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An Experimental Study on Drying Kinetics of Guava Fruit *(*Psidium Guajava L*)* By Thin Layer Drying

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Abstract: *The thin layer drying behavior of Psidium guajava L (guava fruit) cultivar Rayalaseema area AP, India, were studied experimentally to examine the influence of drying air temperature, slice thickness, and air velocity on the drying curves. Drying operation was carried out at 55°C, 60°C and 65°C temperatures, at slice thickness of 2.5 mm, 4 mm and 6 mm at 1 and 1.5 m/sec velocities. The predominant falling rate drying regime was observed. The analysis reveals that, the drying temperature and slice thickness has a significant effect and velocity has a least effect on moisture removal. Drying rate is found to increase with the increase in air temperature and thus reduced the drying time. Drying time increases with increase in slice thickness. The various drying models in defining the suitability of drying behavior were examined by statistical analysis. The analysis reveals, that the Henderson and Pabis model is better model that explains the drying behavior of Guava Fruit (R^2=0.993).*

Keywords: *Guava fruit, Temperature, Velocity, Thickness, Drying kinetics*

I. Introduction

Guava (Psidium guajava L.) fruit is a member of Myrtaceae family believed to be originated in the Central America, Mexico [1] and grows in all subtropical areas. It is claimed to be the fourth most important fruit in terms of area and production after mango, banana and citrus. India is the major world producer of guava [2]. Guava is generally ovoid or pear shaped often marketed as "super-fruits" which has a considerable nutritional importance. The anti-oxidant virtue in guavas is believed to help reduce the risk of cancers of the stomach, esophagus, larynx, oral cavity and pancreas [3]. The vitamin C in guava makes absorption of vitamin E much more effective in reducing the oxidation of the LDL cholesterol and increasing the HDL cholesterol [4].

Drying is a complex process involving simultaneous heat and mass transfer under transient conditions which induces changes in the material during drying. The objective of dehydration is the removal of water to an optimum level at which microbial spoilage and deterioration reactions are greatly minimized. Understanding the Heat and Mass transfer in the material will help to improve drying process parameters and hence the quality. A number of internal and external parameters influence drying kinetics. External parameters include temperature, velocity and relative humidity of the drying medium (air) while internal parameters include density, porosity, absorption-de-absorption characteristics and thermo-physical properties of the material being dried. Drying phenomenon of agricultural products described by thin layer drying models is categorized as theoretical, semi theoretical and empirical [5]. Theoretical approaches take into account the internal resistance to moisture transfer. The semi theoretical and empirical approaches consider only the external resistance to moisture transfer between the product and air [6].

Modern methods for designing air drying operations require the mathematical description of food moisture movement during the process known as 'drying kinetics' [7]. Drying kinetics is generally evaluated experimentally by measuring the weight of a drying sample as a function of time [8]. Mathematical models of the drying process are used for designing new or improving existing drying systems and controlling the drying process [9]. Fick's second law of diffusion has been widely used to describe the drying process. Drying process can be described completely using the drying curves by means of different moisture ratio models that are widely used in most of the food and biological materials; namely, Henderson and Pabis, Page and Wang and Singh.

The Moisture content data on the dry basis at different temperature and velocities were converted in to more useful Moisture Ratio to normalize the curves. The diffusion of the moisture is described by the following moisture ratio equation [10].

$$\mathrm{MR} = \frac{\mathrm{Md_i} - \mathrm{Md_e}}{\mathrm{Md_o} - \mathrm{Md_e}}$$

Where: MR = Moisture Ratio
Md_i = Moisture content of the sample at any time t_i,
Md_e = Moisture content at equilibrium,
Md_o = Original or Initial Moisture content.

Drying Rate (RD_{di}) on mass basis (Instantaneous or any time) is given by

$$RD_{di} = \frac{m_{i-1} - m_i}{m_d \times (t_{i-1} - t_i)}$$

Where: m_i = Initial Mass (gms)
m_d = Final mass (gms)
t_i = Time (min)

The objectives of this study is to experimentally investigate the drying kinetics of Guava (Psidium guajava L.) fruit as a function of drying conditions:

1. To determine the influence of air temperature, velocity, and slice thickness on drying behavior.
2. To critically examine the suitability of thin layer drying models developed by Henderson and Pabis [11], Page [12], and Wang and Singh [13] for describing the drying process.

II. Materials And Methodology

Drying Equipment

Fig. 1 shows the schematic diagram of the Thin Layer Hot Air Dryer developed by Basavaraj et al., [14] for experimental work which ensured the control of the desired drying conditions over a wide range of operating parameters. The drier essentially consists of a drying chamber (0.31m x 0.30 x 0.36m) well lagged on all sides (glass wool covered with compressed wooly cloth 50mm thickness), with three aluminum trays placed one above the other (0.290m x 0.2504m x 0.009m), centrifugal blower and air duct with heating system inside the duct (500W x 4No), Air filters, a control panel with timer, digital temperature indicators, Relay indicator (Automatic). Air flow rate and sample mass were measured with vane probe anemometer **(**Model AM 4201 LT Lutson 0.4 – 30m/s) and Digital electronic balance (±0.1mg) respectively.

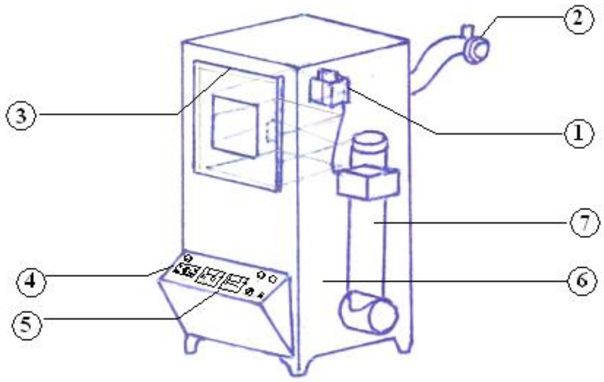

Fig. 1: Hot air dryer

Procedure

Fresh and well ripened guava fruit samples of slice thickness 2.5mm, 4mm and 6 mm weighing 19gms, 55gms, and 91gms (diameter of 30mm) respectively are placed in the 3 trays of the drying chamber and are equilibrated with room temperature. Prior to the drying experiments, the drier was run for about an hour to reach steady state conditions for the desired temperature levels of 55°C, 60°C and 65°C, of the drying air, using a relay to adjust the drying chamber temperature automatically. Air is allowed to flow horizontally at the set velocity over 3 perforated trays on which a known mass of samples were placed as thin layer. During drying process the tray was taken out at a 15 minutes interval to measure weight loss for the determination of drying curves. The drying process was continued and truncated when equilibrium moisture content(EMC) is reached. The dried sample slices were cooled and then packed in LDPE (low density polyethylene) bags that were heat sealed. All the drying experiments were carried in triplicate.

III. Results And Discussions

Drying Curves

Assay of Temperature, Velocity and Slice thickness are shown in the Figures 2, 3 and 4.

Effect of Temperature:

Fig. 2 reveals that, the moisture content (MC) decreases exponentially with increase in drying time. The rate of moisture loss was higher at higher temperatures, and the total drying time reduced substantially with the increase in air temp. Fig. shows that for a slice thickness of 6mm, velocity of 1.5 m/s, drying at 65^{o}C required 285 minutes, whereas 390 minutes required obtaining the EMC at 55^{o}C. The influence of drying temperature on drying rate was more significant because moisture diffusion from the core to the surface controlled the drying process and its drying rate depends mainly on temperature. this is in agreement with the earlier research or Similar observations have been reported in drying of various fruits and vegetables [15, 16].

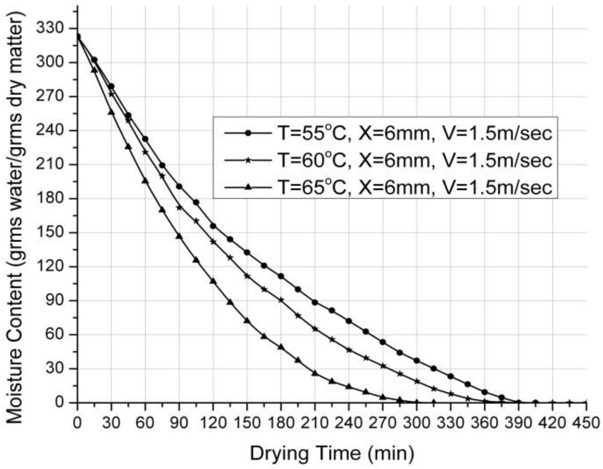

Fig. 2: Shows the effect of Temperature on the variation of the Moisture Content Vs Drying Time at 1.5 m/sec and slice thickness of 6 mm.

Effect of Velocity:

Fig. 3 shows changes in the moisture content with the drying time for two velocities at 65^{0}C, an increase in the velocity of drying air results in decrease in drying time due to increase in heat and mass transfer coefficients between the drying air and sample. From the fig, it is evident that air velocity has little effect on drying behavior of the sample [17].

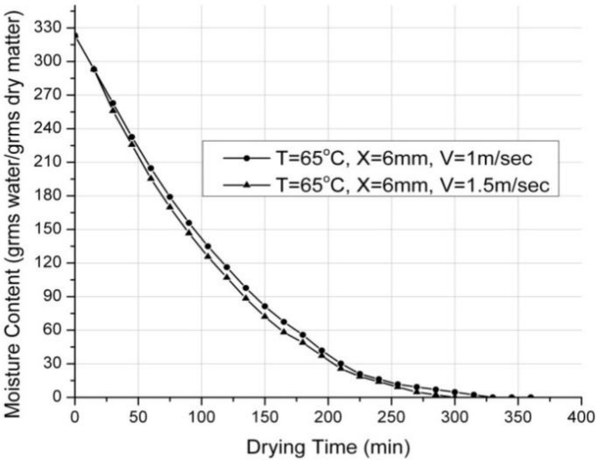

Fig. 3: Shows the effect of Velocity on the variation of the Moisture Content V/s Drying Time at Temperature 65^{o}C for Slice thickness of 6 mm.

Effect of Slice thickness:

Fig. 4 a, b and c shows that an increase in the slice thickness increases the total drying time. Comparing the slice thickness from 6mm to 4 mm for the constant values of temperature of 65^{o}C, and velocity of 1.5 m/s there is a decrease in the total drying time by 12.5% and further decrease in the slice thickness from 4.0mm to

2.5mm decreases the total drying time by 37.93%. The higher the sample thickness the longer will be the drying time.

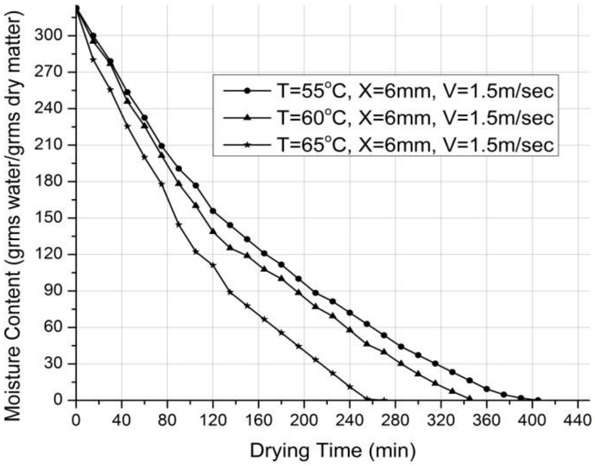

Fig. 4(a)

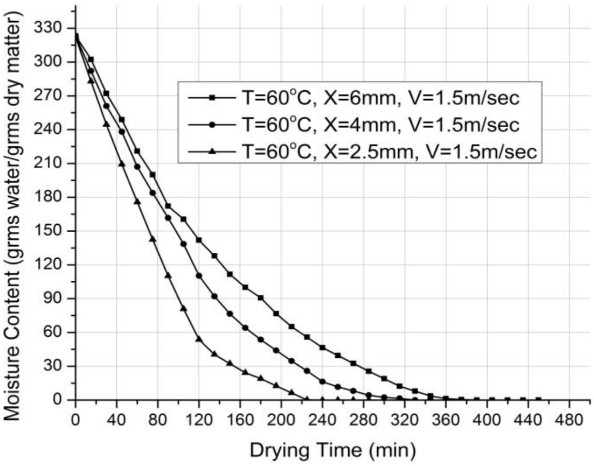

Fig. 4(b)

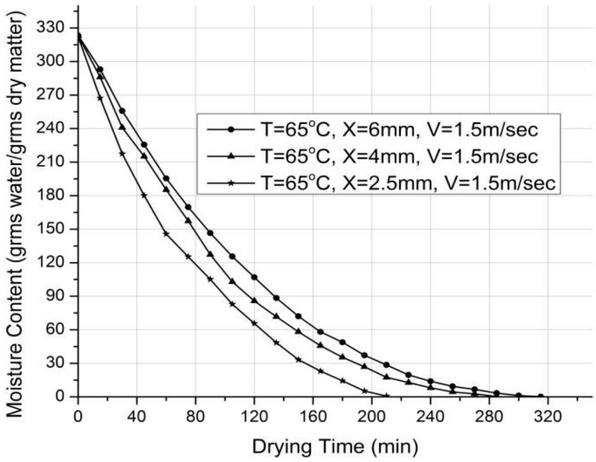

Fig. 4(c)

Fig. 4 (a, b and c) Shows the effect of Slice thickness (2.5mm, 4mm and 6mm) on the variation of Moisture Content V/s Drying time at different Temperatures 50°C, 60°C and 65°C for the Velocity 1.5 m/s.

Fig. 5 shows the variation of experimental Moisture Ratio with drying time of Guava fruit at different temperatures of 55°C, 60°C and 65°C and velocity of 1.5m/s for slice thicknesses of 6 mm.

Fig. 5 describes that moisture removal is considerably fast at the beginning of the drying process and the drying rate slows down as the drying proceeds i.e. moisture ratio decreased exponentially with drying time. It can be observed that the temperature has a major effect to the drying rate. As the drying temperature increases, a considerable increase occurs in the drying rate due to decrease in the relative humidity of drying air.

Increase in temperature from 55°C to 65°C decreases the time that required to reach EMC is almost 20% for 6mm (Fig. 4). The drying time reduced from 325 min to 210 min when air temperature was increased from 55⁰C to 65⁰C at the constant velocity of 1.5 m/s. The Henderson and Pabis model, that has highest value of correlation coefficient $\mathbf{R^2 = 0.993}$ at a temperature of 65°C and velocity 0f 1.5m/s is considered as best model to predict and represent the thin layer drying behavior of Guava Fruit as shown in the Table 1.

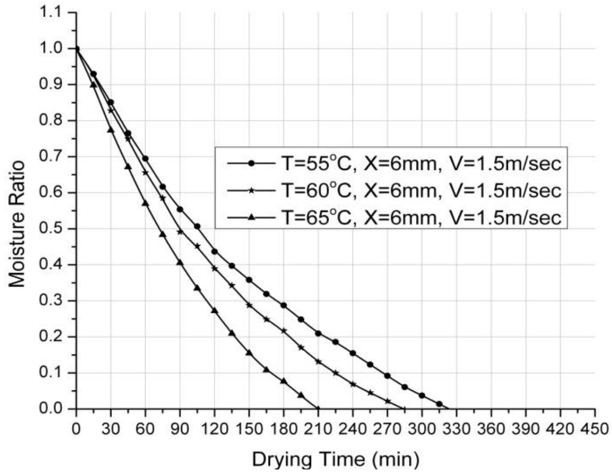

Fig. 5: Variation of Moisture Ratio with drying Time at different temperatures and velocity (1.5m/s) for slice thickness 6mm.

Fig. 6 shows the variation of Drying rate with drying time of Guava fruit at different temperatures of 55°C, 60°C and 65°C and velocity of 1.5m/s for slice thicknesses of 6 mm.

In thin layer drying, temperature plays an important factor affecting the drying rate. The drying rate for drying guava fruits was observed in the falling rate period. It is apparent that drying rate decreases continuously as the drying time increases. The constant drying rate period was absent due to quick moisture removal from the surface of the fruit sample. It is evident that the drying rate falls (sharply) at higher temperature compared to lower temperature. At the beginning as the moisture is very high so was the drying rate higher and as the moisture content approached to equilibrium moisture content drying rate was very low as shown in the Fig. 6

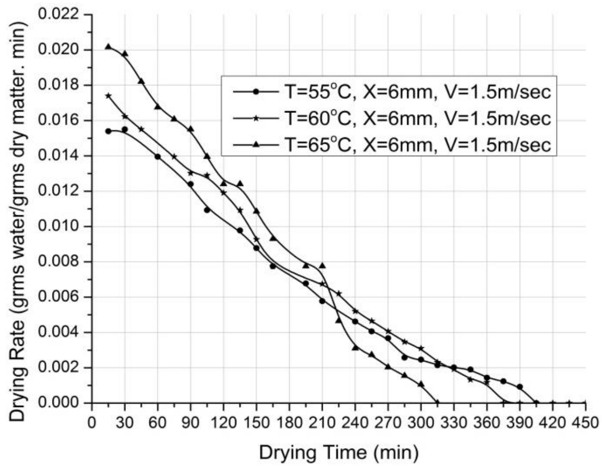

Fig. 6: Variation of Drying Rate with drying Time at different temperatures and velocity (1.5m/s) for slice thickness 6mm.

Table. 1: Estimated values of parameters for different models at different temperatures and velocities

Model Name	Model (MR)	Mass (Grms)	Velocity m/s	Temp	Coefficients			Constant	R^2	Predicted Equation
				°C	a	b	N	K		
Page	$\exp(-kt^N)$	91	1	55	----	----	0.00241	1.433118	0.962	
Henderson and Pabis	aexp(-kt)	91	1	55	1.770615	----	----	0.019888	0.908	
Wang and Singh	$1+at+bt^2$	91	1	55	-0.00499744	7.30041E-06	----	----	0.858	
Page	$\exp(-kt^N)$	91	1	60	----	----	0.0022	1.387850991	0.975	
Henderson and Pabis	aexp(-kt)	91	1	60	1.636138	----	----	0.016085	0.801	
Wang and Singh	$1+at+bt^2$	91	1	60	-0.00509874	7.20934E-07	----	----	0.817	
Page	$\exp(-kt^N)$	91	1	65	----	----	0.00291	1.3746	0.977	
Henderson and Pabis	aexp(-kt)	91	1	65	2.064342	----	----	0.024401	0.932	
Wang and Singh	$1+at+bt^2$	91	1	65	-0.006651973	1.12563E-05	----	----	0.810	
Page	$\exp(-kt^N)$	91	1.5	55	----	----	0.00259	1.226759	0.975	
Henderson and Pabis	aexp(-kt)	91	1.5	55	1.475817	----	----	0.090501	0.717	
Wang and Singh	$1+at+bt^2$	91	1.5	55	-0.00508377	4.76101E-06	----	----	0.872	
Page	$\exp(-kt^N)$	91	1.5	60	----	----	0.00227	1.368682	0.982	
Henderson and Pabis	aexp(-kt)	91	1.5	60	1.811106	----	----	0.016748	0.734	
Wang and Singh	$1+at+bt^2$	91	1.5	60	-0.00545838	3.54024E-07	----	----	0.888	
Page	$\exp(-kt^N)$	91	1.5	65	----	----	0.00335	1.277580355	0.989	
Henderson and Pabis	**aexp(-kt)**	**91**	**1.5**	**65**	**2.1151289**	----	----	**0.01495732**	**0.993**	**2.11512exp(-0.01495t)**
Wang and Singh	$1+at+bt^2$	91	1.5	65	-0.007542398	7.43337E-06	----	----	0.774	

IV. Conclusion

In this experimental study the drying kinetics of guava fruit was analyzed as a function of drying conditions. The influence of air temperature and slice thickness on the drying behavior was more significant than that of the air velocity. An increase in air temperature resulted in higher drying rates and consequently the moisture ratio decreased faster, because of increase in air heat supply rate to the product and faster migration of moisture inside the structure. The entire drying process occurred during the falling period and found that the effect of drying temperature on the drying time was more significant than air velocity where drying temperature decreases the total drying time. It was observed that drying time is longer for lower temperature at 55°C and shortest at 65°C. However with the increase in slice thickness the effect of temperature on the drying rate begins to shorten also moisture ratio decreases exponentially with drying time due to effect of temperature.

From the statistical analysis it is concluded that Henderson and Pabis model (R^2=0.993) is the most suitable model in defining drying behavior of guava fruit.

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