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RESEARCH ARTICLE

Biomass combustor based drying of beetroot

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ABSTRACT: Beetroot powder is used as natural food colourant for red colour. Beetroot were dried in a biomass combustor based dryer and quality parameter were assessed. Drying studies was performed using saw dust briquettes as fuel at different fuel consumption rate (1, 2, 3, 4 and 5 kg/h), air flow rate (100, 175, 250, 325 and 400 m^3/h) and slice thickness of beetroot (2, 3, 4, 5 and 6 mm). All the experiments were carried out using Central Composite Rotatable Design (CCRD) and Response Surface Methodology (RSM) as experimental statistical design. The maximum value of combustor efficiency, ascorbic acid and crude fibre content was found as 52.12%, 12.33 mg/100g and 11.02% while optimum value of drying time and dryer temperature was found as 392 min. and 63°C at 2 kg/h fuel consumption rate, 325 m^3/h air flow rate and 5 mm slice thickness of beetroot on the basis of optimized results using biomass combustor based drying system.

1. INTRODUCTION

Biomass is attracting great attention over the world as a source of renewable energy as well as an alternative to fossil fuels. It is the fourth primary energy sources after coal, oil and natural gas accounting for about 14% of the world's total energy supply (Demirbaş and Demirbaş, 2003). Biomass used as fuel for energy production in heating or electricity generating applications and important alternative for the rural sector. Though most biomass usage in the developing countries is in thermal applications, especially for cooking, the sector is increasingly modernizing to provide efficient secondary energy forms such as liquid fuels and electricity. The possibility of biomass is estimated at about 540 million tonnes per year covering residues from plantations, agriculture and forestry in India. Depending on the physical availability of biomass, it can be converted into solid, liquid and gaseous fuel. Biomass can be converted into energy via either thermo-chemical or biological processes, the latter consisting mainly of gasification, combustion and pyrolysis. Biomass is used to generate and supply heat directly or through steam, hot water and hot air in large numbers of small and medium industries of processing food and agricultural products. The biomass combustion systems and methods are not scientifically designed from the point of efficiency and minimization of emissions, mainly fly ash and smoke except modern sugar mills (Vyas *et al*., 2016).

Beta vulgaris L. commonly known as the red beet or beetroot is a biennial root vegetable grown all over the world and cultivated in loam, sandy loam, and clay loam soils. The yield of beetroot varies from 25 to 30 t/ha (Anonymous, 2018) and especially rich in fibre as well as in sugars, but has moderate caloric value. Beet - root deep red in colour is popular for human consumption and is consumed as raw, in the form of soups, salad as well as cooked with other vegetables. Beetroots are a rich source of vitamin C, potent antioxidants and nutrients, including magnesium, sodium, potassium, and betaine, which is important for the cardiovascular health, medicinal properties improving the digestion and blood quality and better handling beetroot juice can be converted into beetroot powder (Stintzing and Carle, 2004).

Drying is the major thermal energy consuming operation in agro processing industries. In many countries, large amount of food products are dried to improve shelf life, maintain nutritional value, reduce packaging costs, enhance appearance, retain original flavour and lower weights (Baysal *et al.*, 2003). Drying process plays an essential role in the preservation of agricultural produces (Waewsak *et al.*, 2006). Dried beetroot can be consumed in the form of chips, as a replacement for potato or corn

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flakes, rich in trans fatty acids, or after some preparation, also as an ingredient of instant food (Krejcova *et al*., 2007). Beetroot powder has a natural red colour and can be used as food colourant in salads, jams, jellies, deserts, ice creams, beverages and many nutraceuticals substituting artificial red colour (Azam, 2011).

Various drying methods are employed to dry different agricultural produces. The aroma is changed and colour becomes dark in open sun drying. Open sun drying system requires, large space and limited by the accessibility of sunshine and its period. The other energy sources are increasingly becoming more expensive and the supply of hydrocarbons is likely to become uncertain in the future it is important to give attention to the efficient use of biomass in an environment friendly way. With the development of skill for drying of food and agricultural produces supply of hot air at and controlled temperatures and reasonable cost and in measured quantity has become mainly essential.

The combustor was completely rebuilt and the heat exchanger was extended using additional piping with the same geometry. The primary air fans provided a vigorous combustion reaction and the secondary air fans for the complete combustion. A novel drying method, biomass combustor based drying, which has not yet been evaluated for the drying of beets with the help of renewable fuels, could create high quality powders/slices with minimal betaine loss. This research is discussed to develop beet root drying technology for enhancing the shelf life using biomass combustor based dryer system using biomass briquettes as a fuels through heat exchanger.

2. MATERIALS AND METHODS

2.1. Biomass Combustor and Dryer

2.1.1. Physical properties and proximate analysis of saw dust briquettes

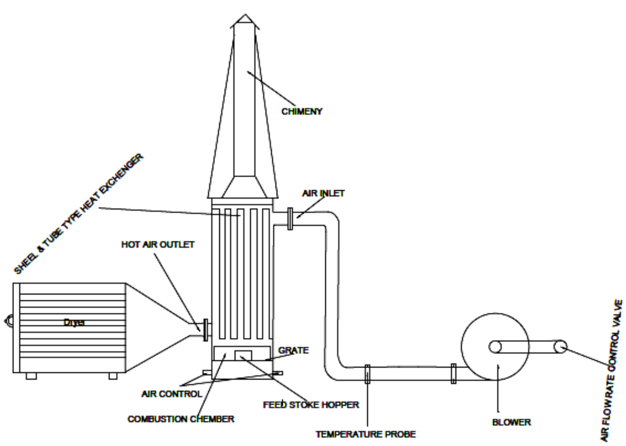
The saw dust briquettes were used as a fuel for biomass combustor. The physical properties (i.e. size and bulk density) and proximate analysis (i.e. moisture content, ash content, volatile matter and fixed carbon) were determined (ASTM, 1983) for saw dust briquettes used in biomass combustor. The calorific value of biomass was measured using advance bomb calorimeter.

2.1.2. Biomass combustor based drying system

The biomass combustor based drying system was designed and fabricated at Department of Renewable Energy Engineering, College of Agricultural Engineering & Technology (CAET), Anand Agricultural University, Godhra, Gujarat. It consists of fuel hopper, combustion chamber, grate for proper combustion of the combustible gas, heat exchanger, chimney, ambient air inlet, hot air outlet and tray dryer provided with 10 numbers of stainless steel trays having capacity of 100 kg/batch, retrofitted with biomass combustor (Fig. 1).

It is a small scale multi-chamber combustor with single pass shell and tube type heat exchanger made of a mild steel sheet. Flow of air with controlling valve is passing through a bottom of the grate to provide a good mixing with the gases from the combustion chamber. A centrifugal blower with the capacity of 100-500 m^3/h of air flow was used to draw the fresh air from the atmosphere. Microprocessor based orifice meter was used to measure

a. Photographic view



b. Schematic diagram of the biomass dryer

Fig. 1. Photographic view and schematics of biomass combustor based drying system.

air flow rate between outlet of the blower and inlet of the heat exchanger. A gate valve is provided at inlet of the blower for regulating the air flow rate for drying. A 16 channel temperature indicator was used to display the temperature using K type thermo couples with temperature range of 0 to 1200ºC at different location during the test. All the experiments were carried out using Central Composite Rotatable Design (CCRD) and Response Surface Methodology (RSM) as experimental statistical design having following independent and dependent variables.

Independent variables:	Dependent variables:
Slice thickness: 5 levels (2, 3, 4, 5 and 6 mm)	Combustor efficiency
Fuel consumption rate: 5 levels (1, 2, 3, 4 and 5 kg/h)	Inside dryer temperature
Air flow rate : 5 levels (100, 175, 250, 325 and 400 m^3/h)	Drying rate

A treatment combination for drying of beet root using biomass combustor based drying system is shown in Table 1. The different slice thickness of beetroot were spread in tray in single layer and kept for drying inside the dryer. Drying was carried out by keeping different air flow rate and fuel consumption rate. During experiment the observations like combustion zone temperature, exhaust gas temperature, inside dryer temperature and drying time were measured at 30 minutes interval.

In order to determine the thermal performance of biomass combustor, efficiency of biomass combustor (η) was calculated as below.

Input of the biomass combustor =

FCR, (kg /h) x CV, (kJ /kg) ...(1)

Where, FCR is fuel consumption rate, kg/h and CV is Calorific value of biomass, kJ/kg

Output of the biomass combustor =

AFR, (m^3 /h) x Cp, (kJ /kg °K) x ΔT (°K) ...(2)

Where, AFR is air flow rate of air, m^3/h, Cp is specific heat air (1.005 as water equivalent), kJ /kg ºK and ΔT is temperature difference of air (Hot air temperature – Ambient temperature), K.

Table 1.
Treatment combinations for drying of beet root using biomass combustor based drying system.

Treatment No.	Coded factor			Uncoded factor		
	Slice thickness, mm	Fuel consumption rate, kg/h	Air flow rate, m^3/h	Slice thickness, mm	Fuel consumption rate, kg/h	Air flow rate, m^3/h
1	-1.0	-1.0	-1.0	3.0	2.0	175.0
2	1.0	-1.0	-1.0	5.0	2.0	175.0
3	-1.0	1.0	-1.0	3.0	4.0	175.0
4	1.0	1.0	-1.0	5.0	4.0	175.0
5	-1.0	-1.0	1.0	3.0	2.0	325.0
6	1.0	-1.0	1.0	5.0	2.0	325.0
7	-1.0	1.0	1.0	3.0	4.0	325.0
8	1.0	1.0	1.0	5.0	4.0	325.0
9	-1.7	0.0	0.0	2.3	3.0	250.0
10	1.7	0.0	0.0	5.7	3.0	250.0
11	0.0	-1.7	0.0	4.0	1.3	250.0
12	0.0	1.7	0.0	4.0	4.7	250.0
13	0.0	0.0	-1.7	4.0	3.0	123.9
14	0.0	0.0	1.7	4.0	3.0	376.1
15	0.0	0.0	0.0	4.0	3.0	250.0
16	0.0	0.0	0.0	4.0	3.0	250.0
17	0.0	0.0	0.0	4.0	3.0	250.0
18	0.0	0.0	0.0	4.0	3.0	250.0
19	0.0	0.0	0.0	4.0	3.0	250.0
20	0.0	0.0	0.0	4.0	3.0	250.0

2.1.3. Sample preparation

Fresh beetroot were procured from local vegetable market of Godhra, Panchmahal district, Gujarat. Sound beetroots of uniform size and shape were randomly selected to maintain homogeneity. An adjustable stainless steel slicer was used for slicing of beetroot after peeling. Different slice thickness was maintained using an adjustable knob given beside the slicer. After slicing, different thickness of beetroot was measured using digital vernier caliper.

2.2. Quality Assessment of Dried Beetroot

2.2.1. Moisture content

The initial and final moisture content (MC) of beetroot is determined following the method D-3173-73, by drying the known weight of sample in hot air oven at 105 ± 2°C for 24 hours (ASTM, 1983) keeping the sample in petri-dish till the constant weight is achieved. The ratio of weight of moisture to the initial weight of the sample is the moisture content on wet basis while the ratio of weight of moisture to the final weight of the sample is the moisture content on dry basis.

2.2.2. Ash content

Oven-dried sample of beetroot taken in the silica crucible was placed in the muffle furnace at 750 ± 25 °C as procedure of D-3174-73, till constant weight is attained (ASTM, 1983). The ratio of the final weight to the initial weight of the sample is the ash content of the moisture free beetroot sample.

2.2.3. Protein content

A known quantity of sample (0.1 to 0.5 g) was extracted with 10 - 50 ml of 0.1N NaOH and placed in water bath for 6 h at 65°C. After cooling, centrifuged and made to desirable final volume (10 / 50 ml) with distilled water. Known aliquot and distilled water of 1 ml, 5 ml of alkaline copper reagent and 0.5 ml of folinciocalteau reagent were added rapidly and immediately. After 30 minutes, the absorbance at 660nm was measured. From the standard graph drawn by plotting concentration of the standard on the X- axis and absorbance on the Y-axis, the amount of protein present in the sample was calculated using following equation (Lowry *et al*., 1951).

$$\text{GF} = \frac{\text{Concentration of BSA stock solution (g)}}{\text{Optical density at 660 nm}} \qquad ...(3)$$

$$\text{Protein (\%)} = \frac{\text{GF x OD (Sample Reading)x Total Volume (ml)x 100 x } 10^{-6}}{\text{Sample Aliquot (ml) x weight of sample (g)}} \qquad ...(4)$$

2.2.4. Fat content

Fat content in samples is soluble in n-Hexane which was extracted from oven dried sample using a soxhlet extraction apparatus. The method reported by AOAC (2000) was used for this analysis. The percentage of fat in the sample was calculated as follows:

$$\text{Fat (\%)} = \frac{\text{weight of fat (g) x 100}}{\text{weight of sample (g)}} \qquad ...(5)$$

2.2.5. Crude fibre

Fibra plus instrument (Make: Pelican Equipment, Chennai) was used for estimation of crude fibre. About 2 g of the sample was treated with 1.25% H_2SO_4 followed by 1.25% NaOH and washed thoroughly with distilled water after each treatment. Neutral residue left over was dried weighed and ignited in a muffle furnace. From the loss in weight of the residue, the percentage of crude fibre was calculated using following formula given by Ranganna (2007).

$$\text{Crude fibre (\%)} = \frac{W2-W3}{W1} \text{ X } 100 \qquad ...(6)$$

Where, W_1 is weight of sample empty crucible, g, W_2 is weight of crucible and sample after washing and drying, g and W_3 is the eight of crucible and ash, g.

2.2.6. Ascorbic acid

The ascorbic acid content of the sample was determined by 2, 6- dichlorophenol indophenol visual titration method (Ranganna, 1986) using the following equation.

$$\text{Dye factor (mg)} = \frac{0.5}{v} \qquad ...(7)$$

$$\text{Ascorbic acid (mg/100g)} = \frac{(\text{dye factor} \times V_2 \times V_4 \times 100)}{(V_1 \times V_3)} \qquad ...(8)$$

Where, v is volume of dye solution required (titre), ml, V_1 is volume of sample extract taken for dye titration, ml, V_2 is Volume of the dye require (titre), ml, V_3 is volume of the sample taken for extraction with HPO_3 (Meta phosphoric acid), ml and V_4 is volume made up, ml.

2.2.7. Carbohydrate

Total carbohydrate content of the sample was estimated by subtracting the measured contents of protein, fat, ash and moisture from 100. The total carbohydrate content was determined using following calculation.

$$\text{Total carbohydrate (\%)} = 100 - (\text{protein} + \text{fat} + \text{ash} + \text{moisture}) \qquad ...(9)$$

Fig. 2. A view of the beetroot dried in a biomass combustor based drying system.

3. RESULTS AND DISCUSSION

3.1. Physical Properties and Proximate Analysis of Saw Dust Briquettes

The saw dust biomass briquettes were used in the biomass combustion. The properties of the briquetted determined as per standard (ASTM, 1983) and proximate analysis are shown in Table 2.

Table 2.
Physical properties and proximate analysis of saw dust briquettes.

Properties of biomass	Saw dust briquettes
Length, mm	9.05
Diameter, mm	36.45
Density, kg/m^3	570.28
Moisture content, (%,w.b.)	8.33
Ash Content (%, d.b.)	3.33
Volatile Matter (%, d.b.)	87.14
Fixed Carbon (%, d.b.)	9.53
Calorific Value, kJ/kg	17071

3.2. Biomass Combustor Based Drying System

Drying was carried out with 20 different combinations of independent variables given by RSM statistical design. The observations on weight loss were recorded at an interval of 30 minutes. All dependent variables and proximate characteristics of dried beetroot were measured for 20 combinations. Optimization was done on the basis of maximum value of combustor efficiency, crude fibre, ascorbic acid, protein and optimum value of drying temperature. Optimized results of independent variables i.e. 5 mm slice thickness, 2.0 kg/h fuel consumption rate and 325 m^3/h air flow rate was given to get maximum value of dependent variables after putting all the temperature and proximate characteristics data of dried beetroot in response surface quadratic model (Table 3). The design expert software of version 8.0.7.1 was used to run response surface quadratic model.

3.2.1. Combustor efficiency

The maximum combustor efficiency was found at 3 mm slice thickness, 2 kg/h fuel consumption rate and 325 m^3/h

Table 3.
Optimized results of proximate analysis and combustor data at all level of slice thickness, fuel consumption rate and air flow rate.

Solution No.	ST (mm)	FCR (kg/h)	AFR (m^3/h)	Combustor efficiency (%)	Dryer temp. (°C)	Drying time (min.)	Crude fibre (%)	Carbo hydrates (%)	Ascorbic acid (mg/100g)	Protein (%)	Fat (%)	Avg. drying rate (g/g,h)	Ash content (%)
1	5.00	2.01	325.0	52.12	63.17	391.8	11.02	72.17	12.33	3.33	1.32	1.28	15.32
2	5.00	2.05	325.0	51.55	63.59	387.2	10.97	72.31	12.23	3.24	1.32	1.30	15.03
3	5.00	2.01	322.6	51.64	63.19	393.8	11.00	72.21	12.36	3.35	1.33	1.27	15.14
4	3.00	2.00	325.0	52.45	61.17	328.7	10.45	76.79	10.46	1.98	1.18	1.65	17.41
5	3.00	2.01	325.0	52.26	61.28	327.4	10.44	76.82	10.44	1.96	1.18	1.66	17.46
6	3.00	2.00	322.1	51.83	61.13	330.4	10.44	76.73	10.50	2.01	1.19	1.65	17.39
7	3.00	2.09	325.0	51.03	62.04	318.3	10.36	77.02	10.29	1.85	1.18	1.73	17.11
8	3.00	2.36	325.0	47.28	64.61	290.3	10.10	77.61	9.84	1.54	1.17	1.96	17.52
9	3.00	2.15	304.9	46.16	62.36	323.3	10.22	76.81	10.46	1.98	1.25	1.74	17.06
10	3.58	2.00	324.6	50.29	55.96	367.1	10.45	74.80	9.53	2.65	1.24	1.29	16.66
11	3.88	2.20	325.0	47.02	57.13	358.1	10.28	74.55	9.08	2.55	1.26	1.33	16.53

ST- Slice thickness; FCR - Fuel consumption rate; AFR - Air flow rate.

air flow rate, while minimum combustor efficiency was observed at 4 mm slice thickness, 3 kg/h fuel consumption rate and 123.9 m^3/h air flow rate (Table 4). The model F value of 31.42 shows that the model is significant ($P<0.05$). R^2 and adjusted R^2 value of the model are 0.97 and 0.94, respectively. The F and P values for lack of fit are 0.16 and 0.97, respectively, indicate the lack of fit is not significant ($P<0.05$). The adequate precision value of 20.02 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of combustor efficiency for the further analysis.

$$\text{Combustor efficiency} = 62.17 - 18.9A - 14.8B + 0.13C + 0.11AB - 0.0035AC - 0.0452BC + 2.47A^2 + 3.45B^2 + 0.0003C^2 \quad ...(10)$$

Where, A is slice thickness, mm, B is fuel consumption rate, kg/h and C is air flow rate, m^3/h.

Analysis of variance of eq. (10) shows that F- value for linear terms of fuel consumption rate (FCR) and air flow rate (AFR) are 51.68 and 178.88 at p value of 0.0001, respectively, showing that both are significant terms ($P<0.05$). F-value for interaction terms of FCR with AFR is 13.77 at p value of 0.0040, indicating that the interaction terms is also significant ($P<0.05$).

The combustor efficiency decreased with increase in fuel consumption rate, while it increased with increase in air flow rate. But it shows no effect of change in slice thickness on combustor efficiency. Similar findings have been reported by Vyas *et al.* (2016) that the maximum and minimum biomass combustor efficiency for biomass briquette was observed 55.56 per cent in case of 300 m^3/h air flow rate and 1 kg/h fuel consumption rate and 29.57 per cent in case of 200 m^3/h air flow rate and 5 kg/h fuel consumption rate, respectively.

3.2.2. Dryer temperature

The maximum dryer temperature was found at 5 mm slice thickness, 4 kg/h fuel consumption rate and 175 m^3/h air flow rate, while minimum dryer temperature was observed at 4 mm slice thickness, 1.3 kg/h fuel consumption rate and 250 m^3/h air flow rate (Table 4).

The model F value of 44.81 shows that the model is significant ($P<0.05$). R^2 and adjusted R^2 value of the model

Table 4.
Average proximate analysis and combustor data at all level of slice thickness, fuel consumption rate and air flow rate.

Treatment No.	Combustor efficiency (%)	Dryer temperature (°C)	Drying time (min.)	Crude fibre (%)	Carbo hydrates (%)	Ascorbic acid (mg/100g)	Protein (%)	Fat (%)	Avg. drying rate (g/g,h)	Ash content (%)
1	25.15	68.23	360	10.49	78.54	11.10	1.84	1.49	1.53	10.41
2	26.24	73.44	450	10.44	81.78	12.50	3.69	1.30	1.19	7.47
3	22.55	83.00	180	10.22	78.74	9.87	2.68	1.20	2.38	9.59
4	23.83	93.00	240	9.73	83.94	8.33	1.13	1.08	1.75	11.64
5	52.12	61.08	330	10.30	76.74	11.10	1.53	1.07	1.58	17.37
6	51.88	64.00	375	10.78	74.04	11.72	2.73	1.19	1.30	15.79
7	35.70	82.00	180	9.69	75.62	8.33	1.35	0.99	3.59	17.15
8	36.17	87.22	225	9.84	75.70	8.33	1.59	0.92	2.79	18.87
9	34.17	83.43	180	9.70	82.47	11.72	1.70	1.21	2.96	10.09
10	35.15	91.50	330	10.05	76.12	14.80	0.71	1.45	1.93	16.50
11	46.78	51.58	525	11.29	67.97	11.10	6.43	1.58	1.05	9.12
12	28.04	87.44	240	9.12	82.49	8.02	0.90	0.90	2.08	10.46
13	17.42	82.36	285	9.13	81.11	5.55	2.41	1.13	1.58	10.83
14	46.93	67.30	270	10.30	78.15	7.40	1.13	1.17	1.95	9.45
15	28.80	66.58	315	9.45	75.94	8.63	1.79	1.31	1.54	7.97
16	28.03	66.58	315	9.51	75.41	7.40	2.70	1.35	1.45	7.01
17	30.47	70.83	315	9.45	77.35	8.63	1.97	1.31	1.74	6.33
18	29.00	69.50	315	9.21	77.52	9.87	1.72	1.37	1.66	6.33
19	24.53	64.67	315	9.48	76.71	8.02	1.78	1.34	1.57	6.64
20	21.44	63.00	315	9.36	79.86	7.40	2.22	1.35	1.70	4.55

are 0.98 and 0.95, respectively. The F and P values for lack of fit are 0.43 and 0.81, respectively, indicate the lack of fit is not significant (P<0.05). The adequate precision value of 24.27 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of dryer temperature for the further analysis.

$$\text{Dryer temperature} = 194.21 - 52.91A - 1.31B - 0.27C + 0.88AB - 0.02AC + 0.02BC + 6.98A^2 + 0.64B^2 + 0.0004C^2 \quad ...(11)$$

Where, A is slice thickness, mm, B is fuel consumption rate, kg/h and C is air flow rate, m^3/h.

Analysis of variance of eq. (11) shows that F- values for linear terms of slice thickness (ST), FCR and AFR are 16.35, 231.07 and 28.45 at p value of 0.0023, 0.0001 and 0.0003, respectively, showing that all three terms are significant (P<0.05). F-value for any interaction terms is not significant (P>0.05). The inside dryer temperature increased with increase in fuel consumption rate, while it decreased with increase in air flow rate. But it shows no effect of change in slice thickness on inside dryer temperature.

3.2.3. Drying time

The maximum drying time was found at 4 mm slice thickness, 1.3 kg/h fuel consumption rate and 250 m^3/h air flow rate, while minimum drying time was observed at 2.3 mm slice thickness, 3 kg/h fuel consumption rate and 250 m^3/h air flow rate (Table 4). The F value of the model, 44.81 indicates that the model is significant (P<0.05). R^2 and adjusted R^2 value of the model are 0.98 and 0.95, respectively. The adequate precision value of 24.27 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of drying time for the further analysis.

$$\text{Drying time} = 68.43 + 262.07A - 236.25B + 1.20C - 3.75AB - 0.10AC + 0.15BC - 23.72A^2 + 21.35B^2 - 0.0028C^2 \quad ...(12)$$

Analysis of variance of eq. (12) shows that F- values for linear terms of ST, FCR and AFR are 107.80, 608.26 and 9.38 at p value of 0.0001, 0.0001 and 0.0120, respectively, show that all three terms are significant terms (P<0.05). F-value for interaction terms of FCR with AFR is 6.15 at p value of 0.0325, indicating that interaction terms is also significant (P < 0.05). The drying time decreased with increase in fuel consumption rate, while it increased with increase in slice thickness. But it shows minor effect of change in air flow rate on drying time.

3.2.4. Average drying rate

The maximum average drying rate was found at 3 mm slice thickness, 4 kg/h fuel consumption rate and 325 m^3/h air flow rate, while minimum average drying rate was observed at 4 mm slice thickness, 1.3 kg/h fuel consumption rate and 250 m^3/h air flow rate (Table 4).

The model F value of 14.79 indicates that the model is significant (P<0.05). R^2 and adjusted R^2 value of the model are 0.93 and 0.87, respectively. The F and P values for lack of fit are 7.83 and 0.02, respectively, indicate the lack of fit is significant (P<0.05). The adequate precision value of 15.77 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of average drying rate for the further analysis.

$$\text{Average drying rate} = 7.44 - 2.41A + 0.03B - 0.01C - 0.10AB - 0.0001AC + 0.003BC + 0.31A^2 - 0.0007B^2 + 0.00001C^2 \quad ...(13)$$

Analysis of variance eq. (13) shows that F- value for linear terms of ST, FCR and AFR are 20.06, 61.44 and 12.78 at p value of 0.0012, 0.0001 and 0.0051, respectively, showing that all three terms are significant (P<0.05). F-value for interaction terms of FCR with AFR is 10.25 at p value of 0.0095, indicating that interaction terms is also significant (P < 0.05). The average drying rate increased with increase in fuel consumption rate and air flow rate, while it decreased with increase in slice thickness.

3.3. Quality of the Dried Beetroot

3.3.1. Crude fibre

The maximum crude fibre was found at 4 mm slice thickness, 1.3 kg/h fuel consumption rate and 250 m^3/h air flow rate, while minimum crude fibre was observed at 4 mm slice thickness, 4.7 kg/h fuel consumption rate and 250 m^3/h air flow rate (Table 4). The F value of the model, 5.57 shows that the model is significant (P<0.05). R^2 and adjusted R^2 value of the model are 0.83 and 0.68, respectively. The F and P values for lack of fit are 17.56 and 0.01, respectively, indicate the lack of fit is significant (P<0.05). The adequate precision value of 7.23 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of crude fibre for the further analysis.

$$\text{Crude fibre} = 18.26 - 1.84A - 1.80B - 0.02C - 0.09AB + 0.002AC - 0.0009BC + 0.21A^2 + 0.32B^2 + 0.00003C^2 \quad ...(14)$$

Analysis of variance of eq. (14) shows that F- value for linear terms of FCR is 25.41 at p value of 0.01, showing that the FCR is significant terms ($P<0.05$). F-value for any interaction terms is not significant ($P> 0.05$).

The crude fibre decreased with increase in fuel consumption rate, while it increased with increase in air flow rate. But it shows no effect of change in slice thickness on crude fibre.

3.3.2. Carbohydrate

The maximum carbohydrate was found at 5 mm slice thickness, 4 kg/h fuel consumption rate and 175 m^3/h air flow rate, while minimum carbohydrate was observed at 4 mm slice thickness, 1.3 kg/h fuel consumption rate and 250 m^3/h air flow rate (Table 4).

The model F value of 1.75 indicates that the model is not significant ($P>0.05$). R^2 and adjusted R^2 value of the model are 0.61 and 0.26, respectively. The F and P values for lack of fit are 6.94 and 0.03, respectively, indicate the lack of fit is significant ($P<0.05$). The adequate precision value of 5.45 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of carbohydrate for the further analysis.

$$\text{Carbohydrate} = 81.53 - 3.70A + 4.38B - 0.02C + 0.59AB - 0.02AC - 0.003BC + 0.77A^2 - 0.67B^2 + 0.0002C^2 \quad ...(15)$$

Analysis of variance eq. (15) shows that F- values for linear terms of FCR and AFR are 5.65 and 5.08 at p value of 0.039 and 0.048, respectively, showing that both are significant terms ($P<0.05$). F-value for any interaction terms is not significant ($P> 0.05$). The carbohydrate content increased with increase in fuel consumption rate, while it decreased with increased in air flow rate. But it shows no effect of change in slice thickness on carbohydrate.

3.3.3. Ascorbic acid

The maximum ascorbic acid was found at 5.7 mm slice thickness, 3 kg/h fuel consumption rate and 250 m^3/h air flow rate, while minimum ascorbic acid was observed at 4 mm slice thickness, 3 kg/h fuel consumption rate and 123.9 m^3/h air flow rate (Table 4). The model F value of 8.31 suggests that the model is significant ($P<0.05$). R^2 and adjusted R^2 value of the model are 0.88 and 0.78, respectively. The F and P values for lack of fit are 1.53 and 0.33, respectively, indicate the lack of fit is not significant ($P<0.05$). The adequate precision value of 10.20 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of ascorbic acid for the further analysis.

The ascorbic acid decreased with increase in fuel consumption rate, while it increased with increase in slice thickness. But it shows no effect of change in air flow rate on ascorbic acid.

$$\text{Ascorbic acid} = 32.04 - 13.04A - 2.14B + 0.05C - 0.44AB + 0.001AC - 0.001BC + 1.80A^2 + 0.50B^2 - 0.0001C^2 \quad ...(16)$$

Analysis of variance eq. (16) shows that F- value for linear terms of FCR is 18.56 at p value of 0.0015, showing that the FCR is significant terms ($P<0.05$). F-value for any interaction terms is not significant ($P > 0.05$).

3.3.4. Protein content

The maximum protein content was found at 4 mm slice thickness, 1.3 kg/h fuel consumption rate and 250 m^3/h air flow rate, while minimum protein content was observed at 5.7 mm slice thickness, 3 kg/h fuel consumption rate and 250 m^3/h air flow rate (Table 4).

The F value of 3.11 for model implies that the model is significant ($P<0.05$). R^2 and adjusted R^2 value of the model are 0.74 and 0.50, respectively. The F and P values for lack of fit are 9.89 and 0.01, respectively, indicate the lack of fit is significant ($P<0.05$). The adequate precision value of 7.27 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of protein content for the further analysis.

$$\text{Protein content} = -0.04 + 3.75A - 2.15B - 0.003C - 0.54AB + 0.002AC + 0.0006BC - 0.32A^2 + 0.54B^2 - 0.00002C^2 \quad ...(17)$$

Analysis of variance of eq. (17) shows that F- values for linear terms of FCR is 14.37 at p value of 0.0035, showing that the FCR is significant terms ($P<0.05$). F-value for any interaction terms is not significant ($P > 0.05$). The protein content decreased with increase in fuel consumption rate, air flow rate and slice thickness.

3.3.5. Fat content

The maximum fat content was found at 4 mm slice thickness, 1.3 kg/h fuel consumption rate and 250 m^3/h air flow rate, while minimum fat content was observed at 4 mm slice thickness, 4.7 kg/h fuel consumption rate and 250 m^3/h air flow rate (Table 4).

The model F value of 3.72 shows that the model is significant ($P<0.05$). R^2 and adjusted R^2 value of the model are 0.77 and 0.56, respectively. The F and P values for lack of fit are 55.41 and 0.01, respectively, indicate the lack of fit is significant ($P<0.05$). The adequate precision value of 5.74 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of fat content for the further analysis.

$$\text{Fat content} = 0.85 + 0.06A + 0.15B + 0.003C - 0.02AB + 0.0006AC + 0.0002\,BC - 0.02A^2 - 0.05B^2 + 0.00001C^2 \quad ...(18)$$

Analysis of variance eq. (18) shows that F- values for linear terms of FCR is 19.87 at p value of 0.0012, showing that the FCR is significant terms ($P<0.05$). F-value for any interaction terms is not significant ($P > 0.05$). The fat content decreased with increase in fuel consumption rate and air flow rate, while it increased with increase in slice thickness.

3.3.6. Ash content

The maximum ash content was found at 5 mm slice thickness, 4 kg/h fuel consumption rate and 325 m^3/h air flow rate, while minimum ash content was observed at 4 mm slice thickness, 3 kg/h fuel consumption rate and 250 m^3/h air flow rate (Table 4).

The F value, 2.98 indicates that the model is significant ($P<0.05$). R^2 and adjusted R^2 value of the model are 0.73 and 0.49, respectively. The F and P values for lack of fit are 13.76 and 0.01, respectively, indicate the lack of fit is significant ($P<0.05$). The adequate precision value of 4.98 indicates that the model can be used to predict the response within the design space as it is greater than 4.0. Considering the criteria, following response model was selected for representing the variation of ash content for the further analysis.

$$\text{Ash content} = 88.57 - 25.78A - 13.12B - 0.13C + 1.04AB + 0.002AC - 0.0008BC + 2.87A^2 + 1.63B^2 + 0.0003C^2 \quad ...(19)$$

Analysis of variance eq. (19) shows that F- values for linear terms of AFR is 6.04 at p value of 0.0338, showing that the AFR is significant terms ($P<0.05$). F-value for any interaction terms is not significant ($P> 0.05$). The ash content increased with increase in fuel consumption rate and air flow rate. For slice thickness, ash content decreased up to 4 mm slice thickness, while it increased from 4 to 6 mm slice thickness.

4. CONCLUSIONS

A biomass combustor based dryer was evaluated for drying of beetroot. Drying studies was performed using saw dust briquettes as fuel at different fuel consumption rate, air flow rate and slice thickness of beetroot. Quality parameters of the dried product were evaluated. The maximum value of combustor efficiency, ascorbic acid and crude fibre content was found as 52.12%, 12.33 mg/100g and 11.02 %. The optimum value of drying time and dryer temperature were found 392 min and 63 °C at 2 kg/h fuel consumption rate, 325 m^3/h air flow rate and 5 mm slice thickness of beetroots on the basis of optimized results using biomass combustor based drying system.

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