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ORIGINAL ARTICLE

Influence of processing conditions on quality of Indian small grey donkey milk powder by spray drying

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Abstract The study was carried out to know the quality of small grey donkey milk powder by spray dryer. Donkey milk powder moisture, fat, protein, carbohydrate and ash were 4.12 (d.b), 5.97, 22.84, 4.64 and 62.43 (%). Donkey milk powder was produced at milk total solids of 20, 25 and 30% concentration at 160, 170 and 180 °C inlet air temperature using two fluid flow nozzle type atomizer of 0.84 mm diameter, pressure of 1.75 kg.cm^{-2}, flow rate of 0.5 L.h^{-1}, blower speed of 2100 rpm. L^*, a^*, b^* and a_w values decreased with increasing concentrated milk feed as well as inlet air temperature. Density decreased as increase of inlet air temperature and increased as increase milk concentration. Flowability was fair according to Hausner ratio (1.25) and Carr's index (20%) values. The heat utilization efficiency increased as increase of concentration and decreased as increase of inlet air temperature. Solubility decreased as increase of concentration and inlet air temperature. Dispersibility decreased as increase of inlet air temperature and increased as increase of concentration. Wetting time increased as increase of concentration and inlet air temperature. Structure of the donkey milk powder was spherical and minerals were abundant.

Keywords Donkey milk powder · Colour · Water activity · Wetting time

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Introduction

Donkey milk is the best alternative or substitute of human milk for infants who are orphan and allergic to cow's milk protein, due to almost similar nutritional and bio-chemical composition compared to human milk. Monti et al. (2012) confirmed that donkey milk is clinically tolerated, palatability and nutritionally good source of food for infants. Donkey milk could be used in the prevention of atherosclerosis and cardiovascular diseases (Tafaro et al. 2007). Donkey milk has higher concentration of vitamins and polyunsaturated fatty acids (Aspri et al. 2016) and contains anti-ageing, anti-oxidant and regenerating compounds, which are described as naturally active in skin hydration and skin ageing prevention. The lipid fraction is characterized by high levels of essential fatty acids and low saturated fatty acids (Gastaldi et al. 2010).

Unsaturated fatty acids in donkey milk are useful in the prevention of the cardiovascular, auto-immune and inflammatory diseases (Martemucci and D'Alessandro 2012; Martini et al. 2014). Donkey milk improves blood flow and reduces blood pressure (Yvon et al. 2018). Hence, it can be used in pharmaceutical, nutraceutical and cosmetic industry. According to 19th livestock census report, Department of Animal husbandry and dairying stated that the Karnataka stands 7th position in donkey population with nine thousand animals, after Rajastan, Maharastra, Uttar Pradesh, Gujarat and Bihar, Jammu and Kashmir. Small grey donkey breed is one of the breed of donkey available in India and are small to medium in size. The average milk production is varies from 0.2 to 1 $L.day^{-1}$.

Donkey milk composition is perishable in nature and the long term storage is difficult. Use of processing techniques for milk by converting into powder form, the long term storage is possible without much loss of its nutritional value. Conversion of powder consists of several unit operations *i.e.,* pre-heating, filtration, pasteurization, concentration of milk through evaporation of water which reduces the water activity and water content and another one is decrease of water content in milk using high temperature short time process method which is spray drying, whereas decrease of moisture content as well as water activity considerably and prolongs the shelf-life (Welti-Chanes and Velez-Ruiz, 2009).

Milk powder quality is much important and it changes with respect to different inlet/outlet air temperature as well as concentration of milk fed. The quality of milk powder is based on moisture content, a_w, protein, colour, density, flowability, solubility, wettability, dispersibility and other physical properties which are important in further formulation for development of food products. Therefore, the objective of this study was influences of process conditions on quality of Indian Small grey donkey milk powder by spray drying.

Materials and methods

Procurement of milk from small grey donkey and unit operations involved in production of spray dried donkey milk powder

Milk sample was collected after parturition from post-monsoon (October to November) to winter season (December to February), during lactation period of 58th to 62nd days from ten multiparous small grey donkey, age of 14 years, with good healthy body conditions, in the village of *Chikkabanagere*, Sira Taluk, Tumkur District, Karnataka, India. Donkey milk was milked manually at 6.30 AM. Milk was completely removed from both udders, milking yield was ranged from 350 to 950 mL from the animals which was collected in sterilized polyethylene terepthalte bottle and mixed together (30 L), kept in an ice box at 4 °C during transport. The collected sample was frozen at −20 °C until analysis. The cold donkey milk was thawed till it comes to original liquid form. Milk sample was separated in to four samples, in that 1050 mL of one milk sample was used for characterization and the analysis was carried in triplicate. The remaining three sample each of 9.5 L used for further process. The following unit operations were involved in the present study; Milk sample was preheated at 35 ± 1 °C for 10 min, filtered through muslin cloth of 45 µm, pasteurized at 75 °C for 15 s and homogenized at 17.23 and 3.44 MPa in I and II stages. Donkey milk was concentrated to increase the total solids content through rotary vacuum flash evaporator at a water bath temperature of 60 °C and 45 rpm. Total solids in the milk were measured using refractometer for every 30 min interval of initial run for 2 h and for every 15 min of interval. The total solids level was measured continuously till it reaches to desired level of total solids *i.e*., 20, 25 and 30% from 9.37% total solids. Concentration process was carried out for 3.5–4.0 h. Donkey milk has more water content, highly priced and considering concentration process is an expensive in terms of time and energy. So, these levels of milk total solids level were chosen.

Milk total solids of 20, 25 and 30% were fed to spray dried through two fluid flow nozzle atomizer having a diameter of 0.84 mm outlet, inlet/outlet air temperature of 160/85, 170/85 and 180/85 °C, feed flow rate of 0.5 $L.h^{-1}$, atomization pressure of 1.75 $kg.cm^{-2}$ and blower speed of 2100 rpm. Nine samples of powder were collected in aluminium foil laminated polyethylene (AFLP) packaging material kept in desiccators at 30 ± 1 °C and its quality parameters such as proximate composition, functional and reconstitutional properties of donkey milk powder were determined as per AOAC and SOP. All the analysis was carried in triplicate.

Characterization of donkey milk

The moisture content was determined by hot air oven method No.990.20, fat by the Gerber method No.2000.18, protein by Kjeldahl's method No.991.20, total ash by muffle furnace method No.925.23 (AOAC, 2005) and lactose by difference method No.1656 (IS, 1997) using the following expression.

$$\text{Lactose } (\%) = 100 - (\text{moisture content} + \text{fat} + \text{protein} + \text{ash}) \quad (1)$$

Characterization of donkey milk powder

The moisture content and total fat was determined using gravimetric and Gerber method No.925.10 and 2000.18 (AOAC, 2016). Protein and total ash in sample was estimated by Kjeldahl's and muffle furnace method No.930.29 and 930.30 (AOAC, 2005). Lactose by difference method No.1656 (IS, 1997) as mentioned in equation No. 1.

Functional properties

Functional properties such as colour, water activity, loose bulk density, tapped bulk density, Hausner ratio (HR), Carr's index (CI) and heat utilization efficiency of spray dried donkey milk powder were determined at using different independent variables (Inlet air temperature and concentrated milk feed) standard procedures as explained below.

Colour

Hunter lab colourimeter (Model: Colour Flex EZ; sample function CIELAB scale D65/10°) was used for determining the colour value L^* (black = 0, white = 100), a^* (redness > 0, greenness < 0 and b^* (yellowness > 0, blue < 0) for each sample (Pugliese et al. 2017). The browning index (BI) is defined as brown colour purity and is one of the most common indicators of browning in food products containing sugar. By using these coordinates, the browning index was calculated using the following equations (Ferrer et al. 2005).

$$\mathrm{BI} = \frac{100^*(\mathrm{x} - 0.31)}{0.17} \tag{2}$$

$$\mathrm{x} = \frac{(a * +1.75\mathrm{L}^*)}{(5.645L * +a * -0.301b *)} \tag{3}$$

where, BI is browning index and L^*, a^*, b^* are the colour coordinates determined by the colorimeter.

Water activity

The water activity (a_w) of the sample was measured at 30 °C room temperature using an Rotronic Hygro series 3 water activity meter Lab model HP23.

Bulk density

The bulk density of the sample at different treatment was measured according to the procedure described by Lebrun et al. (2012). The loose and tapped bulk density of milk powder was computed using the following formula:

$$\text{Loose bulk density } (\mathrm{g.cc}^{-1}) = \frac{\text{Weight of powder (g)}}{\text{Bulk powdered volume (cc)}} \tag{4}$$

$$\text{Tapped bulk density } (\mathrm{g.cc}^{-1}) = \frac{\text{Weight of powder (g)}}{\text{Tapped powdered volume (cc)}} \tag{5}$$

Flowability and cohesiveness

The spray dried donkey milk powder was evaluated for their flowability and cohesiveness in terms of Carr's index (CI) and Hausner ratio (HR), respectively and are calculated from the below mentioned equations.

$$Carr's\ index\ (\%) = \frac{Tapped\ bulk\ density\ (g.cc^{-1}) - Loose\ bulk\ density\ (g.cc^{-1})}{Tapped\ bulk\ density\ (g.cc^{-1})} \times 100 \tag{6}$$

$$\text{Hausner ratio} = \frac{\text{Tapped bulk density } (\mathrm{g.cc}^{-1})}{\text{Loose bulk density } (\mathrm{g.cc}^{-1})} \tag{7}$$

Computation of heat utilization efficiency (HUE) of spray dryer

Evaporation process cost is cheaper than spray drying of per kg of water in spray dryer. The HUE of spray dryer was computed using MATLAB software version 7.8.0.347 (R2009a) with following considerations;

Heat utilization efficiency of spray dryer =

$$\eta = \frac{\text{Amount of heat energy utilized by liquid droplets spraying}}{\text{Amount of heat energy supplied to ambient air}}$$

$$\eta = \frac{M_w \lambda_{Tw}}{M_a(H_{Tx} - H_{Ta})} \tag{8}$$

where,

M_w = Water evaporation rate, kg water.s^{-1}.

λ_{Tw} = Latent heat of water evaporation at the wet bulb temperature of mixed air, J. kg water^{-1}.

M_a = Net mass flow rate of air leaving dryer, kg.s^{-1}.

H_{Tx} = Enthalpy of heated air, J. kg dry air^{-1}.

H_{Ta} = Enthalpy of ambient air, J. kg dry air^{-1}.

Reconstitution properties

Solubility of the donkey milk powder was determined according to the method reported by Zhang et al. (2013). Wettability of the powder sample was measured according to the method reported by Jinapong et al. (2008). The dispersibility of donkey milk powder was measured according to the method reported by, Fonseca et al. (2011).

Particle morphology and elemental conformation

The surface morphology, structural orientation and conformation of the elements in donkey milk powder done by attaching them to a double-sided adhesive carbon tab mounted on scanning electron microscope (SEM) stubs. Excessive powder at the surface of the stub was removed by directing compressed air. The sample was coated with gold palladium and examined with microscope operating at an accelerating voltage of 1 to 30 kV, a pressure of 10 to 3000 Pa and enlargement of < 7 to 1000000x. The obtained images were loaded in to Inca-software (Oxford, 7ROJ6VOT) and confirmed the elements present in the donkey milk powder (Pazos et al. 2013 and Linna et al. 2014).

Experimental design

The experimental design was done with the aid of the Design-Expert software version 7.7.0 by selecting FCRD. Test of statistical significance was performed on the total error criteria, with a confidence interval of 95%.The significant terms in the model were found by analysis of variance (ANOVA) for each response. The effects of milk concentration and inlet air temperature (Independent variables) on the proximate composition, functional and reconstitution properties (Dependent variables) of the spray dried donkey milk powder were carried out in triplicate.

Results and discussion

Physico-chemical properties of small grey donkey milk and donkey milk powder

The mean physico-chemical properties of donkey milk and powder are presented in Table 1. Fat, protein, ash, lactose content were higher in donkey milk powder compared to donkey milk sample it is due to increase of total solids in the powder and water content in the donkey milk powder was decreased due to HTST process. The reported values could be correlated with the values reported by Li et al. 2018 and Polidori et al. 2019. The differences of reported values compared to present value due to variation of milk concentration and different processing conditions used and also drying technique.

Effect of concentration and inlet air temperature on functional properties of spray dried donkey milk powder

Colour is an important property for product acceptability. Colour of milk powder is off white to yellow. It is evident from Table 2, the L^* values of donkey milk powder slightly decreased with increase in inlet air temperature significantly due to the greater intensity of browning reactions, whereas there was not much variation in L^* values of donkey milk powder with concentration. a^* and b^* value of donkey milk powder were significantly ($p < 0.05$) affected by the concentration as well as inlet air temperature, but lower variation was observed in b^* value with increase of concentration as well as inlet air temperature. The colour values of the present values were closer to skimmed milk powder than whole milk powder reported by Pugliese et al. 2017. The differences of colour values compared to the typical milk powder might be due to modification of the particles size, concentration of the particles and pigments, evaporation and drying, reported by Walstra et al. 2006.

The overall browning index calculated from L^* a^* b^* of donkey milk powder and it showed varied intensity of non-enzymatic browning reactions (maillard reactions). The browning index ranged from 2.29 to 1.65, presented in Table 2. Lower browning was observed in the donkey milk powder as increase of inlet air temperature and concentration it may be due to decrease of L^* value (Ding and Ling, 2014). Browning of donkey milk powder is favoured by higher temperatures and concentration level. Composition of donkey milk is a mixture of proteins and lactose which are expected to get involved in different stages of Maillard reactions during processing depending on the temperature and humidity of the system (Stanciuc et al. 2010).

Water activity (a_w) is an important index and affects the shelf-life of the product. Water activity decreased from 0.25 to 0.15 as inlet air temperature increased from 160 to 180 °C as well as milk concentration level from 20 to 30%, presented in Table 2. These results were consistent with other research findings of Seth et al. 2017.

Table 1 Physico-chemical properties of small grey donkey milk and small grey donkey milk powder

Fresh donkey milk	M.C (%)	Fat (%)	Protein (%)	Ash (%)	Lactose (%)	pH
	90.63 (w.b)	0.76	1.91	0.40	6.30	7.19
S.D	0.36	0.03	0.06	0.02	0.31	0.06
Donkey milk powder	4.12 (d.b)	5.97	22.84	4.64	62.43	-
S.D	0.02	0.14	0.04	0.13	0.19	-

*Significance level $P < 0.05$; M.C. = Moisture content; d.b. = Dry basis; S.D. = Standard deviation; No. of replications = 3

Table 2 Functional properties of spray dried Small grey donkey milk powder

Conc	Temp	Colour*				a_w*	LBD	TBD	HR*	CI	HUE
(%)	(°C)	L^*	a^*	b^*	BI		(g.mL^{-1})*	(g.mL^{-1})*		(%)*	(%)*
20	160	93.83	− 1.61	10.26	1.40	2.29	0.35	0.47	1.34	25.53	39.39
	170	92.65	− 1.47	10.15	1.30	2.22	0.34	0.45	1.32	24.44	36.60
	180	91.75	− 1.32	9.48	1.18	2.05	0.33	0.43	1.3	23.25	33.86
25	160	93.66	− 1.41	9.89	1.23	2.12	0.38	0.5	1.31	24	39.52
	170	92.44	− 1.38	9.7	1.22	2.11	0.36	0.47	1.3	23.4	37.21
	180	90.52	− 1.22	9.36	1.10	1.99	0.35	0.45	1.28	22.22	34.96
30	160	93.11	− 1.21	9.64	1.06	1.95	0.47	0.6	1.27	21.66	40.08
	170	91.97	− 1.17	8.84	1.04	1.86	0.44	0.55	1.25	20	37.82
	180	90.27	− 1.02	7.66	0.93	1.65	0.42	0.51	1.21	17.64	35.56
	S.D	0.070	0.017	0.094	0.087	0.001	0.005	0.009	0.014	0.886	0.309

*Significance level $P < 0.05$; BI = Browning index; a_w = Water activity; LBD = Loose bulk density; TBD = Tapped bulk density; HR = Hausner ratio; CI = Carr's index; No. of replications = 3 S.D. = Standard deviation; HUE = heat utilization efficiency

Loose bulk density and tapped bulk density of the sample ranged between 0.33 to 0.47 and 0.43 to 0.60 g.mL^{-1} presented in Table 2. The bulk density decreased as increase of inlet air temperature and increased as increase of concentration significantly ($p < 0.05$) due to skinning over or case-hardening of the droplets at the higher temperatures through rapid formation of dried layer at the droplet surface and particle size. Bulk density increased with increase in feed concentration due to the decrease of occluded air content, lead to decrease in particle volume, thus increasing particle density and bulk density reported by Goula and Adamopoulos, 2003. Similar results to the present values was reported by Sulieman et al. (2014) for camel milk powder as 0.40 and 0.52 g.mL^{-1} and Pugliese et al. (2017) for skimmed milk powder as 0.54 and 0.73 g.mL^{-1} and whole milk powder as 0.44 and 0.62 g.L^{-1}.

The Hauser ratio and the Carr index determine the flowability of the sample. Slightly similar flow characteristics were observed for all the processing conditions for the donkey milk powder in the present study. CI and HR values ranged from 17.64 to 25.53% and 1.21 to 1.34 presented in Table 2. The CI and HR values were decreased with increase in inlet air temperature as well as concentration it may be due to the reduction of particle size as well as increase of surface area per unit mass of powder reported by Fitzpatrick et al. 2004;

Kim et al. 2002. As compared to standard values for flowability reported by Lebrun (2012), powder with CI and HR values between 16 to 25% and 1.19 to 1.34 is treated as fair and possible. In the present study spray dried donkey milk powder has possible and fair flowability. These results were consistent with other study reported by Sulieman et al. 2014. As water content higher in powder, the product will be more cohesive and difficult to flow.

Drying is an energy intensive operation. HUE of the process was calculated using in MATLAB R2009a software. HUE of spray dryer was lower at 180 °C of inlet air temperature and 20% of concentrated milk feed, whereas the higher value was noted at 160 °C of inlet air temperature and 30% of concentration, presented in Table 2. In the present study, HUE of spray dryer decreased with increase in the inlet air temperature significantly due to the energy losses from the exhaust pipe of the dryer and thermal efficiency increased with increasing concentration due to rapid evaporation. Similar result to the present value was reported by reported by Bahnasawy et al. 2010.

Effect of concentration and inlet air temperature on reconstitution properties of spray dried donkey milk powder

Solubility values ranged from 97.09 to 99.13% presented in Table 3. Solubility of milk powder decreased as increase of inlet air temperature due to the formation of a network of cross-linked proteins at the surface. Similar result to the present study was revealed by Koc et al. (2012) and David et al. (2020). Wetting time ranged from 337.26 to 498.00 s presented in Table 3. Wetting time increased with increase of inlet air temperature significantly ($P < 0.05$) as well as concentration due to lower amount of residual moisture content at higher inlet air temperature and presence of free fat on the surface of the particles reported by Chegini and Taheri, 2013; Zbikowska and Zbikowski, 2006. Wetting time of whole milk powder was > 15 min reported by Kim et al. (2002).

Table 3 Reconstitution properties of spray dried small grey donkey milk powder

Milk Conc. (%)	Temp. (°C)	Solubility (%)*	Wettability (s) *	Dispersibility (%)*
20	160	99.13	337.26	88.34
	170	99.10	379.06	84.74
	180	98.87	412.00	78.89
25	160	98.78	362.05	88.68
	170	98.66	385.50	86.24
	180	98.23	453.02	83.84
30	160	98.48	371.60	90.80
	170	98.09	393.80	87.64
	180	97.09	498.00	84.91
	S.D	0.092	2.18	1.11

Conc. = Concentration; Temp. = Temperature; s: second; S.D. = Standard deviation

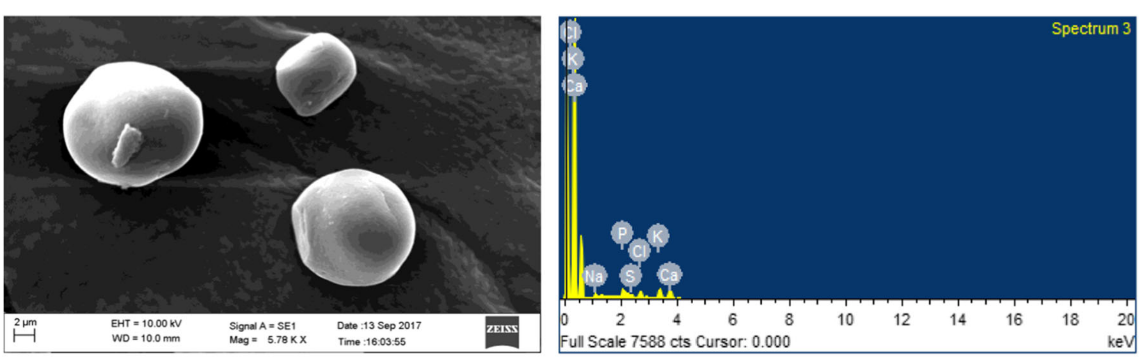
*Significance level $P < 0.05$; No of replications = 3

Dispersibility of the sample ranged from 83.84 to 90.80%, presented in Table 3. Dispersibility of the sample decreased significantly with increase in inlet air temperature. This could be linked to the exposed fat at the powder particle surface, which could limit the powder dispersibility in water (Zouari et al. 2020). Among the process parameters for donkey milk powder, 160, 170 and 180 °C of inlet air temperature and 20, 25 and 30% of milk concentration level, it was optimized at 170 °C of inlet air temperature and 30% concentration milk based on higher desirability value compared to other processing conditions based on maximum protein, ash, fat, lactose, L^*, a^*, density, HUE, solubility, dispersibility and minimum moisture, b^*, BI, Carr's Index, Hausner's ratio, wetting time properties of donkey milk powder.

Particle morphology and elemental confirmation of optimized spray dried donkey milk powder

The particle morphology and elemental confirmation of the sample was observed under a scanning electron microscope (SEM) and element detection sensor (EDS), presented in Fig. 1 a and b. The morphology and elements of the powder particles is affected by the nature of the feed concentration, degree of heat treatment, composition and processing parameters. From Fig. 1 a, it can be observed that the donkey milk powder particles with smaller vacuoles that have some of minute small minute particles entrapped on the surface. The visual observance observes slightly towards the spherical shape with smooth surface it might be due to surface covered by free fat. Borges et al. (2017) reported the similar results for buffalo milk powder. In the drying temperature, the droplets size produced by the atomizer nozzle is responsible for the smooth or wrinkled appearance of powder, since smaller droplets at higher temperatures allow faster evaporation of water, due to their larger surface area, thus inducing the formation of smoother surfaces reported by Kim et al., 2009.

From Fig. 1b, it can be observed that elemental composition of the spray dried donkey milk powder. The straight up y-axis shows the numeral of x-ray counts whereas the x-axis shows energy in kev. Na, P, S, Cl, K and Ca elements are abundant in the samples as 9.63, 11.58, 4.13, 17.35, 29.20 and 28.11 (% weight). Pazos et al.



(a) (b)

Fig. 1 **a** sample of SEM micrograph (5.78 K ×) **b** EDX spectra of the element distribution of optimized spray dried donkey milk powder

(2013) reported relatively lower values compared to the present study results for commercial whole milk and skim milk powder, it may be due to the compositional difference in milk.

Conclusion

Mean values of brightness (colour), water activity, loose bulk density and tapped bulk density of small grey donkey milk powder were 91.97, 0.18, 0.44 $g.cc^{-1}$, 0.55 $g.cc^{-1}$. Flow properties such as CI and HR improved significantly as increase of concentrated milk feeding as well as inlet air temperature and the mean value was 1.25 and 20.00% and these values indicates fair flowability in donkey milk powder. HUE increased as increase of concentrated milk fed and decreased as increase of inlet air temperature and the mean value of HUE of spray dried donkey milk powder was 37.82%. The mean values of solubility, wetting time and dispersibility of spray dried Small grey donkey milk powder were 98.09%, 393.80 s, 87.64%, respectively. The independent variables were optimized at 170/85 °C (inlet air temperature) and 30% (Concentrated milk feed) by FCRD, Design expert software statistical tool. Spray dried donkey milk powder was spherical in shape with smooth structured and the K and Ca were abundant in the product.

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Declarations

Conflict of interest Authors declares that no conflict of interest in the present study.

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