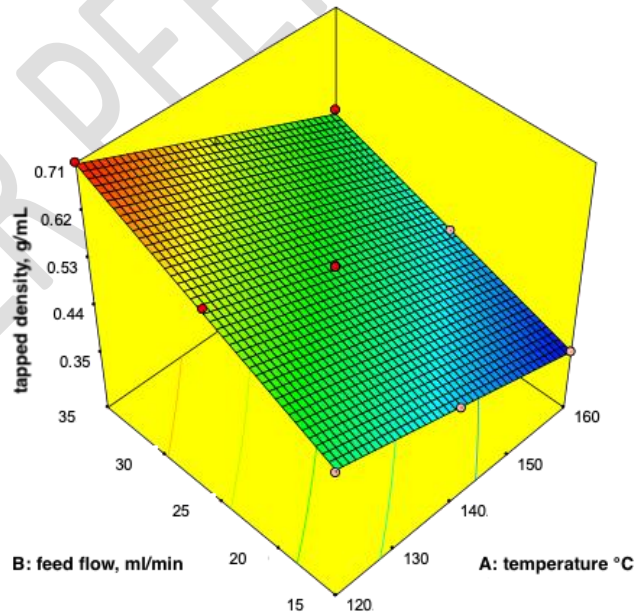


Figure 6: Variation of tapped density with inlet air temperature and feed flow rate.

Optimization of Spray Drying process variable of Rice Milk Powder

The spray Drying temperature and feed flow rates were optimized with a 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.

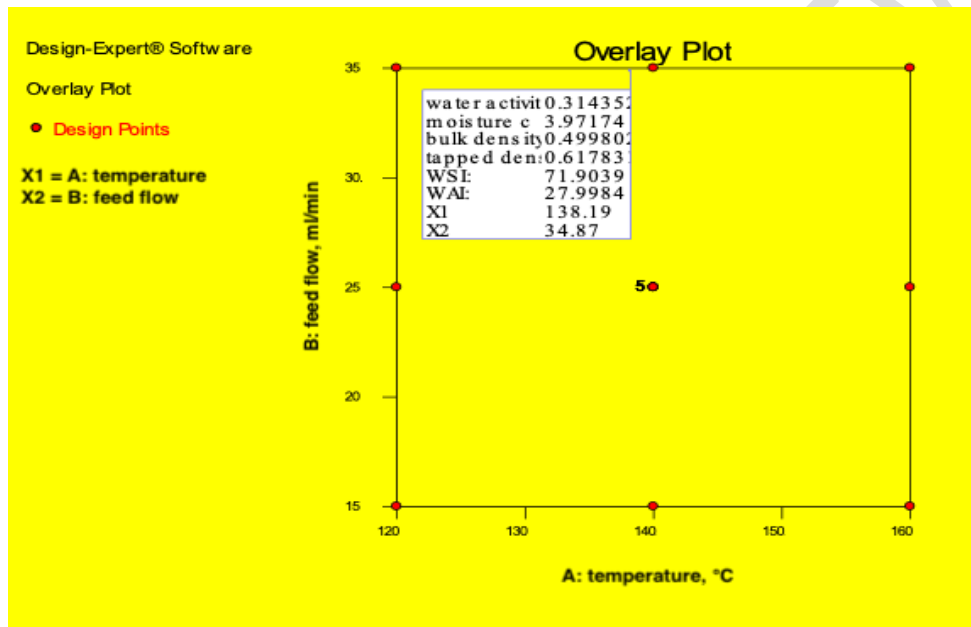


Figure 7 Optimised spray drying condition for rice milk powder

4. Conclusions

The rice milk was spray dried at feed flow rates of 15, 20, 25, 30 and 35 MLM^{-1} and inlet drying air temperatures of 120, 130, 140, 150, and 160°C. With the increase in inlet drying air temperature, the moisture content, bulk, and tapped density of the spray-dried powder decreased. With the increase in feed flow rate, the values of the moisture content, bulk density, and tapped density of the powder were increased.

5. References

- Aboufazli, F., Shori, A.B., Baba, A.S., 2016. Effects of the replacement of cow milk with vegetable milk on probiotics and nutritional profile of fermented ice cream. *LWT- Food Science and Technology* 70(1), 261–270.
- Adhikari, B., Howes, T., Bhandari, B.R., Troung, V., 2001. Stickiness in foods: A review of mechanisms and test methods. *International Journal of Food Properties* 4(1), 1–33.
- Anonymous, 2016. Explosive growth in dairy alternatives market expected through 2020, study finds. Plant Based Foods Association. Available at www.plantbasedfoods.org/explosive-growth-dairy-alternatives-market-expected-2020-study-finds. Accessed April 9, 2018.
- Anonymous, 2019. FAOSTAT-Agriculture Data, Agricultural Production, Crops Primary. FAO, Rome. Available at <https://www.fao.org/faostat/en/#data/QCL> on 19.08.2019. Accessed on 19th September 2019.
- Avila, E.L., Rodríguez, M.C., Velasquez, H.J.C., 2015. Influence of maltodextrin and spray drying process conditions on sugarcane juice powder quality. *Revista Colombiana de Agronomía Medellín* 68(1), 7509–7520.
- Aydar, E.F., Tutuncu, S., Ozcelik, B., 2020. Plant-based milk substitutes: Bioactive compounds, conventional and novel processes, bioavailability studies, and health effects. *Journal of Functional Foods* 70(1), 103975.
- Bernat, N., Chafer, M., Chiralt, A., Gonzalez-Martinez, C., 2014. Hazelnut milk fermentation using probiotic *Lactobacillus rhamnosus* GG and inulin. *International Journal of Food Science and Technology* 49(1), 2553–2562.
- Chegini, G.R., Ghobadian, B., 2007. Spray drying parameters for fruit juice drying. *World Journal of Agricultural Sciences* 3(2), 230–236.
- Gujaral, H.S., Rosell, C.M., 2004. Improvement of breadmaking quality of rice flour by glucose oxidase. *Food Research International* 37(1), 75–81.
- Gupta, A.S., 1978. Spray drying of citrus juice. In: 7th Annual Meeting, American Institute of Chemical Engineers, paper no. 55f.
- Hartmann, G., Koehler, P., Wieser, H., 2006. Rapid degradation of gliadin peptides toxic for coeliac disease patients by proteases from germinating cereals. *Journal of Cereal Science* 44(3), 368–371.
- Janssen, M., Busch, C., Rödiger, M., Hamm, U., 2016. Motives of consumers following a vegan diet and their attitudes towards animal agriculture. *Appetite* 105(1), 643–651.

- Joshi, R., Mo, C., Lee, W.H., Lee, S.H., Cho, B.K., 2015. Review of rice quality under various growth and storage conditions and its evaluation using spectroscopic technology. *Journal of Bio systems Engineering* 40(2), 124–136.
- Kim, H.Y., Hwang, I.G., Kim, T.M., Woo, K.W., Park, D.S., 2012. Chemical and functional components in different parts of rough rice (*Oryza sativa* L.) before and after germination. *Food Chemistry* 134(1), 288–293.
- Makinde, M.F., Adebile, V.T., 2018. Influence of processing treatments on quality of vegetable milk from almond (*Terminalia catappa*) kernels. *Acta Scientific Nutritional Health* 2(6), 37–42.
- Manzoor, M.F., Manzoor, A., Siddique, R., Ahmad, N., 2017. Nutritional and sensory properties of cashew seed (*Anacardium occidentale*) milk. *Modern Concepts & Developments in Agronomy* 1(1), 1–4.
- Marcoa, C., Rosell, C.M., 2008. Effect of different protein isolates and transglutaminase on rice flour properties. *Journal of Food Engineering* 84(1), 132–139.
- Masters K., 2002. *Spray Drying* (4thEdn.). *Spray Dry Consult Intl.* ApS, Denmark, Halstead Press, New York, 696.
- Paul, A. A., Kumar, S., Kumar, V., Sharma, R., 2019. Milk analog: Plant based alternatives to conventional milk, production, potential and health concerns. *Critical Reviews in Food Science and Nutrition* 60(18), 3005–3025.
- Qian, H., Zhang, H., 2013. Rice flour and related products. In: Bhandari, B., Bansal, N., Zhang, M., Schuck, P. (Eds.), *Handbook of Food Powders: Processes and Properties*. Wood Head Publishing, Philadelphia, PA, 553–575.
- Samborska, K., Gajek, P., Dwórznička, A.K., 2015. Spray drying of honey: The effect of drying agents on powder properties. *Polish Journal of Food and Nutritional Science* 65(2), 109–118.
- Schuck, P., Blanchard, E., Dolivet, A., Méjea, S., Onillon, E., Jeantet, R., 2005. Water activity and glass transition in dairy ingredients. *Le Lait, INRA Editions* 85(4–5), 295–304.
- Sebastiani, G., HerranzBarbero, A., Borrás-Novell, C., Alsina Casanova, M., AldecoaBilbao, V., Andreu-Fernández, V., García-Algar, O., 2019. The effects of vegetarian and vegan diet during pregnancy on the health of mothers and offspring. *Nutrients* 11(3), 557.
- Sharma, S.K., Mulvane, S.J., Rizvi, S.S., 2000. *Food Process Engineering: Theory and Laboratory Experiments*. Wiley-Inter Science. A John Wiley and Sons, Inc., Publication. New York, USA, 9.

- Shepherd, A.D., Betschart, A.A., Saunders, R.M., Rockey, G., Huber, G., 1981. Broken spark interest in rice soy infant milk. *Rice Journal* 84(5), 16–21.
- Shih, F.F., Champagne, E.T., Daigle, K., Zerín, S., 1999. Use of enzymes in the processing of protein products from rice bran and rice flour. *Nahrung*43(1), 14–18.
- Van Dalen, G., 2004. Determination of the size distribution and percentage of broken kernels of rice using flatbed scanning and image analysis. *Food Research International* 37(1), 51–58.
- Wang, W., Dufour, C., Zhou, W., 2015. Impacts of spray-drying conditions on the physico-chemical properties of soy sauce powders using maltodextrin as auxiliary drying carrier. *CyTA - Journal of Food* 13(4), 548–555.
- Zareifard, M.R., Niakousari, M., Shokrollahi, Z., Javadian, S., 2012. A feasibility study on the drying of lime juice: the relationship between the key operating parameters of a small laboratory spray dryer and product quality. *Food Bioprocess Technology* 5(1),1896–1906.