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# Air Drying of Guava: (I) Drying Kinetics at Different Temperature and Thickness

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**Abstract- This study was conducted to analyze the drying behavior of guava (*P. guajava*, family: Myrtaceae). The drying was done by using a Cabinet dryer at a constant airflow rate and constant or variable temperature and thickness. The values for the index ‘n’ of the power-law equation depicting thickness dependents of drying rate constant are less than 2 (1.79, 1.50, and 1.03) for all the conditions indicating that external resistance to mass transfer was significant and internal resistance to mass transfer did not control the drying process under the given conditions. While analyzing the effect of temperature, the activation energy values for the diffusion of water from guava were found to be 15.26 kcal/g-mole, 7.88 kcal/g-mole, and 9.18 kcal/g-mole for 3mm, 4mm, and 5mm thickness, respectively.**

**Keywords – Drying Kinetics; Guava; Temperature; Thickness.**

## I. INTRODUCTION

One of the most nutritious fruits, the guava, *Psidium guajava* L., of the myrtle family (Myrtaceae), is almost universally known by its common English name or its equivalent in other languages. In Bangladesh, it is called payara. It originated in tropical America (Mexico to Peru), where it still occurs in the wild. Guava is often called the "apple of the tropics". Guava stands fifth in production among the most important fruits of Bangladesh and can be grown all over the country. The annual production is about 45,000 m. tons in an area of about 10, 000 ha [1]. Though the districts of Barisal, Pirojpur, Jhalokathi, and Chittagong are the main guava producing areas, it is available in all areas of Bangladesh.

The guava includes about 150 species, but only a few have horticultural values. Guava fruit, usually 4 to 12 cm long, is round or oval depending on the species. Raw guavas are eaten out-of-hand but are preferred seeded and served sliced as a dessert or in salads. Bars of thick, rich guava paste and guava cheese are stapled sweets, and guava jelly is almost universally marketed.

Guava has high levels of vitamin A, B, C, and potassium which are thought to help improve skin tone and texture with their antioxidant and detoxifying properties. The beautiful astringents are thought to tighten up loose skin and leave it glowing. Guavas contain both carotenoids and polyphenols like gallocatechin, guaijaverin, leucocyanidin, and amritoside – the major classes of antioxidant pigments – giving them relatively high potential antioxidant value among plant foods. As these pigments produce the fruit skin and flesh color, guavas that are reddish-orange have more pigment content as polyphenol, carotenoid, and pro-vitamin A, retinoid sources than yellow-green ones.

Guavas have astringent properties which can cure cough and cold symptoms; this is supported by a high vitamin C. It reduces mucus, loosening the cough and disinfecting the respiratory tract. Guavas can help support weight loss by helping the body feel full up for longer. As the production is very high, a considerable amount is spoiled every year because of improper storage facilities in our country. If we can store guava then it can be used for further processing. The best way of preserving fruits is drying or dehydration. This process costs less than other preservation methods and requires a simple instrument. The sun-dried vegetables had inferior color, texture, and acceptability compared to the vegetables dried in the cabinet dryer.

In the mechanical dryer, desired temperature and airflow could be maintained. Compared to sun/solar drying, higher airflow and temperature can be used in mechanical drying. This leads to high production rates and improved quality products due to shorter drying time and reduction of the risk of insect infestation and microbial spoilage as well as minimum nutrient loss. Since mechanical drying is not dependent on sunlight so it can be done as and when necessary. Thus, it was decided to study the kinetics of air drying of guava to obtain optimum conditions to preserve guava.

## II. MATERIALS AND METHODS

### A. *Mechanical drying*

Cabinet dryer, Model OV-165 (Gallen Kamp Company) was used for dehydration of guava. The dryer consists of a chamber in which trays of products were placed. Air was blown by a fan past a heater and then across the trays of products being dried. The velocity of air was recorded (0.6m/s) by an anemometer. For determining the effect of temperature on the drying constant of guava, guavas were cut into slices. Freshly sliced guavas of a constant thickness of known weight and dried at a constant air velocity (0.6 m/s) at various dry bulb temperatures (50°C, 55°C, and 60°C). Weight loss was used as a measure of the extent of drying. To determine the effect of temperature on the rate of drying, from a known initial moisture content of the sample. To determine the effect of thickness on drying rate, 3, 4, and 5 mm thick guava slices were dried at a constant air velocity (0.6 m/s) using constant air dry-bulb temperature. Gravimetric measurements were used to determine weight loss and thus also moisture content.

Brooker et al.,[2] defined drying as a simultaneous heat and mass transfer process. The heat is required to evaporate the moisture which is removed from the drying product surface by an external drying medium, usually air. Biological products undergoing dehydration under constant external conditions (airflow, humidity, and temperature) in a thin layer may exhibit three periods of drying.

These are:

1. Constant rate period $(M_c \leq M_t \leq M_o)$
2. First falling rate period $(M_{hyg} \leq M_t \leq M_c)$
3. Second falling rate period $(M_e \leq M_t \leq M_{hyg})$

where,

$M_t$= Moisture content, dry basis (db) at any time

$M_c$= Critical moisture content (db)

$M_o$= Initial moisture content (db)

$M_{hyg}$= Hygroscopic moisture content (db)

$M_e$= Moisture content (db) in equilibrium with drying air conditions.

A constant rate period of drying is found when external resistance to moisture removal from the product surface is significantly higher compared to internal resistance to moisture transport to the product surface. In this case, the water vapor pressure at the product surface remains at or near the saturation water vapor pressure. The rate of water removal in this period may be approximated by an analogy with the wet-bulb thermometer analysis as given by Brooker et al.,[2]. The constant rate period, if any, is followed by the first falling rate period and it starts from the critical moisture content. The second falling rate begins when the moisture content is within the hygroscopic rate. Both the first and second falling rate period can be characterized by the same basic diffusion equation, the difference being that the effective diffusion coefficient $(D_e)$ changes from a higher value for the first falling rate period to a lower value for the second falling rate period. Since food dehydration is assumed to be a diffusion process, Fick's second law is applied to describe the mass transfer during drying.

The expression

$$\frac{\delta M}{\delta t} = \nabla D_e M$$

where,

$M$ = Moisture content (dry basis)

$t$ = Time

$D_e$ = Effective diffusion coefficient

$\nabla$ = Mass transfer constant

To find a solution of the above unsteady-state diffusion equation for three-dimensional transport for the case of initial uniform moisture distribution in the sample and negligible external resistance, appropriate boundary conditions are assumed. The solution for an infinite slab (with thickness, $L$), when dried from one major face[2]–[4] is:

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} Exp.\left[\frac{-(2n+1)^2 \pi^2 D_e t}{L^2}\right] - - - - (1)$$

For a low $M_e$ values and for moisture ratio $MR$ < 0.6, equation (1) reduces to

$$\frac{M_t}{M_0} = \frac{8}{\pi^2} e^{-\frac{\pi^2 D_e t}{L^2}} = \frac{8}{\pi^2} e^{-mt} - - - - - - - - - - - - - - - - - - - - (2)$$

Where,

$m = \frac{\pi^2 D_e}{L^2}$, drying rate constant $(sec^{-1})$

Rearranging equation (2) gives:

$$ln\frac{M_t}{M_0} = ln\frac{8}{\pi^2} - mt - - - - - - - - - - - - - - - - - - - - - (3)$$

Consequently, a straight line should be obtained when plotting ln $(MR)$ versus time $(t)$. The slope of the regression line is the drying rate constant, $m$ from which the effective diffusion coefficient, $D_e$ is calculated. The diffusion coefficient, $D_e$ has an Arrhenius type of relationship with drying air dry bulb temperature (abs) [3], [5]. The relationship is as follows:

$$\frac{d\ ln\ D_e}{dT_{abs}} = \frac{E_a}{RT_{abs}^2}$$

$$or, ln\ D_e = ln\ D_o - \frac{E_a}{RT_{abs}} - - - - - - - - - - - - - - - - - - - - (4)$$

where,

$D_o$ = the constant of integration and is usually referred to as a frequency factor when discussing the Arrhenius equation.

$E_a$ = activation energy of diffusion of water, cal / g-mole

$R$ = gas constant, cal / g-mole, °K

$T_{abs}$ = absolute temperature, °K

From equation (4) it is obvious that plotting diffusion co-efficient $(D_e)$ versus the inverse absolute temperature on semi-logarithmic co-ordinates would lead to the evaluation of activation energy for the diffusion of moisture during drying. From the semi-theoretical equation as shown in equation (2), it may be noted that the drying rate constant, $m$ is a function of the square of the thickness of the product dehydrated, as

$$m = \frac{\pi^2 D_e}{L^2} - - - - - - - - - - - - - - - - - - - - - - - - - - - (5)$$

Symbolically, this may represent as:

$$m = A(L)^{-n}$$

$$\text{or, } Log\ (m) = Log(A) - nLog(L) - - - - - - - - - - - - - - - - (6)$$

Where, $A = \pi^2 D_e$ and $n = 2$.

The above relationship shows that if external resistance to mass transfer is negligible and if simultaneous heat and mass transfer effects are considered, the value of the exponent of the power-law equation should be 2. But the above conditions are not always satisfied and experimentally determined 'n' value is found to be less than 2 [3].

## III. RESULTS AND DISCUSSION

### *A. Influence of thickness on drying rate*

The effects of thickness on the drying rate of Guava were investigated at a different air dry bulb temperature (50°C, 55°C, and 60°C) and a constant air velocity (0.6 m/s) in a cabinet dryer. The results were analyzed using equation (6) and moisture ratio and drying time (hr) were plotted on a semi-log scale (Figure 1).

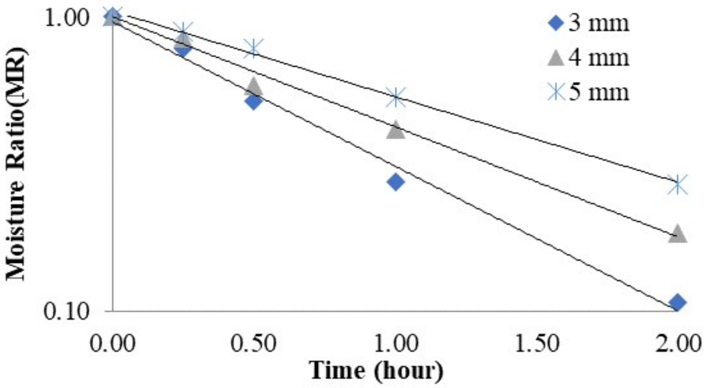

Figure 1: Typical representation of effect of thickness on drying rate (at 60°C temperature)

The equations for 50°C temperature:

ln (MR) = ln 1.16-0.89t (for 3mm thickness, t=hr)---------------------(7)

ln (MR) = ln1.06-0.57t (for 4mm thickness, t=hr) ---------------------(8)

ln (MR) = ln1.00-0.35t (for 5mm thickness, t=hr) ---------------------(9)

The equations for 55°C:-

ln (MR) = ln1.28-1.06t (for 3mm thickness, t=hr) ---------------------(10)

ln (MR) = ln1.20-0.63t (for 4mm thickness, t=hr) ---------------------(11)

ln (MR) = ln1.12-0.49t (for 5mm thickness t=hr) ----------------------(12)

The equations for 60°C:

ln (MR) =ln0.96-1.13t (for 3mm thickness, t=hr) ----------------------(13)

ln (MR) =ln0.99-0.85t (for 4mm thickness, t=hr) ----------------------(14)

ln (MR) =ln1.04-0.67t (for 5mm thickness, t=hr) ----------------------(15)

From Equations 7 to 15, a bed for 3mm thickness guava required the least drying time while drying time increased with increasing the thickness such as 4 and 5mm thickness. It was due to the lower thickness of the bed as the drying is a Fickian diffusion process and these rate constants are thickness dependent[3], [6]. For all air dry bulb temperatures, the fastest drying was observed for 3mm thickness and the rate constants are 0.89, 1.06 and 1.13$hr^{-1}$ at 50°C, 55°C and 60°C, respectively and the highest drying rate constant is found at 60°C (1.13 $hr^{-1}$). However, the decrease in drying rate was not proportional to the increase in thickness. Thus more products can be dried in a given time with higher thickness with a consequent increase in dryer capacity[3].

The dependence of the drying rate constant on thickness is shown by a log-log plot (Figure 2) for 50°C, 55°C, and 60°C as in equations 16-18.

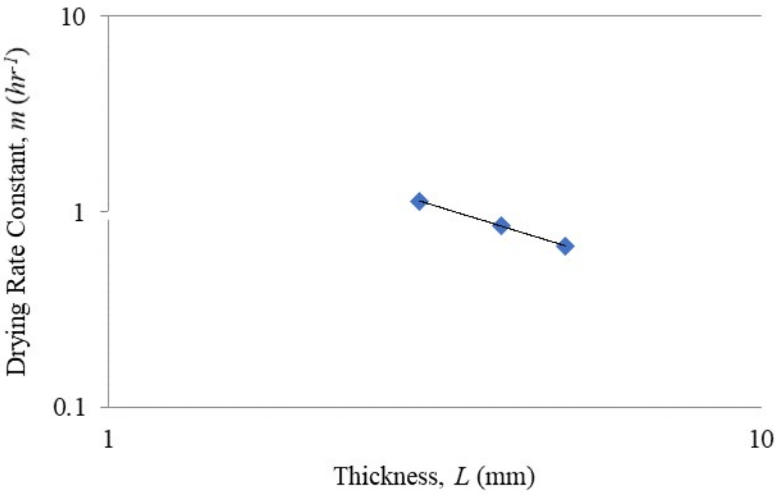

Figure 2: Typical representation influence of thickness on drying rate constant (at 60°C temperature)

The power-law equations are:

$m = 6.52L^{-1.79}$(50°C) -----------------------------------------(16)

$m = 5.36L^{-1.50}$(55°C) -----------------------------------------(17)

$m = 3.51L^{-1.03}$(60°C ------------------------------------------(18)

The value of exponent 'n' of the power-law equation was found to be 1.79, 1.5, and 1.03 for 50°C, 55°C, and 60°C, respectively. The values found are lower than those predicted by the theoretical drying equation (Equation 6). These low values of 'n' may be attributed to the presence of significant external resistance to mass transfer [3] and thus increased airflow up to a certain level would give a higher drying rate. This also means that internal resistance to mass transfer did not control the drying process under the given conditions. The low 'n' values resulted primarily due to low airflow rate (<1 m/s), since a similar sample thickness range did not indicate the presence of external mass transfer resistance under conditions of high air velocity (>2 m/s)[3]. The difference in 'n' value obtained due to change in air dry-bulb temperature may be attributed to simultaneous heat and mass transfer effects.

### *B. Influence of temperature on drying time*

To determine the influence of temperature on drying behavior, 3mm thickness Guava was dried in a mechanical drier at three different air bulb temperatures (50°C, 55°C, and 60°C), and for 4mm thickness and 5mm thickness same process was repeated. The experimental drying data were analyzed using equation 6 and plots of moisture ratio (MR) versus drying time were made on semi-log co-ordinate and regression lines were drawn (Figure 3) and the following equations were developed (Equation 19-27).

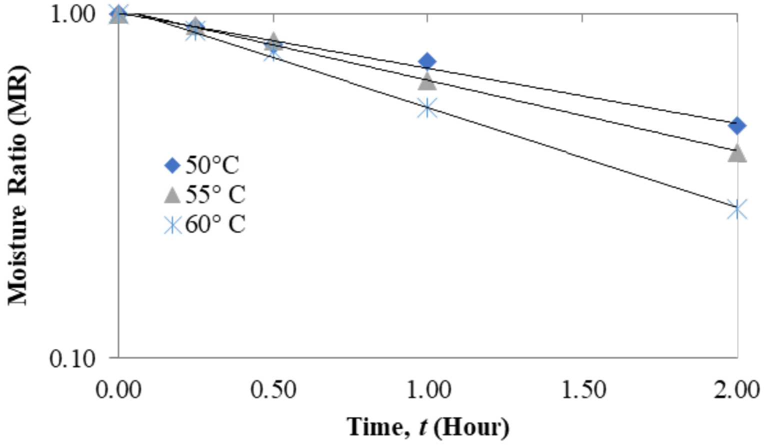

Figure 3: Typical representation of effect of temperature on drying rate constant (3mm thickness)

For 3mm thickness sample:

$\ln(MR) = \ln 1.16 - 0.89t$ (for 50°C, t=hr)--------------(19)

$\ln(MR) = \ln 1.28 - 1.06t$ (for 55°C, t=hr) -------------(20)

$\ln(MR) = \ln 0.96 - 1.13t$ (for 60°C, t=hr) -------------(21)

For 4mm thickness sample:

$\ln(MR) = \ln 1.06 - 0.57t$ (for 50°C, t=hr) -------------(22)

$\ln(MR) = \ln 1.20 - 0.63t$ (for 55°C, t=hr) -------------(23)

$\ln(MR) = \ln 0.98 - 0.85t$ (for 60°C, t=hr) -------------(24)

For 5mm thickness sample:

$\ln(MR) = \ln 1.00 - 0.35t$ (for 50°C, t=hr) ------------(25)

$\ln(MR) = \ln 1.12 - 0.49t$ (for 55°C, t=hr) ------------(26)

$\ln(MR) = \ln 1.04 - 0.67t$ (for 60°C, t=hr) ------------(27)

It seems that the moisture ratio (MR) (hence moisture content) decreases with increasing temperature and time. When the temperature of the drier is increased, the drying rate constant increased, which is seen from Equations 19-27. To obtain MR=0.1 (end of commercial thin layer drying), the time required can be calculated easily from these equations.

At high-temperature drying rate may initially increase but may give rise to casehardening with reduced drying rate and product quality will deteriorate due to cooking, instead of drying. High temperature also may result in higher non-enzymatic browning with even higher deterioration in quality [3], [7]. Thus, the selection of optimum temperature for drying is of significance during the mechanical drying of any food product.

From the drying rate constant, determined by regression equations (Equation 19-27), the diffusion coefficient was determined. Diffusion coefficient $(D_e)$ versus inverse absolute temperature $(T_{abs}^{-1})$ was plotted on a semi-log coordinate and a regression line was drawn (Figure 4).

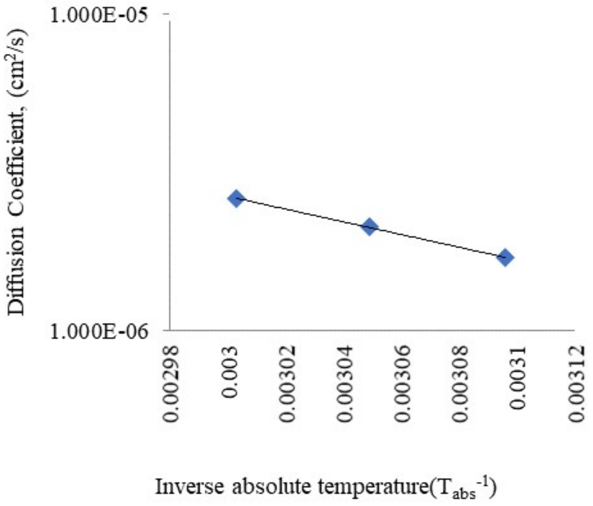

Figure 4: Typical representation of the effect of temperature on diffusion coefficient (5mm thickness)

The dependency of diffusion coefficient on absolute temperature can be represented as:

$D_e = 64438\, e^{-7682\, T_{abs}^{-1}}$ (3mm thickness) ----------------------------------(28)

$D_e = 0.609\, e^{-3967\, T_{abs}^{-1}}$ (4mm thickness) ----------------------------------(29)

$D_e = 2.7652\, e^{-4619\, T_{abs}^{-1}}$ (5mm thickness) ----------------------------------(30)

From the slope of the resultant straight line (Equation 28-30), activation energy $(E_a)$, diffusion of water was calculated and found to be 15.26 kcal/g-mole, 7.88 kcal/g-mole, and 9.18 kcal/g-mole for 3mm thickness, 4mm thickness, and 5mm thickness, respectively. These activation energy values are lower than those reported for onion[8] (26.83 kcal/g-mole), [9] (18.23 kcal/g-mole), wheat[10] (17.64 kcal/g-mole), aroids 5.12[11] kcal/g-mole and for Stevia[12] leaves were 5.25 kcal/g-mole. The difference observed in activation energy values may be attributed to simultaneous heat and mass transfer effects[3].

## IV.CONCLUSION

This manuscript focused on the kinetics of air drying kinetics of guava which showed that drying was conducted in presence of significant external resistance to mass transfer and the relationship of drying rate constant with thickness can be expressed as a power-law equation with ‘n’ value less than 2. Drying temperature and thickness influence the activation energy. The activation energy is important to manipulate optimum drying time and temperature as well as to minimize losses of heat-sensitive nutrients. Thus, high-quality dehydrated guava could be developed with high nutrient content, and spoilage of guava can be prevented during peak season benefiting the farmers as well as the country.

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