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Studies on the drying kinetics and quality assessment of banana pseudostem waste for effective utilization as a value added product

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ABSTRACT

The study was aimed at drying of pseudostem by different drying methods viz sun drying, solar polyhouse drying and cabinet drying at 50, 60 and 70°C. The changes in moisture content during drying were noted by recording the weight loss of the samples at every intermittent interval. The experimental data were fit to thin layer mathematical models and the goodness of fit was evaluated. Logarithmic model was found to give the best fit in terms of high coefficient of determination (R^2) and low chi-square value. The effect of drying on per cent shrinkage, colour and nutritional quality such as crude fibre and total ash was estimated. Time and temperature had a reasonable impact on the shrinkage value of the dried samples ($P < 0.05$). The quality parameters revealed that cabinet drying of banana centre core slices at 60°C resulted in better product by colour value, crude fibre and total ash.

Keywords: Pseudostem; drying; mathematical models; shrinkage; quality

INTRODUCTION

Banana is a tropical herbaceous plant; its stem is composed of concentric layers of leaf sheaths. It constitutes the fourth most important global food commodity grown in more than 100 countries (Abiodun-Solanke and Falade 2010). Each banana plant produces a single bunch of fruits. Apart from fruit it generates huge quantity of biomass as waste in the form of pseudostem, leaves, suckers etc and of these on an average about 60 to 80 tons/ha is pseudostem alone. The pseudostem is a clustered and cylindrical aggregation of leaf stalk bases. Banana pseudostem has been known as a potential cellulose source though usually discarded as agricultural waste in many countries. Banana fibre can be used as raw material in industries for production of a range of products like paper, cardboards, tea bags, currency notes and can be reinforced as polymer composite in high quality dress materials.

Central core is innermost tender portion of the pseudostem which is edible. About 10 to 12 tons/ha central core can be obtained in banana (Patil and Kolambe 2011). In many parts of India the pith or the tender core of the banana pseudostem has been used as food after boiling and the addition of spices. Banana stem can be cooked or consumed raw in juice form. The stem is cooked in various ways in south Indian cuisine and in some parts of West Bengal. It is a rich source of fibre and helps in weight loss. Its high fibre content creates a feeling of satisfaction and hence reduces the intake of food. It also helps to ease constipation. Banana stem is said to be a diuretic and helps to detoxify the body. It is used to prevent and treat kidney stones (Chandrasekaran 2012). The core of the stem is believed to be useful in stomach upset and diabetes. Hence this biomass wasted in the fields could be explored to be processed and used as a health supplement in food due to its high fibre content.

Drying is one of the most cost-effective ways of preserving foods of all varieties which involve removal of water by application of heat. A variety of food sub-types are preserved using drying which includes marine products, meat products as well as all fruits and vegetables. Fruits, vegetables and their products are dried to enhance storage stability, minimise packaging requirements and reduce transport weight (Sagar and Kumar 2010). To analyze the drying behaviour of a food product it is quite essential to study the drying kinetics of the food (Kadam et al 2011). The mathematical modeling of the drying processes and equipment allows design engineers to choose the most suitable operating conditions and then size the drying equipment and drying chamber accordingly to meet desired operating conditions. The principle of modeling is based on having a set of mathematical equations that can adequately characterize the system (Gunhan et al 2005).

Banana centre core mainly comprises of 90 per cent moisture and hence cannot be kept for a long period of time. It can be converted into flour which is used to prepare bakery products, soup etc. No much literature is available on the drying and kinetics of banana centre core. Hence in this study an attempt was made to dry banana centre core by different drying methods and to model the drying parameters using various mathematical models.

MATERIAL and METHODS

Sample preparation: Banana pseudostem of Nendran variety was procured from local market. The outer sheath of the banana pseudostem was peeled off manually using a knife and the central core alone was taken for the experiment. It was sliced using a stainless steel knife. Since it is much prone to enzymatic browning which needs to be arrested the size reduced samples were subjected to pre-treatment by soaking in a solution of 0.2 per cent concentration of potassium meta-bisulphite (KMS) for ten minutes in order to control browning.

Drying: During the study about 500 g sliced banana centre core was taken to analyse the drying behaviour of the samples under different drying methods and conditions. Experiments were carried out by sun drying, solar polyhouse drying and cabinet drying at 50, 60 and 70°C. The initial moisture content of the sample was observed by hot air oven method. During drying the samples were weighed at every half an hour interval and it was continued till they attained constant weight.

Equilibrium moisture content: Two gram of dried banana centre core slice was weighed and spread uniformly on Petri dishes. The Petri dishes were exposed to different relative humidity levels inside desiccators containing saturated solution of different salts having definite relative humidity levels. The gain in weight of the samples was recorded at every alternate day for 2 weeks till it attained equilibrium.

Equilibrium moisture content was determined at each relative humidity as below:

$$\text{Equilibrium Moisture Content (\%)} = \frac{W1 - W2}{W1} \times 100$$

where

W1= Initial weight of sample (g)
W2= Final weight after equilibration (g)

Mathematical modeling: In this study the moisture ratio (MR) and the drying rate of samples during the drying process were calculated using the following equations:

$$MR = \frac{Mt - Me}{M0 - Me}$$

$$\text{Drying rate} = \frac{Mt - Mt + dt}{dt}$$

where

MR, M_0, Me, Mt and Mt + dt are the moisture ratios, initial moisture content, equilibrium moisture content, moisture content at t and moisture content at t + dt (kg moisture/kg dry matter) respectively and t is drying time (min). To select the best model for describing the drying curve during drying process the thin layer drying equations in Table 1 were tested.

Table 1. Mathematical models for fitting drying kinetics of banana centre core slices

Model name	Model equation
Page	MR= exp $(-kt^n)$
Newton	MR= exp (-kt)
Logarithmic	MR= a exp (-kt) + c

The regression coefficient (R^2), the root mean square error (RMSE) and the mean square of the deviations between the experimental and calculated values for the models or chi-square were performed.

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre.i} - MR_{exp.i})^2\right]^{1/2}$$

$$\chi 2 = \frac{\sum_{i=1}^{N}(MRexp.i - MRexp.i)2}{N - n}$$

Quality parameters of dried samples

Shrinkage: For the sliced samples the diameter and thickness of the slice were measured using a 0.01 mm accuracy vernier caliper. These measurements were taken both before and after the drying of the samples. Based on the dimensions the initial and final volume was calculated to find the shrinkage per cent as below:

$$\text{Shrinkage} = \frac{v1 - v2}{v1} \times 100$$

where v1= Volume (before drying)

v2= Volume (after drying)

Estimation of color value: Color flex meter (Model: 45˚/0˚, M/s Hunter Lab, Reston, Virginia, USA) was used for the measurement of color.

Estimation of total ash: Total ash content of the dry pseudostem samples was determined by standard procedure IS: 1797-1985.

Crude fibre estimation: Crude fibre was estimated according to the standard procedure given by Sadasivam and Manickam (1992).

Statistical analysis: Statistical analysis was carried out to study the effect of different drying parameters on the independent variables. Analysis of variance (ANOVA) was conducted with completely randomized block design (CRD) using the statistical software AGRES.

RESULTS and DISCUSSION

Drying characteristics of banana center core using sun drying

The time taken to dry banana center core slices under sun from an initial moisture content of 1755.28 per cent (db) to 5.13 per cent (db) was about 810 min. Drying rate was initially high and it reached a maximum of 4.06 when dried for 150 minutes. Moisture content of sliced sample decreased steadily from 1755.28 to

1146.74 per cent with time. On continuous drying a slow and gradual decline in the moisture content was observed along with the drying rate. Initially drying rate was faster due to the presence of high moisture content and as the moisture content decreased the drying rate began to fall. The drying rate was 3.43 per cent initially at 30 minutes which reached beyond 4.06 per cent at about 150 minutes of drying (Fig 1). This finding is in agreement with the results of Latapi and Barrett (2006) under sun drying of tomato.

Drying characteristics of banana center core by solar polyhouse drying

The initial drying rate was fast (2.66 g/100 g) because of the presence of high moisture content and as the drying time increased the drying rate began to fall and it deceased to final drying rate of 1.98 g/100 g as seen in Fig 1. Similar result was observed for drying tomato, capsicum, carrot, cabbage, leafy vegetable and apple in solar polyhouse dryer which led to a considerable reduction in drying time and better quality dried products in terms of colour and pungency in comparison to products dried under the sun (Shahi et al 2011).

Drying characteristics of banana center core by cabinet drying

It took 360 minutes for drying banana center core slices from initial moisture content of 3821.56 per cent (db) to a final moisture content of 22.76 per cent (db). The drying process was faster when compared with sun and solar drying; the heat flow was uniform and constant during the process of drying as this drying was performed in a controlled condition. Fig 2 depicts that the initial drying rate was at its peak 28.66 g/100 g because of the presence of high moisture content and as the drying time increased the drying rate began to fall as the moisture content in the sample began to decrease at a final drying rate of 11.51 g/100 g. It shows that the drying time decreases substantially with the increase in temperature of the drying air. This can be explained by the increased heat transfer potential between the air and the center core slice enhancing the mass transfer within the sample and the evaporation of the water from its surface. Similar result was observed in mushroom drying (Argyropoulos et al 2008).

It took 180 minutes of drying to reach a moisture content of 14.67 per cent (db) from an initial value of 2749 per cent (db). The drying period was less when compared with the other previous process as the temperature was high. The initial drying rate was at its peak 22.81 g/100 g because of the presence of high moisture content and as the drying time increased the drying rate began to fall as the moisture content in the sample began to decrease at a final drying rate of 13.28 g/100 g (Fig 2). It was seen that for the drying at different temperatures the moisture loss increased with the increase in temperature (Faisal et al 2013).

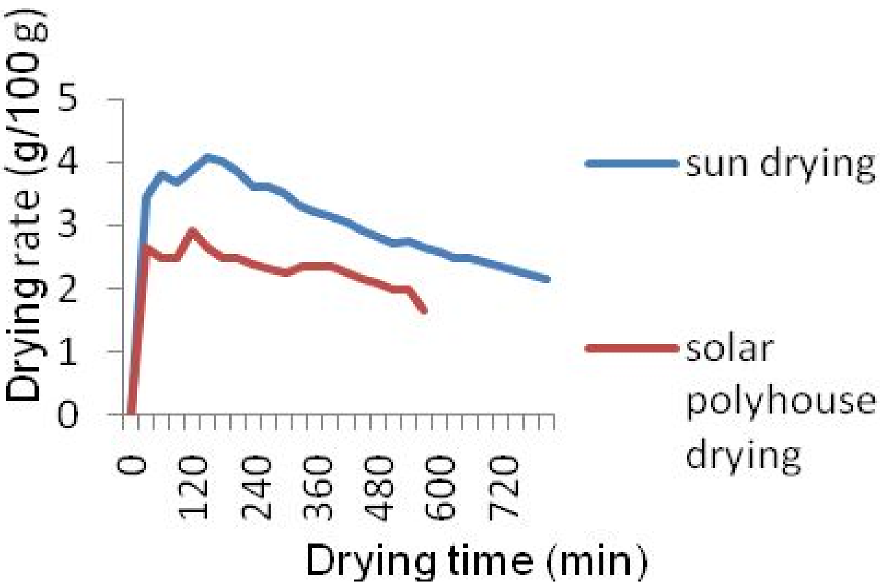

Fig 1. Effect of sun and solar drying on the drying behavior of banana centre core

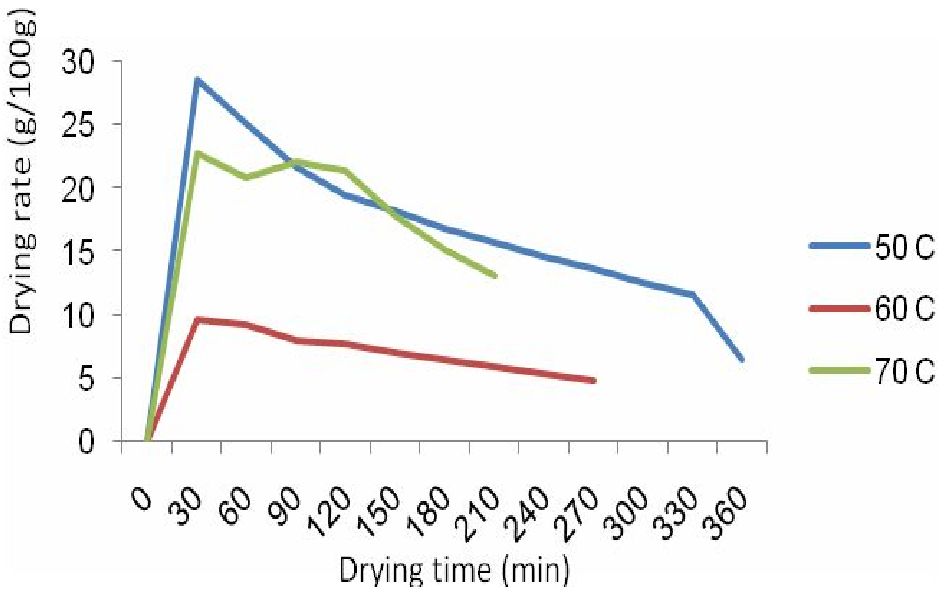

Fig 2. Effect of cabinet drying at different temperature on the drying behavior of banana centre core

Equilibrium moisture content (EMC) of dried banana center core samples

The equilibrium moisture content of sliced and dried banana center core was studied by exposing them to different salts at different relative humidity the results of which are presented in Table 2. Dried banana center core slice exposed to 53 per cent RH took 15 days to reach an EMC of 15.09 per cent (db) with no changes in appearance and color whereas it took 17 days to reach 16.32 per cent (db) EMC at 70 per cent RH.

Mathematical model

The experimental data during drying of banana centre core by different drying methods were fitted to the mathematical models and are presented in Table 3. The acceptability of models was based on high R^2, low chi-square and RMSE values.

As can be seen from the results generally high correlation coefficients are found for the drying models. Nevertheless the results have shown that the highest values of R square and the lowest values of chi-square and RMSE could be obtained with the Logarithmic model. Thus the Logarithmic model may be assumed to represent the drying behavior of dried banana center core slices.

Shrinkage (%) of banana center core slices during drying

An important physical change that occurs during food drying is the decrease in the outer surface of the product due to loss of water during drying. The shrinkage per cent of banana centre core slices based on the volumetric change was analysed and presented in Table 4.

Time and temperature have a reasonable impact on the value of the dried samples shrinkage ($P < 0.05$). From Table 4 the highest shrinkage percentage was observed in the solar dried slice and the lowest in the 60°C slice. Based on the statistical analysis sun dried slice and solar dried slice were considered to be the best treatments in case of shrinkage. This may be due to the effect of long duration of drying resulting in shrinkage of food material increasing with the amount of water being removed since more the water is removed the more contraction stresses are exerted on the material. Drying at 70°C exhibited lowest value of shrinkage due to quick drying. During fast drying processes the product surface dries much faster than its core. Non-volatile compounds migrate with the diffusing water and precipitate on the product's surface and form a crust that keeps the product dimensions thereafter. The drying time increases significantly as the slice increases. Similar results were observed for mushroom. The thinly sliced mushrooms dried faster compared to thick slices at all selected temperatures due to the decreased diffusion path for moisture migration within the sample (Argyropoulos et al 2008).

Table 2. Equilibrium moisture content of the dried banana center core samples

Sample	Name of salt	RH (%)	Days to reach equilibrium	% EMC (db)	Remarks
Slice	$Mg(NO_3)_2$	53	15	15.09	No colour change
	NaCl	70	17	16.32	Colour change with browning

Table 3. Drying model parameters for dried banana center core slices at different drying conditions

Drying treatment	Model name	Model equation	R^2	RMSE	Chi-square
Sun drying	Page	MR= $\exp(-kt^n)$	0.9947	0.022	0.000469
	Newton	MR= $\exp(-kt)$	0.9817	0.0411	0.00163
	Logarithmic	MR= $a\exp(-kt)+c$	0.99807	0.01059	0.000108
Solar drying	Page	MR= $\exp(-kt^n)$	0.9889	0.0335	0.00106
	Newton	MR= $\exp(-kt)$	0.9526	0.0692	0.00456
	Logarithmic	MR= $a\exp(-kt)+c$	0.9959	0.0199	0.000375
50°C Cabinet drying	Page	MR= $\exp(-kt^n)$	0.9929	0.0274	0.00068
	Newton	MR= $\exp(-kt)$	0.9869	0.0372	0.00127
	Logarithmic	MR= $a\exp(-kt)+c$	0.9986	0.0117	0.000127
60°C Cabinet drying	Page	MR= $\exp(-kt^n)$	0.9826	0.16	0.0022
	Newton	MR= $\exp(-kt)$	0.9454	0.0918	0.00843
	Logarithmic	MR= $a\exp(-kt)+c$	0.9905	0.0383	0.0012
70°C Cabinet drying	Page	MR= $\exp(-kt^n)$	0.9946	0.025	0.0006
	Newton	MR= $\exp(-kt)$	0.9776	0.0524	0.00247
	Logarithmic	MR= $a\exp(-kt)+c$	0.9978	0.0158	0.000252

Table 4. Effect of drying on shrinkage percentage of banana center core slices $CD_{0.01}$

Drying treatment	Shrinkage percentage
Sun dried	93
Solar dried	94.09
50°C	90.15
60°C	79.12
70°C	65.43
SED	1.0124
$CD_{0.01}$	3.2088
$CD_{0.05}$	2.2558
CV (%)	1.47

Table 5. Changes in L, a and b value for banana center core slices during drying

Drying treatment	L	a	B
Sun dried	42.02	3.52	11.55
Solar dried	49.08	3.64	9.11
Tray dried 50°C	50.64	2.58	12.4
Tray dried 60°C	57.04	2.4	9.51
Tray dried 70°C	53.91	1.36	12.62

Each value is a mean of three replications

Effect of drying on color of banana center core

The 'L' value indicates the difference between lightness and darkness where a low number (0-50) indicates dark and a higher number (51-100) indicates light color. It was observed from Table 5 that the 'L' value was highest in the cabinet dried sample at 60°C and the least in the sun dried sample.

Changes in quality of banana center core during drying

From the Table 6 it can be observed that the crude fibre content was more at 60°C followed by 70°C. This may be due to higher yield of dry matter at higher temperature. In the case of total ash content of the samples 50°C drying resulted in higher value. Quality analysis of dried banana center core slices revealed that 60°C tray dried samples were the best. It can be seen from the table that the crude fiber content was highest in the 60°C dried samples whereas it was less at lesser temperature of drying. In the case of total ash content it was more at 50°C drying temperature and on par with the sample dried at 50°C.

Table 6. Changes in quality of banana center core slices

Drying treatment	Crude fiber (%)	Ash (g)
Sun dried	20	0.27
Solar dried	22	0.31
Tray dried 50°C	23	0.5
Tray dried 60°C	28	0.48
Tray dried 70°C	26	0.33
SED	1.0715	0.0071
$CD_{0.01}$	3.5955	0.0224
$CD_{0.05}$	2.4710	0.0158
CV (%)	3.57	2.31

CONCLUSION

Drying of banana centre core slices took 210-800 min drying time based on the different methods and temperature of drying from an initial moisture content of 460 per cent (db) to a final moisture content of 5 per cent (db). Among the models for studying the drying kinetics of banana centre core Logarithmic model gave the best fit based on high R^2 value. Shrinkage percentage was found to be on the higher side for sun dried samples whereas cabinet drying at 60 and 70°C retained the shape as seen from lower shrinkage percentage. The quality of cabinet dried sample at 60°C was found to be better in terms of colour, crude fibre and total ash estimated.

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