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Drying Characteristics of Bael Fruit (*Aegle marmelos*) Pulp in Mechanical Tray Dryer

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A B S T R A C T

Bael or *Aegle marmelos* is a spiritual, religious and medicinal plant. The pulp of the bael fruit contains many functional and bioactive compounds such as carotenoids, phenolics, alkaloids, coumarins, flavonoids, terpenoids and other antioxidants which may protect against chronic diseases. The pulp of bael fruit was extracted. The crude mass, containing seed, pulp and fibre was added with water having equal quantity, mixed and heated for 1 min at 80°C. pH was maintained with the help of citric acid solution. The mixture was passed through 20 mesh sieves to separate out the seeds to obtain pulp for drying purpose. Bael fruit pulp were dried in tray dryer at three drying temperatures *viz.* 55, 60 and 65°C and four thickness of pulp on the tray (2, 4, 6 and 8mm). The initial moisture content of sample was in the range of 74.49 per cent to 77.10 per cent (wb). Final moisture content ranges in between 6.86 – 9.96 per cent (wb) for dried bael fruit pulp. Maximum Average drying time was found at temperature 55^{o}C (8mm) of about 1020 min and minimum at 65^{o}C (2mm) was 480 min. Moisture reduction per hour was higher at initial stages and then started to decrease with drying time. It was observed that drying occurred completely in falling rate period and no constant rate period was observed at all drying temperatures. The moisture diffusivity varied in the range of 1.21 x 10^{-9} m²/s to 5.84 x 10^{-8} m²/s during drying.

Introduction

Bael (*Aegle marmelos*) is an indigenous fruit of India belongs to family Rutaceae and it is commonly known as Bengal quince (John and Stevenson, 1979), Bilva, Indian quince, Golden apple, Holy fruit, Bel,Sriphal, Stone apple and Maredo in India. It has tolerance to arid conditions (Chundawat, 1990) as well as high rainfall. The Bael tree has its origin from Eastern Ghats and central India. Bael fruit is a sub-tropical, deciduous tree and fruit is globuse with grey or yellowish hard woody shell. Inside this, there is soft yellow or orange coloured mucilaginous pulp with numerous seeds. It has numerous seeds, which are densely covered with fibrous hairs and are embedded in a thick, gluey and aromatic pulp (Kaushik *et al.*, 2008).

The production of bael in India is 0.08583 MT in 2015-16 (Anonymous, 2015) from some major production state *i.e.* Uttar Pradesh, Jharkhand, Uttaranchal, Orissa, Rajasthan, Madhya Pradesh, Chhattisgarh etc.

The pulp of fruit contains many functional and bioactive compounds such as carotenoids, phenolics, alkaloids, coumarins, flavonoids, terpenoids, and other antioxidants which may protect against chronic diseases (Anonymous 2012). The flavour is sweet, aromatic and pleasant, although tangy and slightly astringent in some varieties. It resembles a marmalade made, in part with citrus and in part with tamarind. Numerous hairy seeds are encapsulated in a slimy mucilage (Kundu *et al.,* 2014)

Bael (*Aegle marmelos)*is one of the most important minor fruit crops with medicinal and antioxidant properties grown in India from sea level to moderately high altitude. Fruit development stages (FDS) are associated with significant changes in carbohydrates, sugars and poly-phenol content. Bael contains appreciable amount of minerals like Ca, Mg, Fe and other elements which are very important for human health.

Bael powder can be stored for long time, if harvested at 4-8 months after fruit set (Kaur and Kalia, 2017). It is useful in the treatment of diabetic patients due to high contents of mucilage and secondary metabolites as coumarin and mamelosin (Prajapat *et al.*, 2012). Bael is also effective against cancer, cardiovascular diseases and ulcer. (Maity *et al.,* 2009)

Number of fruits, vegetables and medicinal plants are dried for their uses in the foods and medicines. The pulp of bael fruit contains many functional and bioactive compounds. Drying is a traditional process applied to food dewatering. If this pulp is dried to make powder then it will be useful in curing many diseases. Dried products and industrial applications require appropriate manufacturing procedures at the industrial level. No systematic methodology is reported so far made for getting a dried product from bael fruit. Therefore, the present study focuses to investigate the drying behaviour of bael fruit pulp and investigate a suitable drying.

Materials and Methods

The present investigation for developing the bael fruit pulp powder was carried out in the Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan. The various methods are used to predict various dependent variables such as drying time, drying rate, colour, water activity and ascorbic acid and finally the methodology used for quality evaluation of bael fruit pulp powder is also presented.

Fruit

The fruit may be round, oval, or oblong, 2 to 8 in (5-20 cm) in diameter, may have a thin, hard, woody shell or a more or less soft rind, gray-green until the fruit is fully ripe, when it turns yellowish. It is dotted with aromatic, minute oil glands.

Inside, there is a hard-central core and 8 to 20 faintly defined triangular segments, with thin, dark-orange walls, filled with aromatic, pale-orange, pasty, sweet, resinous, more or less astringent, pulp. Embedded in the pulp are 10 to 15 seeds, flattened-oblong, about 3/8 in (1 cm) long, bearing woolly hairs and each enclosed in a sac of adhesive, transparent mucilage that solidifies on drying. (Julia and Miami, 1987).

Raw Materials

Bael fruit (NB-5) will be used for this investigation. It will be procured from nearest local market of Udaipur. Decayed fruit were discarded.

Sample preparation

The fruit pulp was extracted according to the method adopted by Roy and Singh (1979). The crude mass (pulp + seeds + fibre) was added with equal quantity of water, mixed and heated for 1 min at 80°C while maintaining the pH 4.3 with the help of citric acid solution. The mixture was passed through 20 mesh sieves to obtain pulp for drying purpose.

Drying of bael fruit pulp

Before drying experiments, initial moisture content of the examples was determined. The initial moisture content of bael fruit pulp was 359.98% (db) and final moisture content of the finished product was about 30% (db). Three air-drying temperatures (55, 60 and 65°C) and four thickness of pulp on the tray (2, 4, 6 and 8 mm) were chosen to obtain the drying characteristics of bael fruit pulp. After the dryer reached at steady-state conditions for the set points (for 1 h), the pulp was distributed uniformly into the tray in all four thicknesses. Moisture loss was recorded at every 5 min interval for 20 min, 10 min interval for 80 min, 15 min interval for 60 min, 20 min interval for next 80 min and after that 1 hr interval until the constant weight was achieved. For measuring the weight of the sample during experimentation, the tray with sample was taken out of the drying chamber, weighed on the digital top pan balance and placed back into the chamber (within 15 s). The digital top pan balance was kept very close to the drying unit. Drying was continued until the moisture content of sample reached about 30-40% (db). The replications of experiments were taken. The dried samples were cooled at normal room temperature (25 ± 2°C) and packed in polyethylene bags and sealed.

The process flow chart used for development of bael fruit pulp powder is presented in Fig 1.

Measurement of Initial Moisture Content

The moisture content of the fresh bael fruit pulp was determined before drying by using hot air oven method. (AOAC, 2000)

$$\text{Moisture content (wb \%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

W1 = mass of original sample (g), W2 = mass of the sample after drying (g)

Drying Characteristics

Moisture content

The reduction in moisture content of bael fruit pulp was recorded at an interval of 5 min for first 20 min, then at an interval of 10 min for next 80 min, then 15 min for next 60 min, 20 min for another 80 min and afterwards 60 min interval till the end of drying process.

$$\text{Moisture Content (db)} = \frac{W_\theta - DM}{DM} \times 100$$

Where, W_θ=Weight of sample at time θ (g), DM = Dry matter of the sample (g)

Drying rate

The moisture content data recorded during experiments were analysed to determine the moisture lost from the samples in particular time interval. The drying rate of sample was calculated by following mass balance equation (Brooker *et al.*, 1974).

$$R = \frac{WML\ (kg)}{Time\ interval\ (min) \times DM\ (g)}$$

Where, R=Drying rate at time θ,g water/ g.min, WML=Initial weight of sample – Weight of sample after time θ

Moisture ratio

The moisture ratio was calculated by using the following equation:

$$Moisture\ ratio = \frac{M - M_e}{M_0 - M_e}$$

Where,

M = Moisture content at any specified time t (per cent db)
Me = Equilibrium moisture content (per cent db)
M_0 = Initial moisture content (per cent db)
M_e in comparison to M_0 and M is very small, hence M_e can be neglected and moisture ratio can be presented in simplified form (Doymaz, 2004; Goyal *et al.*, 2007).

$$MR = \frac{M}{M_0}$$

Results and Discussion

Moisture loss of pulp as a function of drying time was very similar for all drying temperatures and drying thickness. In the starting of drying process, decrease in moisture content was faster, which is evident due to availability of high moisture initially. At initial stages moisture depletion per hour was higher and then started to decrease with drying time. These results are in good agreement with the earlier studies Meisami-asl and Rafiee (2009) for apple drying and Kumar *et al.*, (2011) for carrot pomace drying.

The moisture content of bael fruit pulp decreased exponentially with drying time under all drying conditions. The drying followed a typical trend of drying behavior for food materials as reported earlier by Singh, (2001). As the drying air temperature increased, the drying curves exhibited steeper slope indicating that the drying rate increased with increase in drying air temperature. This resulted into substantial decrease of drying time.

It can further be observed that the moisture content decreased at a faster rate for the samples having lesser thickness, which may be due to increase in thickness of inner layers of pulp resulting in lower moisture removal. It can be noted from Figure 2, 3, 4 and 5 that the drying times to reach the final moisture content for the fresh bael pulp sample were 300 – 780, 360 – 840, 400 – 960 and 480 - 1080 at temperatures of 55- 65°C for various thickness of 2, 4, 6 and 8 mm respectively. Obviously, within a certain temperature range (55–65°C), increasing drying temperature speeds up the drying process, thus shortens the drying time. Similar findings have been reported for fruit and vegetable products drying (Vergara *et al.*, 1997; Fenton and Kennedy, 1998; Ramaswamy, 2002; Wang *et al.*, 2007).

The drying time increased with the increase in thickness of drying layer, which is evident due to less exposed area available for evaporation per unit mass of pulp. The initial moisture content of sample 2mm after mixing water in raw pulp, citric acid was also added to maintaining the ph 4.5 and thin layer drying of 7 h was in the range of 74.49 to 76.59 (per cent, wb) and after drying up to (nearly) constant weight, the moisture content was reduced in the range of 6 to 10 per cent (wb) for different drying air temperatures.

The typical curves showing variation in moisture content with drying time of dried pulp for different air temperature.

The initial moisture content of sample having 2mm layer thickness was in the range of 314.17 per cent to 327.08 per cent (db). It can be seen from Fig2; it took nearly 780 min of drying to reduce the moisture content from 314.17 per cent to 10.04 per cent (db) when drying air temperature was 55^0 C.

Effect of temperature on drying rate curves of bael fruit pulp

The drying rate for the bael fruit pulp was estimated from the difference in its moisture weight in a known time interval and expressed as g of moisture evaporated per g of dry matter-min. The drying rate as a function of moisture content at different drying air temperature for bael fruit pulp with treatment in tray dryer is shown in Fig. 6 to 9. It can be seen that initially the drying rate was more and subsequently it reduced with drying time. It can also be seen that they follow typical drying rate curves. The maximum drying rate for 2mm layer thickness sample was observed at initial stage of drying 4.583, 4.192 and 3.401 g-water/ gdry matter-min, for 4mm layer thickness sample 4.781, 3.964 and 3.365 g-water/ g-dry matter-min, for 6mm layer thickness 3.393, 2.703 and 2.174 g-water/ g-dry matter-min and for 8 mm layer thickness 2.045, 1.840 and 1.584 g-water/ g-dry matter-min at 65, 60 and 55ºC of drying air temperature respectively. These drying rates continuously decreased with respect to time.

From the observation it can be seen that a constant rate-drying period was not found in drying curves. The entire drying process took place in the falling rate period; the curves typically demonstrated smooth diffusion controlled drying behaviour under all drying temperatures. Moreover, an important influence of air-drying temperature on drying rate could be observed in these curves. It is obvious from these curves that the drying rate was decreased with the increase in thickness and increased with the increase in temperature, so the highest values of drying rate were obtained during the experiment at 65ºC and 2mm thickness. These results are similar to the earlier studies outcomes of different vegetables (Akpinar, 2003; Doymaz *et al.,* 2010; Doymaz *et al.,* 2011).

A second order polynomial relationship was found to have fitted adequately to desirable variations in the drying rates with moisture content at all three experimental temperatures and is represented by equation 1:

$$Y = Ax^2 + B\,x + C \qquad 1$$

Where, Y is the rate of drying in g water evaporated per g dry matter-min. A, B and C are constants and x are the moisture content in g water per g of dry matter. It is also seen that the values of coefficient of correlation are more than 0.90 at all the process temperatures which shows the good correlation among the predicted and observed values.

Similar trend was also reported by various research workers for different food products such as for papaya by (Jain *et al.,* 2011).

Effect of temperature on moisture diffusivity

The moisture loss data from convective drying were analyzed and moisture ratios at various time intervals were determined. The ln (MR) was plotted with drying time in order to find out moisture diffusivity. The variation in ln (MR) with drying time has been presented in Fig. 10 to 13 for tray drying. The variation in ln (MR) with drying time for each case was found to be linear with inverse slope. The slope became steeper with increase in temperature level. Moisture diffusivities were calculated and from the slopes of these straight lines (Maskan *et al.*, 2002; Doymaz, 2004; Kadam *et al.*, 2011).

Table.1 Drying rate equation with respect to moisture content (% db)

Treatment	Temperature (˚C)	Equation	R^2
65°C	2	$y = 0.00004x^2 + 0.003x + 0.041$	0.987
	4	$y = 0.511x^2 - 0.243x + 0.294$	0.945
	6	$y = 0.280x^2 - 0.043x + 0.181$	0.937
	8	$y = 0.092x^2 + 0.272x + 0.079$	0.962
60°C	2	$y = 0.00006x^2 - 0.005x + 0.323$	0.981
	4	$y = 0.562x^2 - 0.707x + 0.331$	0.917
	6	$y = 0.284x^2 - 0.303x + 0.226$	0.931
	8	$y = 0.078x^2 + 0.249x + 0.041$	0.986
	2	$y = 0.00007x^2 - 0.011x + 0.594$	0.957
55°C	4	$y = 0.586x^2 - 0.858x + 0.340$	0.937
	6	$y = 0.194x^2 - 0.125x + 0.12$	0.924
	8	$y = 0.151x^2 - 0.02x + 0.083$	0.987

Table.2 Moisture diffusivity values for dried bael fruit pulp

Treatment	Drying temperature (˚C)	Regression equation	Diffusivity	R^2
	2	y = -0.009x - 0.137	3.65×10^{-9}	**0.992**
65°C	4	y = -0.012x + 0.188	1.94×10^{-8}	**0.978**
	6	y = -0.010x + 0.352	3.65×10^{-8}	**0.857**
	8	y = -0.009x + 0.372	5.84×10^{-8}	**0.883**
	2	y = -0.005x - 0.253	2.02×10^{-9}	**0.987**
	4	y = -0.007x +0.113	1.13×10^{-8}	**0.942**
60°C	6	y = -0.007x + 0.236	2.55×10^{-8}	**0.927**
	8	y = -0.006x + 0.173	3.89×10^{-8}	**0.931**
	2	y = -0.003x - 0.136	1.21×10^{-9}	**0.936**
55°C	4	y = -0.004x + 0.013	6.49×10^{-9}	**0.912**
	6	y = -0.004x + 0.080	1.46×10^{-8}	**0.938**
	8	**y = -0.004x + 0.093**	$\mathbf{2.59 \times10^{-8}}$	**0.994**

Fig.1 Flow chart for development of bael fruit pulp powder

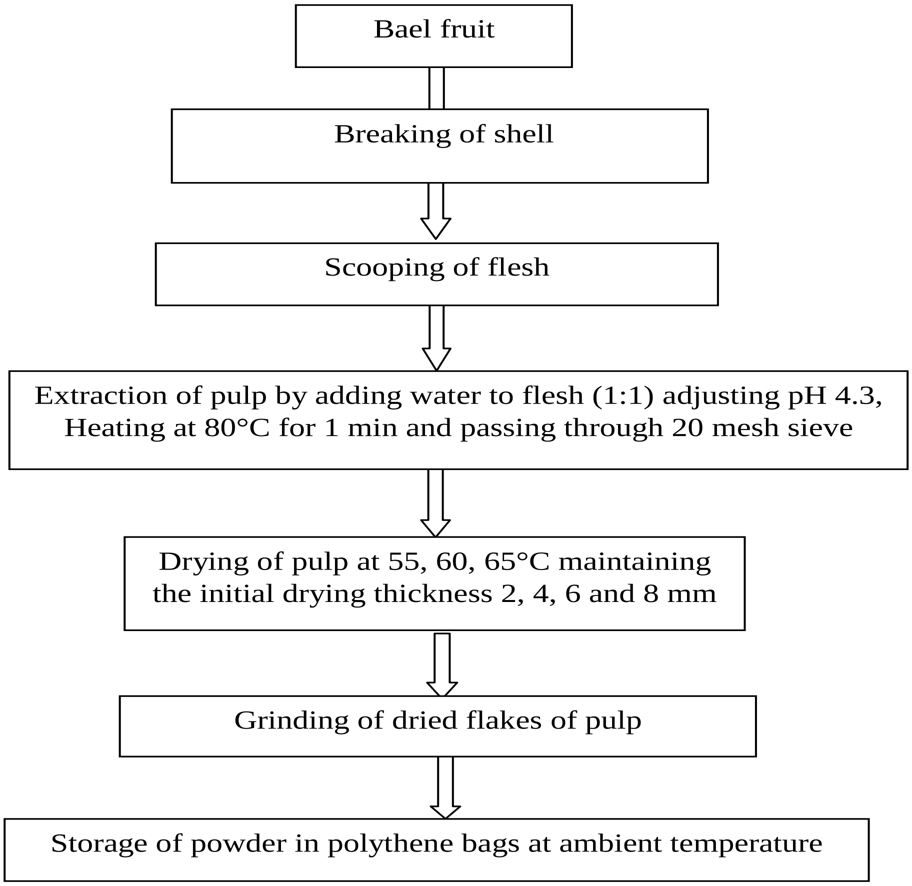


Fig.2 Drying curves of bael fruit pulp obtained for 2mm thickness at different air Temperature

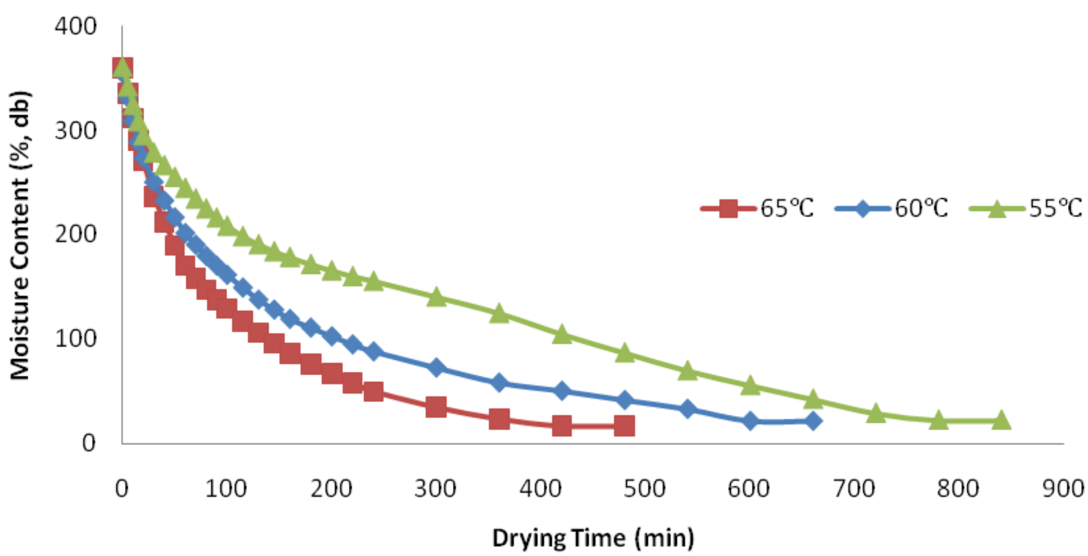


Fig.3 Drying curves of bael fruit pulp obtained for 4mm thickness at different air Temperature

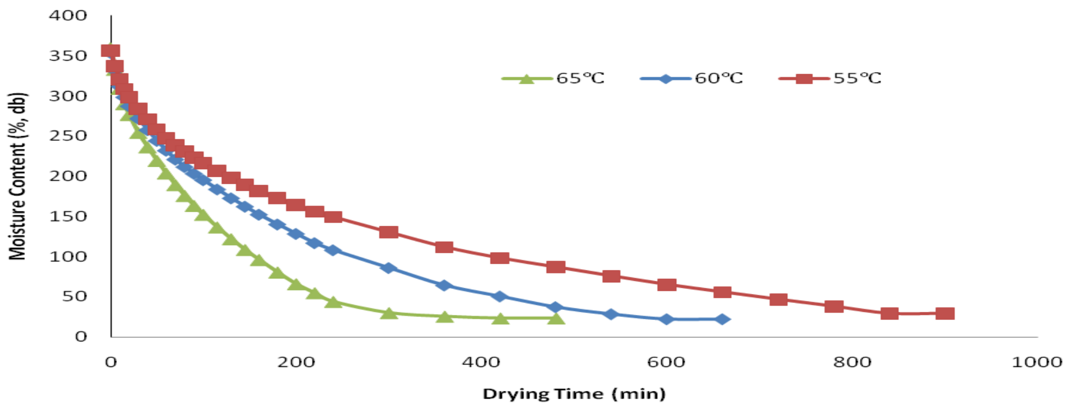


Fig.4 Drying curves of bael fruit pulp obtained for 6mm thickness at different air Temperature

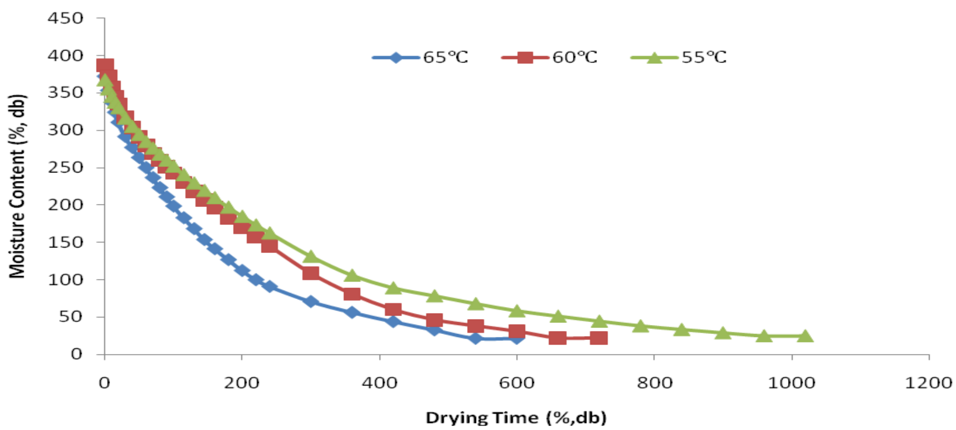


Fig.5 Drying curves of bael fruit pulp obtained for 8mm thickness at different air Temperature

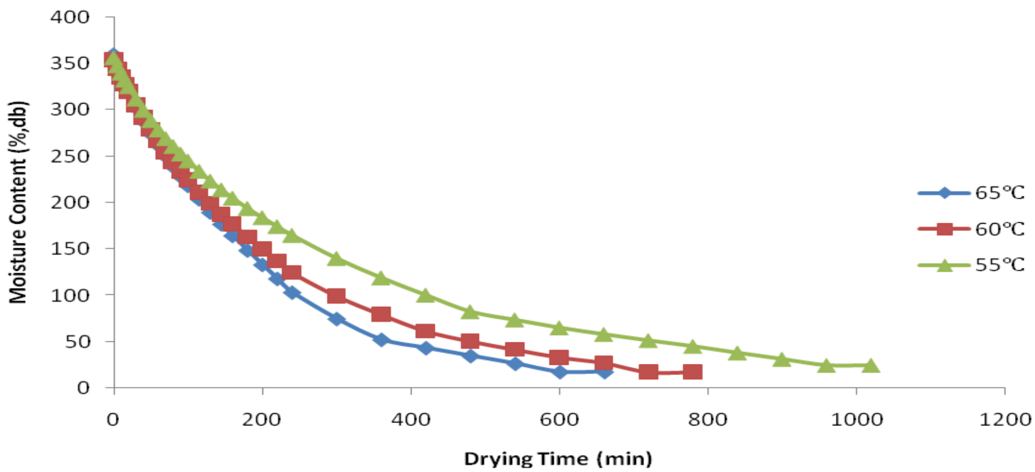


Fig.6 Drying rate curves of bael fruit pulp obtained for 2 mm thickness at different air Temperature

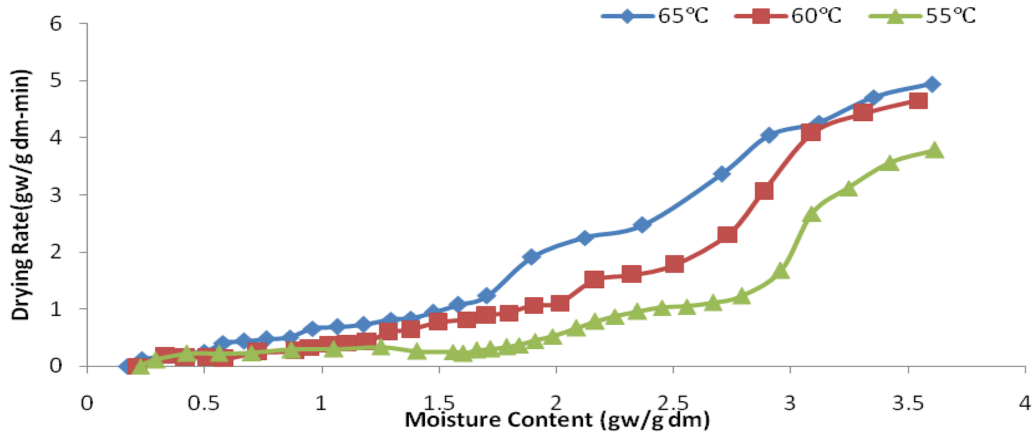


Fig.7 Drying rate curves of bael fruit pulp obtained for 4 mm thickness at different air Temperature

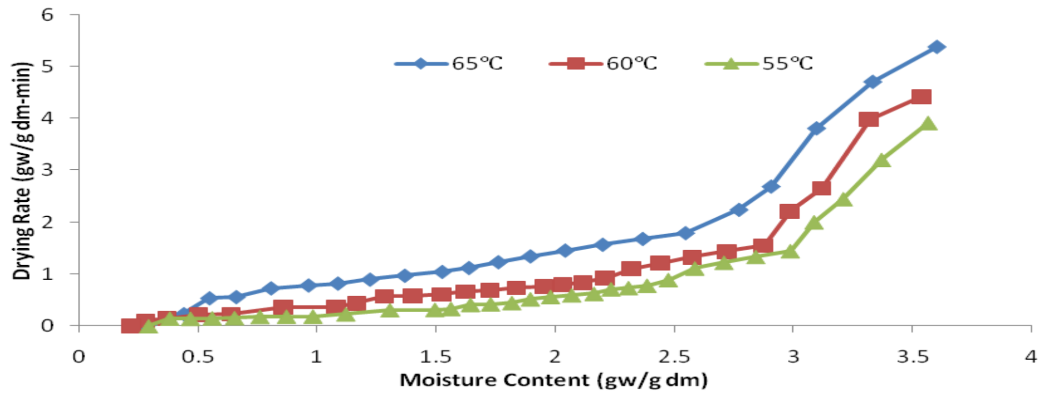


Fig.8 Drying rate curves of bael fruit pulp obtained for 6 mm thickness at different air Temperature

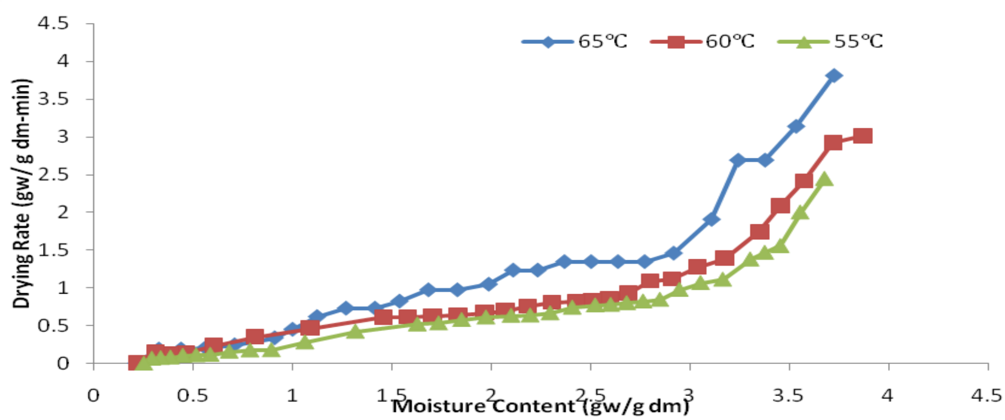


Fig.9 Drying rate curves of bael fruit pulp obtained for 8 mm thickness at different air Temperature

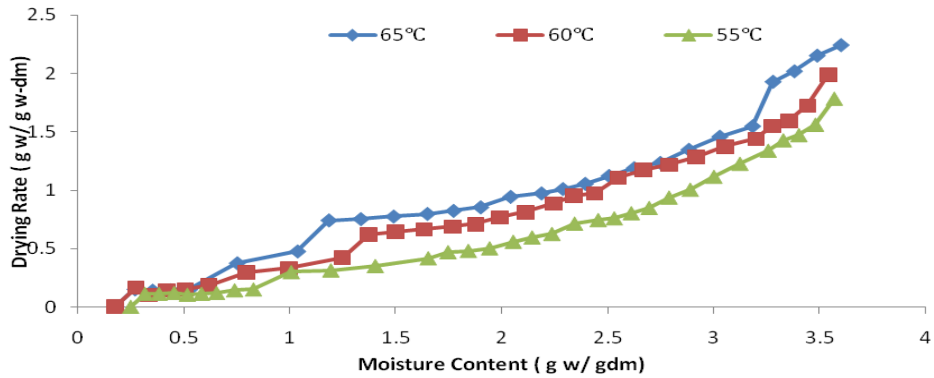


Fig.10 ln MR verses drying time for bael fruit pulp for 2 mm thickness at different air temperature

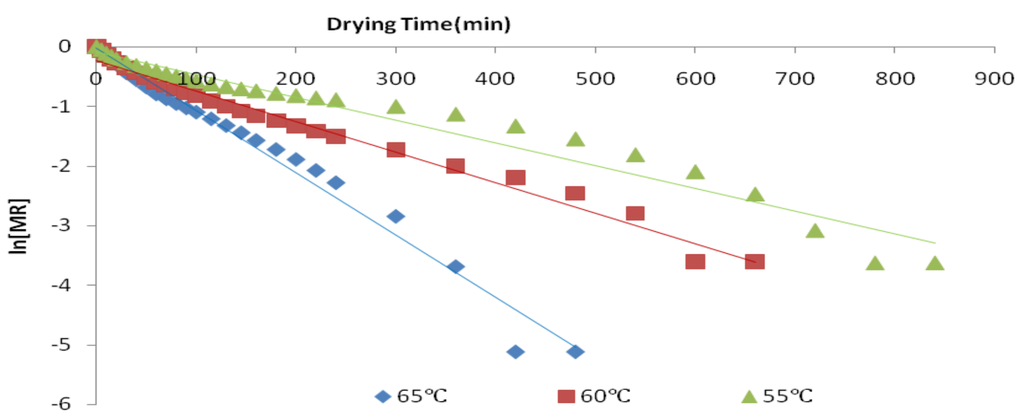


Fig.11 ln MR verses drying time for bael fruit pulp for 4 mm thickness at different air temperature

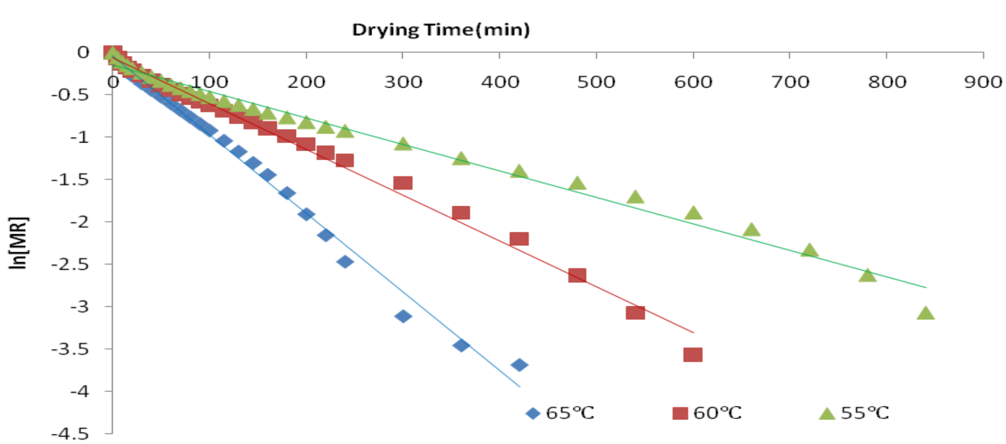


Fig.12 ln MR verses drying time for bael fruit pulp for 6 mm thickness at different air temperature

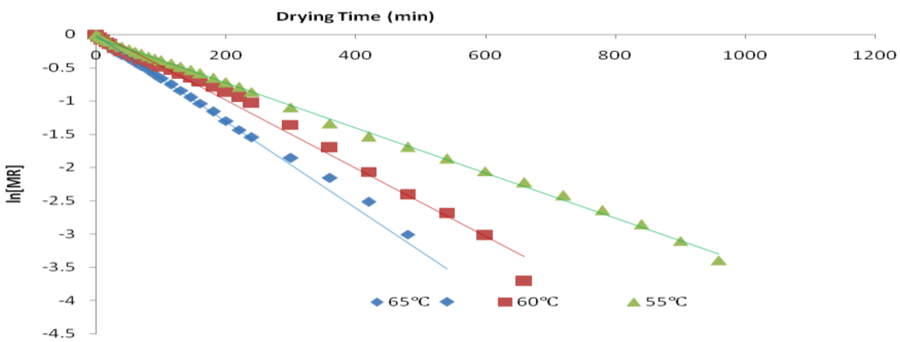


Fig.13 ln MR verses drying time for bael fruit pulp for 8 mm thickness at different air temperature

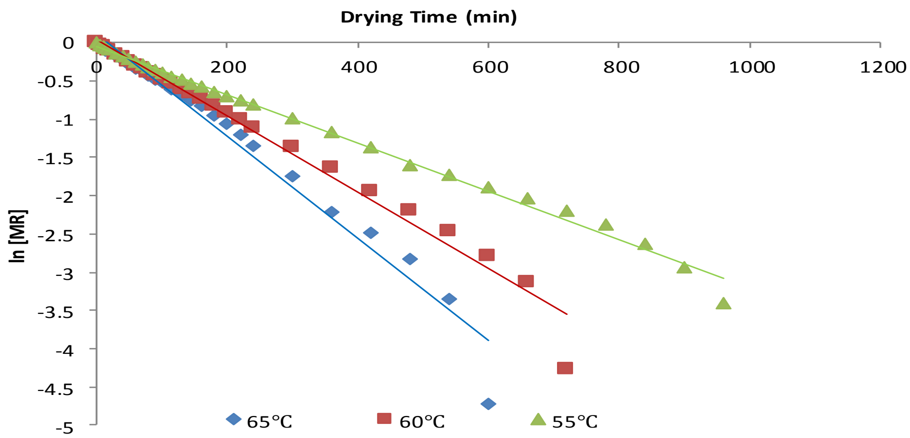
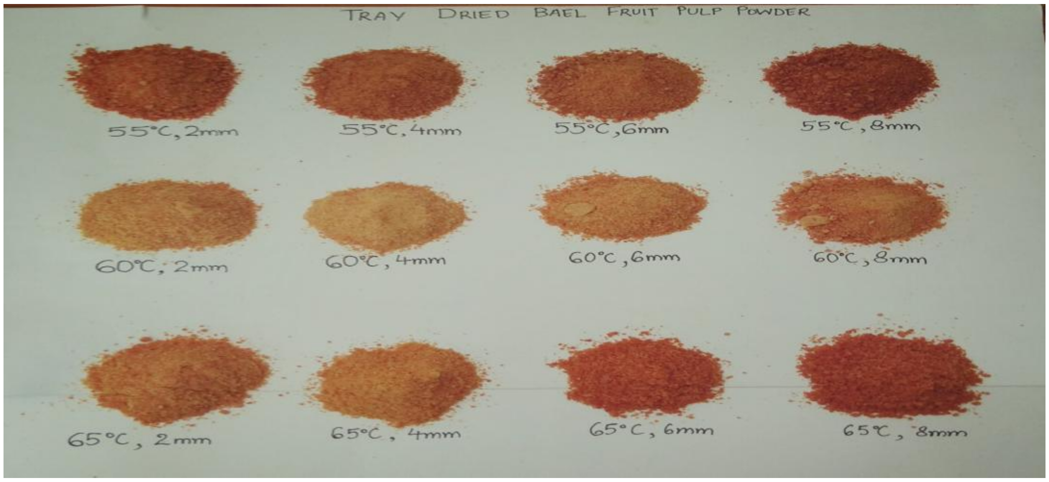


Plate.1 Dried bael fruit pulp powder



For bael fruit pulp the moisture diffusivity increased from 1.21×10^{-9} to 3.6×10^{-9} m^2/s as the drying air temperature increased from 55 to 65ºC for 2mm thickness of layer. moisture diffusivity increased from 6.49×10^{-9} to 1.94×10^{-8} m^2/s as the drying air temperature increased from 55 to 65ºC for 4mm thickness of layer and moisture diffusivity increased from 1.46 x 10^{-8} to 3.65 x 10^{-8} for 6mm and for 8mm. It increased from 2.59 x 10^{-8} to 5.84 x 10^{-8} at temperature increased from 55 to 65°C.

Tray dried bael fruit pulp powder

The initial moisture content of sample was in the range of 74.49 per cent to 77.10 per cent (wb). Final moisture content ranges in between 6.86 – 9.96 per cent (wb) for dried bael fruit pulp. Average drying time was found to be more at temperature 55^{o}C and 8mm thickness of about 1020 min, less time was found at temperature 65^{o}C and 2mm thickness of about 480 min. Moisture reduction per hour was higher at initial stages and then started to decrease with drying time. It was observed that drying occurred completely in falling rate period and no constant rate period was observed at all drying temperatures. The moisture diffusivity varied in the range of 1.21 x 10^{-9} m²/s to 5.84 x 10^{-8} m²/s during drying.

Among the range of variables taken for the convective drying of bael fruit pulp sample, sample which has thickness of 2mm at 60°C air temperature was found optimum in terms of response.

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