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EFFECT OF MANGO PUREE THICKNESS ON REFRACTANCE WINDOW DRYING FOR MAKING MANGO LEATHER

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ABSTRACT

This study aims to evaluate the thickness effect of mango puree on the Refractance Window™ (RW) drying method and dried multiple layer mango leather properties. RW drying of mango puree of 2 mm and 4 mm thickness was done to make mango leather and its drying kinetics was studied. Four commonly used thin layer models were tested to determine the best fit model to describe drying kinetics. Colour and hardness measurements were done for the dried mango leather. The Page model (PM) was observed to best fit the experimental drying data with higher R^2 value (>0.99) and lower RMSE (<0.03), χ^2 (<0.05) value. The optimum time and temperature required to obtain the final product in RW dryer is 20-60 min depending upon the thickness of the mango puree layer and 95 ^oC, respectively. RW dried mango leather color and texture was achieved better from 2 mm layers than from 4 mm layers.

KEYWORDS: *Mango Leather, Refractance Window Drying, Thickness, Modeling, Color*

INTRODUCTION

Mango has been grown in India since ancient times and is considered to be king of fruits. Among the world's top mango producing countries India ranks first with global area and production of 44.51% and 36.19% respectively. As per Final Area & Production Estimates for Horticulture Crops, made available by NHB 2016-17, 92.846 MMT fruits produced by India under 6.480 MH area. The total Mango production in India was 19.687 MMT under 2.263 MH area in the year 2015-16 (Anonymous 2017). Alphonso, Dashery, Langra, Himsagar, Chousa are the most popular varieties produced in India. Mango leather is traditional Indian fruit leather made from sun drying of a mixture of mango puree and sugar solution, it is also known as Aam papad. It can be made popular in the offseason of mangoes by preserving it for months (Wikipedia 2017).

Drying is necessary to decrease the moisture content of food product to reduce deteriorative reactions and has made possible the production of different value-added food (Omolola et al. 2017). It helps in ease of transportation, storage of foods, prolongs shelf life, reduces loss, and prevents microbial growth. But, if the drying process is not accurately applied, then it could have adverse effects on product quality attributes such as nutritional value, shelf stability and sensory properties such as flavor, color, taste, and texture (Di Scala and Crapiste 2008). Consumer preferences to dehydrated food of good quality constantly encourage efforts towards the development of superior and novel drying system (Topuz et al. 2009).

Therefore, a negotiation among all influencing reasons should be made to develop desirable technology. The owners of MCD Technologies have developed novel Refractance Window (RW) method, which is rather simple in operation and inexpensive. Despite using direct temperature, it uses infrared along with thermal energy of hot water at atmospheric pressure for food dehydration for preserving the precious nutrients found in whole foods (Abonyi et al. 2002; Nindo et al. 2003b; Nindo and Tang 2007). The spectra of liquid food water molecules absorb the infrared energy matching wavelength transmitted by Mylar (Zotarelli et al. 2015). The RW drying is a thin film drying system having high heat and mass transfer rates that increase the rate of drying (Nindo et al. 2003a). Its thin-layer drying function has made it introduced to the drying of fruit and vegetable purees or slurries (Abonyi et al. 2002).

Thin layer drying of food products is often evaluated using curve models which are categorized as theoretical, semi-theoretical and empirical models (Erbay and Icier 2010). Semi-theoretical models better fit the experimental data and efficiently describe the transport processes compared to models of another group. The analysis of drying process and drying kinetics of many agricultural foods were found best described by using semi-theoretical models (Rayaguru and Routray 2012). There are various studies based on the mathematical modeling of thin-layer drying of several fruits and vegetables such as for carrot slices (Sonmete et al. 2017), sweet cherry (Doymaz and Smail 2011) and pumpkin (Guiné et al. 2012)

There is a research gap found on multiple layer mango leather using RW drying study and its mathematical modeling. Therefore, the major objectives of this paper was (i) to study mango puree thickness effect on the drying kinetics for making multiple layer mango leather using RW drying technique, (ii) drying observations were validated using commonly used thin layer drying models and (iii) to determine the effect of thickness of mango puree on the quality attributes i.e. color and texture of RW dried multiple layer mango leather.

MATERIALS AND METHODS

Mango Pulping

Langra variety ripe mangoes were converted into puree by using adapted pulper. Potassium metabisulphite (0.75% of puree) was mixed with mango puree. Pre-cleaned and sterilized glass bottles were filled with puree and sealed with metal caps. The bottles were sterilized in boiler filled with water at 121 $^{\circ}$C temperature for 20 min, then cooled in the open air to reach ambient temperature. They were placed inside the refrigerator for further use and yearlong preservation.

Refractance Window Drying of Mango Puree to Make Mango Leather

Mango Puree Spreading

The laboratory scale float (24 x 15 x 3 cm) was prepared from Mylar® sheet (DuPont) to conduct experiments in batch mode. Uniform thickness of mango puree was spread by means of Film Coating machine (MTI CORPORATION).

Refractance Window Drying

The RW drying was conducted in a water bath (S. D. Instruments & Equipment, Kolkata, India) at 95±2 $^{\circ}$C temperature (Nindo et al. 2003b). Product temperature <75 $^{\circ}$C was maintained during drying experiment almost all the time, as indicated by Type-J thermocouple. Digital balance (Sartorius) was used to weigh whole float and the puree assembly at 1 min intervals to determine the moisture content of puree and hot air oven (Orion, India) was used to determine residual moisture in mango leather after completion of the drying process. Desirable moisture content in the mango should be in the range of 15-25% (wb) to categorize it as intermediate moisture food.

The thickness of the dried mango leather was measured using dial gauge (Mitutoyo 7301). The mango puree 2nd layer was spread over the 1st dried layer of mango leather using Film coating machine and RW dried up like in the earlier case. Mango puree of three-layer each of 2 and 4 mm thickness was dried to produce multiple layered mango leather. Triplicate of each experiment was done and for analysis average data was used.

Study of Drying Kinetics of Mango Puree to make Mango Leather

Mango leather moisture content (M_c) and drying rate (DR) for Refractance Window (RW) drying experiments (Chong et al. 2008) were calculated using the following equations:

$$M_c=(M_t-M_f)/M_f \quad (1)$$

$$DR=(M_{ct}-M_{c(t+\Delta t)})/(\Delta t \times A) \quad (2)$$

Where M_c= Moisture content of mango leather, kg water/ kg dry mass

M_t= Mass of moist mango leather, kg

M_f= Mass of bone-dry mango leather, kg

M_{ct}= Moisture content of mango leather at time t s, kg water/kg dry mass

$M_{c(t+\Delta t)}$ = Moisture content of mango leather at time t+Δt s, kg water/kg dry mass

A = Area of the spread mango puree film, m^2

The mathematical modeling is a functional aspect of prediction and analysis of drying process and the equipment. Four well-known thin layer drying models were used for fitting drying curves; namely, Henderson and Pabis model (HPM) as Eq. 3, Lewis model (LM) as Eq. 4, Page model (PM) as Eq. 5 and Modified Page model (MPM) as Eq. 6. The first term of Fick's second law general series solution is HPM. The LM is a special case of HPM, where the intercept is considered as a unity. An empirical modification to overcome limitations of LM is PM to illustrate agricultural products drying characteristics (Doymaz and Smail 2011). The modification of the Page model is MPM.

$$MR= (M-M_e)/ (M_o-M_e) =A_0 \exp (-k_0t) \quad (3)$$

$$MR= (M-M_e)/ (M_o-M_e) = \exp (-k_0t) \quad (4)$$

$$MR= (M-M_e)/ (M_o-M_e) = \exp (-k_0t^n) \quad (5)$$

$$MR= (M-M_e)/ (M_o-M_e) =A_0 \exp (-k_0t)^n \quad (6)$$

Where MR = moisture ratio,

M = moisture at actual time,

M_e is equilibrium moisture content,

M_o = initial moisture content,

t = time and

k_0, A_0, n = constants

The experiential and theoretical drying kinetic models were analyzed using non-linear regression analysis to determine the parameters of the selected models using the "*nlinfit*" and "*nlparci*" function of the Statistic Toolbox of Matlab® R2015a (8.5.0.197613) (The MathWorks Inc., USA) with Curve Fitting option. The drying data curves were plot using data analysis and graphing software Origin Pro 8.5 SR1. The experimental data to selected drying models goodness of fit to was determined by the statistical parameters, namely; coefficient of determination (R^2), root mean square error (RMES) as Eq. 7 and chi-square (χ^2) as Eq. 8. These parameters were calculated using the following equations:

$$RMSE=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pred,i})^2} \quad (7)$$

$$\chi^2=\frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pred,i})^2}{N-n} \quad (8)$$

Where, N = number of experimental data points used in the regression analysis,

n = number of constant parameters of the model,

$MR_{exp.}$ = experimental moisture ratio,

$MR_{pred.}$ = predicted moisture ratio and

N = Number of observations

Effective Diffusivities

The drying curves were plotted as moisture ratio (MR) vs. drying time, drying rate vs. moisture content and moisture diffusivity vs. unaccomplished moisture change (X/Xc) from data of RW drying experimental results. The drying kinetics study and determination of trends of RW drying of different layers of mango puree was done using drying curves (Chong et al. 2008; Ghanem 2010). The drying curves i.e. MR vs. drying time was modeled as per the best fit thin layer model to check the accuracy of the drying process. The effective diffusivity (Deff) of RW dried mango leather was obtained by means of Fick's second law solution (Eq. 9). Natural logarithm application on Eq. 9 gave Eq.10. The effective diffusivity, Deff values were obtained from the slope of the straight line as Eq.11 by plotting ln(MR) vs. drying time (t).

$$MR=\frac{8}{\pi^2}(e^{-D_{eff}t(\frac{\pi}{2l})^2}) \quad (9)$$

$$lnMR=ln\frac{8}{\pi^2}-D_{eff}(\frac{\pi}{2l})^2t \quad (10)$$

$$Slope=-D_{eff}(\frac{\pi^2}{4l^2}) \quad (11)$$

RW Dried Mango Leather Quality Attributes Determination

Colour

Chromameter (KONICA MINOLTA CR-400, Japan) was used to measure mango puree and RW dried mango leather color parameter (Nindo et al. 2007; Caparino et al. 2012). The 'L*', 'a*', 'b*', C and h values were recorded. The numeric description of colour in colorimeter using L*, a* and b* is defined as L* for lightness or darkness as black (0) to white (100); a* for red (> 0) or green (< 0); b* for yellow (> 0) or blue (< 0). Chroma (C) for saturation or vividness to determines color chromaticity and vividness (Shende et al. 2016). Hue (h) of color determines an angular measurement as

0º equals red and 90º equals yellow (Nindo et al. 2003a). Total color difference ΔE was determined using standard formula (Gnanasekharan et al. 1992; Nindo et al. 2007).

Texture

The Texture Analyzer (TA.XT2i, Stable Micro Systems Ltd., USA) was used to analyze mango leather texture at the different thickness. Texture Analyzer was set as: pre-test speed: 10 mms $^{-1}$, test speed: 0.5 mms $^{-1}$, post-test speed: 0.5 mms $^{-1}$, rupture test distance: 2 mm, strain: 30%. The texture profile analysis of mango leather used two compression cycles (Bourne 1978) as shown in Figure 1, where the mango leather was compressed continuously two times up to the maximum force. The reduction in force was recorded when the second time the maximum force was kept in the same position. After two compression processes, the probe returned to its initial point. Three replicate measurements were taken for texture analysis. The different parameters of texture profile analysis diagram were: F_1= first cycle maximum load, F_2 = second cycle maximum load, A_1= area under the first curve, A_2= area under the second curve, T_1= elapsed time from area A_1 and T_2= elapsed time from area A_2.

RESULTS AND DISCUSSIONS

Mango Pulping

The pulping of Langra variety of mango was done using adapted pulper (IIT Kharagpur, India) and the puree obtained was 63.23±0.32% of 11.62±1.38 kg raw sample.

Drying Kinetics

Single Layer Mango Puree Drying Kinetics Study to Make Mango Leather

The RW drying was done to study drying kinetics of mango leather from mango puree of 2 mm and 4 mm thickness. Mango puree of 2 mm thick shrunk and became 0.66±0.02 mm and mango puree of 4 mm thickness became 1.41±0.04 mm after RW drying (Shende et al. 2016). Product sizes, drying temperature and relative humidity generally affects drying kinetics (Farkas et al. 2000; Chong et al. 2008). The experimental results from RW drying of mango puree were plotted as moisture content vs. time, drying rate vs. moisture content and moisture diffusivity vs. unaccomplished moisture change (X/X_c) (Shende et al. 2016). The single layer drying of mango puree having 2 mm thickness took 15 min to reach constant mass (Figure 2a). The wet food temperature rises gradually and reaches 73°C after 2 – 3 min of commencement of RW drying due to the combined effect of conduction, convection and infrared radiation heat (Nindo et al. 2003a). The mango puree initial moisture content was measured as 3.38 kg water/ kg dry mass. After 15 min of drying the moisture content of the layer observed was 0.42 kg water/ kg dry mass (29.53%, wb). RW drying of thin-film mango puree was a rapid process due to the consequence of elevated heat and mass transfer rate. This drying process was facilitated by the infrared heat of hot water below the thin Mylar sheet (<0.25 mm) and thin puree layer on a large surface. After the required drying of puree, the leather was prevented to reach the temperature of hot water by evaporative cooling (Abonyi et al. 2002).

The single-layered mango puree drying curve shows constant rate period drying was only for 5 min with an average drying rate as 0.00204 kg water $m^{-2}s^{-1}$ (Figure 2b). Afterward, the drying process entered into a falling rate region and divided into two sub-periods, first and second falling rate period. It can be observed from drying rate curve carefully that from 6th min onwards (0.0012 kg water $m^{-2}s^{-1}$) up to 10th min (0.0009 kg water $m^{-2}s^{-1}$), first falling rate period and from 11th min (0.0006kg water $m^{-2}s^{-1}$) to the end of the drying (0.0003 kg water $m^{-2}s^{-1}$), second falling rate period Similar results were reported for high-quality mango powder and for tomato powder by Caparino et al. (Caparino et al. 2012), Zotarelli et al. (Castoldi et al. 2015) and Castoldi et al. (Castoldi et al. 2015)respectively.

Moisture diffusivity is an important characteristic of the undergoing mechanism of the falling rate drying period. The effective diffusivity values at all the points were determined by the slope of a straight line obtained from the plot of natural logarithm of moisture ratio (ln(MR)) versus drying time (Chong et al. 2008; Ghanem 2010; Shende et al. 2016), linear relation was justified with R-squared value 0.988 (Figure 2c). So, the plotting of the results could be started only after the falling rate drying period had set in. During starting from 3 min to 11 min a specific trend in the graph was found which is more or less convex in shape (Figure 2d) and the range of diffusivity values was $5.98x10^{-10}$ to $1.35x10^{-9}$ m^2s^{-1}. Thereafter, instantaneous moisture diffusivity values were obtained which were quite variable in magnitude and the final diffusivity value decreased to $4.84x10^{-10}$ m^2s^{-1}. Thus any specific trend in the graph for the latter portion of the drying period could not be apprehended. Similar results were obtained by Ochoa-Martínez et al. (Ochoa-Martínez et al. 2012) for drying of mango slices and Chong et al. (Chong et al. 2008) for Chempedak slabs.

Analysis of Thin Layer Drying Models

The thin-layer drying models as Eq. 3 to 6 were used to fit the experimental data to describe the drying kinetics of RW drying to make mango leather. The constant parameters for each model with their confidence interval (CI) were determined for every layer (both 2 mm and 4 mm) drying and are shown in Table 1 and 2. The drying constant (k_0) value for HPM, LM and PM has shown the similar trend for both 2 mm and 4 mm layer drying and has decreased with the increase in thickness and number of layers. Its value was the highest for MPM in mathematical modeling of entire layers. Thus, it is the function of puree thickness for RW drying process and at lower thickness, its value was greater may be due to factors such as the path of water transport within the solid matter gets shorter, the surface to volume ratio increases and resistance to external mass transfer decreases (Saraceno et al. 2012). The constant A_0 was not affected by the increase in a number of layers in case of 2 mm thick layer but for 4 mm layers its value increased with the increase in the number of layers. The constant n value was higher for PM than MPM in mathematical modeling of entire layers.

The model's adequacy were based on the of R^2, RMSE, and χ^2 values. The R^2 value for all the cases was higher than 0.95, indicative of a good fit. The PM was observed to be the best model for describing mango puree drying characteristics, for all puree layer thicknesses because its R^2 value was highest and RMSE and χ^2 value lowest among all the four models in all cases in this study. The best fit models were arranged in ascending order as PM>HPM>LM> MPM.

Multiple Layer Mango Puree Drying Kinetics of to make Mango Leather

The moisture content of mango leather was removed up to intermediate moisture food moisture content using RW drying process. The shorter drying time and higher drying rates were observed with the increase of the water temperature and the reduction in thickness of mango puree i.e. 2 mm mango puree require shorter drying time to produce higher drying rates when compared to 4 mm mango puree layer (Castoldi et al. 2015). The drying curves show that 2 mm 1^{st} layer took 15 min to reach 0.419 kg water/ kg dry mass (Figure 2a) whereas 4 mm 1^{st} layer took 34 min to reach 0.625 kg water/ kg dry mass (Figure 3a). The second layer of puree spread over the first dried leather, the drying time increased and took 25 min to reach 0.469 kg water/ kg dry mass for 2 mm 2^{nd} layer (Figure 2a) whereas took 66 min to reach 0.650 kg water/ kg dry mass (Figure 3a) for 4 mm 2nd layer. The 2 mm 3^{rd} layer took 36 min to reach 0.578 kg water/ kg dry mass whereas 4 mm 3^{rd} layer took 88 min to reach 0.685 kg water/ kg dry mass. Thus, as the number of layers increased, the time required of drying increased because the increase in thickness and number of layer resulted in slow drying rate when compared to single layer drying (Castoldi et al. 2015).

The MR residual values increase with the increase in thickness and number of layers resulting in the increase in experimental drying data error. The constant rate drying is shorter for multiple layers drying as compared to single layer drying and was limited to less than 3 min and rest of the drying occurred in falling rate period for all the subsequent layers. Falling rate period drying for 2 mm 1st layer reached at 3rd min whereas for 4 mm 1st layer it reached 6th min. The drying rate values for mango puree of 2 mm layer was greater than 4 mm layer (Figure 2b and Figure 3b), because the thinner layer allows a higher rate of moisture transfer to surrounding (Ochoa-Martínez et al. 2012). The drying of 2 mm layer (Figure 2a, 2b, 2c, and 2d) and 4 mm layer (Figure 3a, 3b, 3c and 3d) of mango puree follow different trends of the curve and the final product obtained differed in quality attributes.

Drying of three layers of puree is possible due to diffusion with constant moisture diffusivity being the controlling factor. Diffusion of water is greater in single layer drying and it decreases with the increase in a number of layers and an increase in the thickness of mango puree layer. The diffusivity values were determined for drying of multiple layer mango puree to make leather by the slope of a straight line obtained from the plot of natural logarithm of moisture ratio (ln(MR)) versus drying time (Chong et al. 2008; Ghanem 2010; Shende et al. 2016), linear relations were justified with R-squared value ranging from 0.961 to 0.994 (Figure 2c and Figure 3c). The moisture diffusivity values range from 1.54 x 10^{-9} to 2.28 x 10^{-11} m^2s^{-1} (Figure 2d and Figure 3d) which were smaller than the diffusivity values for single layer drying (Ochoa-Martínez et al. 2012). As the number of layers increased and the thickness of mango puree increased, the undulating nature of moisture diffusivity was observed in the whole of the falling rate period. The moisture diffusivity for drying mango puree of 2 mm thickness was ranging from 1.59 x 10^{-10} to 1.53 x 10^{-09} m^2s^{-1}, whereas for 4 mm thick mango puree drying it was ranging from 2.87 x 10^{-10} to 2.25 x 10^{-11} m^2s^{-1}. Therefore, moisture diffusivity for drying mango puree of thickness 2 mm was higher than for 4 mm leather using RW drying method.

Quality Attributes of RW Dried Mango Leather

Colour

Drying is used to prolong the shelf life of food products. However, during drying the appearance of dried food could change considerably. Polyphenol oxidase (PPO) of amino acid produce dark-colored melanin compounds due to the Maillard reaction, which is undesirable (Chong et al. 2013). Mango puree and finally dried mango leather color measurement were carried out. The highest L* value for mango puree indicates that it was brighter than mango leather. The lightness value of mango puree i.e. 77.62±0.54 decreases and thus mango leather become darker as L* value decreases with the increase in number and thickness of puree layers as shown in Table 3. The L* value for 2 mm 1st layer mango puree dried mango leather was 65.35±0.38 whereas for 2 mm 6th layer mango leather was 47.33±0.89. The value of a* for mango puree was -2.82±0.32 which means that the color belongs to the mixture of faint green and red colors. Value of a* increases during drying process i.e. 0.45±0.21 for 2 mm 1st layer and 14.70±0.54 for 2 mm 6th layer mango leather respectively, this is due to increase in the red color of mango leather with the increase in number and thickness of puree layers. The value of b*, which shows the yellow color, was 51.33±1.21 for mango puree and after drying the value of b* for mango leather was 49.91±0.92. The decrease in value of b* during the drying process was due to the change in color from bright yellow to reddish yellow. Mango leather becomes dark with the increase in number and thickness of puree layers as the value of b* for 2 mm 1st layer was 49.91±0.92 and 2 mm 6th layer was 35.09±0.35. A similar result of color parameters of mango puree and RW dried mango powder was determined by Caparino et al. (Caparino et al. 2012).

The change in color of mango puree occurred during the drying process due to the polyphenol oxidase (PPO) activity. Polyphenol oxidase (PPO) of mango is a copper-containing enzyme, which is related to the transformation of phenolic compounds to quinines (Yemenicioğlu et al. 1999). The slower enzymatic discoloration of mango puree during drying was accomplished, by reducing the oxidation of o-quinones to diphenols due to higher ascorbic acid and protein content of mango, when compared with the change in color of other fruits (Mcevily et al. 1992). The increase in the number of layers and thickness of mango puree resulted in mango leather become more red, dark, and decrease in hue value. The color change value i.e. ΔE value was 12.92 for 2 mm 1st layer whereas 38.58 for 2 mm 6th layer mango leather with respect to mango puree (Nindo et al. 2007) may be due to due thicker layer took more time to dry and remained in contact with heat for longer duration causes more browning or discoloration to occur (Castoldi et al. 2015). The change in color of mango leather may also occur due to pigment degradation, Maillard reaction, ascorbic acid oxidation and enzymatic browning (Manzocco et al. 2001; Chong et al. 2013). Similar results were observed by Nindo et al. (Nindo et al. 2007) for RW evaporation of blueberry and cranberry juices.

Texture

Among the principal factors, the texture is considered while determining the acceptability of foods (Bourne 1978). The texturometer imitate human jaw action during food product first bites. Texture profile analysis (TPA) was performed by two-cycle compression using a small, flat cylindrical disk, which was forced down (Bourne 2002). It can be observed from Table 4 that with the decrease in thickness of the mango puree layer, the solid content of mango leather increased for the same thickness of individual mango. Finally dried leather from 2 mm 6 layer of mango puree has total thickness of 3.76 mm, which was higher than 4 mm 3rd layer mango puree i.e. 3.41±0.04 mm. The hardness of leather has increased with the increase in puree thickness (Shende et al. 2016). The exposure of mango leather to heat during drying process resulted in the significant increase in hardness may be due to constituent’s polysaccharide cell wall depolymerization such as pectin (Yang et al. 2007; Chong et al. 2008).

Texture analysis of mango leather has not detected any fracturability in it may be due to improper semi-solid metrics coupled with its chewing. Compressive or tensile stress makes a cohesive product to adhere itself. Thicker mango leather from 4 mm thick mango puree took more chews to break it down was more cohesive than 2 mm due. Structural integrity was not retained by more macerated or thoroughly chewed foods to spring back, thus exhibit lesser springiness, greater gumminess. Toughness or stickiness arises chewiness to a food product, which means food does not get easily chewed. Thus, leather from 4 mm thick mango puree was tougher and more difficult to chew than 2 mm layer leather. More cohesiveness and hardness yield more gumminess to the product. The resilient product means substance or object ability to retain back its shape after deformation. Mango leather from 4 mm thick mango puree was more resilient than 2 mm thick. A similar result was reported by Chong et al. (Chong et al. 2008) for Chempedak slabs.

CONCLUSIONS

Intermediate moisture mango leather was prepared using RW drying process. It was observed from dying curve that single-layered mango leather constant rate period was for the very short duration of 5 min and shorter than 3 min for multiple layers of puree to make mango leather in RW drying process. Later, the process enters into falling rate region i.e. first falling rate period, followed by the second falling rate period. The drying time increased with the increase in number and thickness of the layer and slow drying rate was observed as compared to single layer drying. Among four commonly used thin layer models, the PM was observed to be the best fit with higher R^2, lower RMSE, and χ^2 value. Diffusion with constant moisture diffusivity is the controlling factor for drying of mango puree in the falling rate period and its value was observed to be greater in single layer drying and it decreased with the increase in a number of layers and thickness of mango puree. Moisture diffusivity values for drying mango puree of thickness 2 mm was greater than 4 mm for leather using RW drying method. Drying of 2 mm layer and 4 mm layer of mango puree yielded different trends for the drying curves and the final product differed in quality attributes. The increase in a number of layers and thickness of mango puree resulted in mango leather become more red, dark, dull and decrease in hue value. Mango leather was more cohesive chewy springy resilient and gummy from 4 mm thick puree than 2 mm thick.

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APPENDICES

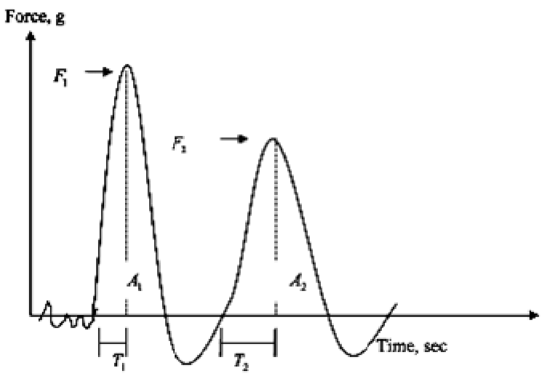
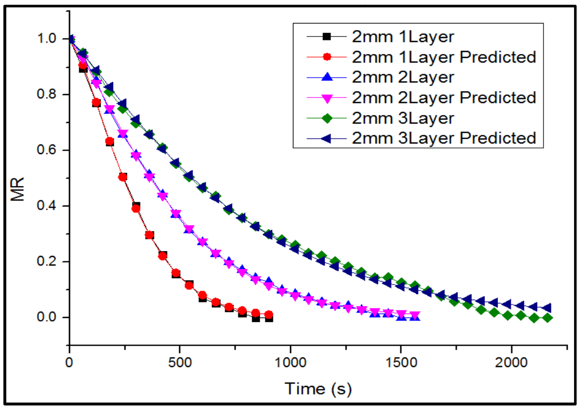
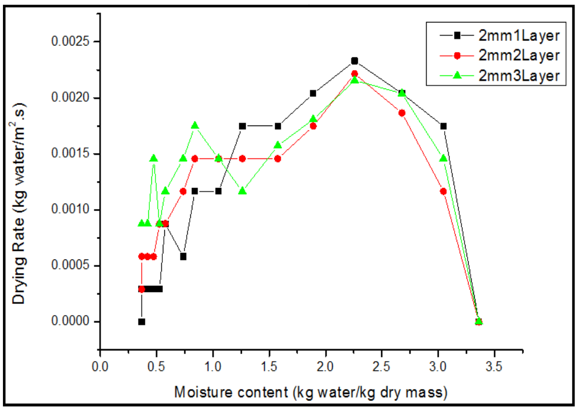


Figure 1: Force-Time Diagram of Texture Profile Analysis (TPA) (Chong et al., 2008).



(a)



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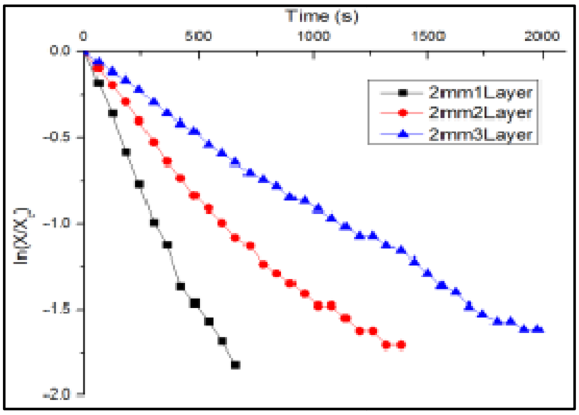

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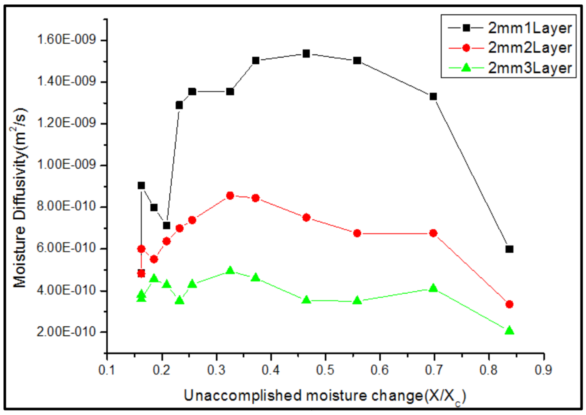
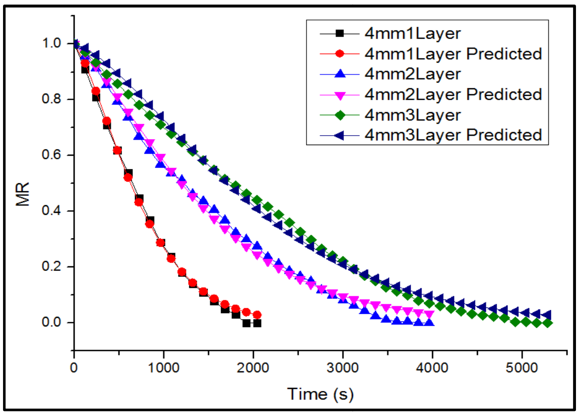
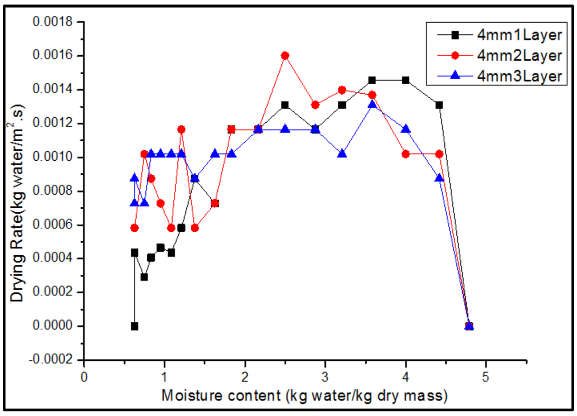


(d)

Figure 2: Drying Kinetics of 2mm Six Layer of Mango Puree: (A) Variation of Moisture Content (D. B.) and Time (Min), (B) Variation of Drying Rate (Kg Water $M^{-2} S^{-1}$) and Moisture Content (D. B.), (C) Variation of Natural Logarithmic Values of Unaccomplished Moisture Change with Time and (D) Moisture Diffusivity Curve.



(a)



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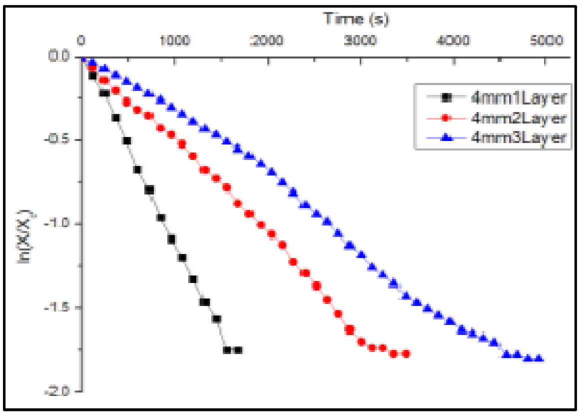
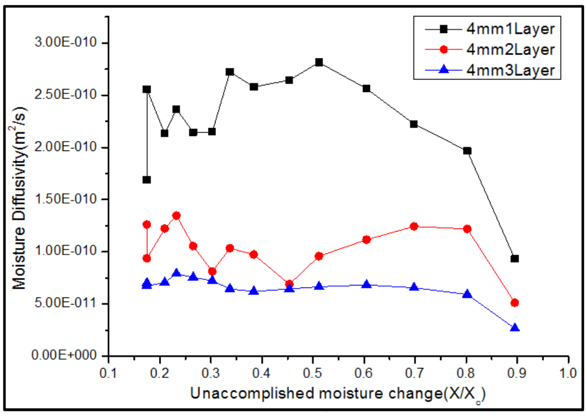


(c)



(d)

Figure 3: Drying Kinetics of 4mm Three layer of Mango Puree: (A) Variation of Moisture Content (D. B.) and Time (Min), (B) Variation of Drying Rate (Kg Water $M^{-2} S^{-1}$) and Moisture Content (D. B.), (C) Variation of Natural Logarithmic Values of Unaccomplished Moisture Change with Time and (D) Moisture Diffusivity Curve.

Table 1: Theoretical Models Parameter Result for 2 mm Thin-Layer Mango Leather using RW Drying

Layer	Model	Parameter	Value	CI (95%)	R^2	RMSE	χ^2
1	HPM	A_0	1.0860	0.9991, 1.173	0.978	0.0518	0.0368
		k_0	0.2142	0.1864, 0.2421			
	LM	k_0	0.1981	0.1743, 0.2218	0.969	0.0593	0.0487
	PM	k_0	0.0958	0.0891, 0.1025	0.999	0.0077	0.0008
		N	1.4160	1.377, 1.455			
	MPM	k_0	1.0580	-6.411e+06, 6.411e+06	0.969	0.0617	0.0522
		N	0.1872	-1.134e+06, 1.134e+06			
2	HPM	A_0	1.0810	1.042, 1.12	0.992	0.0291	0.0229
		k_0	0.1367	0.1292, 0.1443			
	LM	k_0	0.1271	0.1198, 0.1343	0.985	0.0381	0.0391
	PM	k_0	0.0712	0.06714, 0.07519	0.999	0.0077	0.0016
		N	1.2590	1.234, 1.284			
	MPM	k_0	0.1657	-3.947e+05, 3.947e+05	0.985	0.0388	0.0407
		N	0.7666	-1.826e+06, 1.826e+06			
3	HPM	A_0	1.0500	1.02, 1.079	0.992	0.0269	0.0267
		k_0	0.0844	0.08079, 0.088			
	LM	k_0	0.0804	0.07748, 0.08338	0.989	0.0308	0.0351
	PM	k_0	0.0525	0.04628, 0.05877	0.996	0.0186	0.0128
		N	1.1580	1.114, 1.202			
	MPM	k_0	0.2003	-6.106e+05, 6.106e+05	0.989	0.0312	0.0361
		N	0.4014	-1.223e+06, 1.223e+06			

HPM= Henderson and Pabis model, LM= Lewis model, PM= Page model, MPM= Modified Page model, k_0= drying constant (min^{-1}); A_0 = drying coefficient, n = drying coefficient, R^2 = coefficient of determination, SSE= sum square error, RMSE= root mean square error and χ^2= reduced chi-square.

Table 2: Theoretical Models Parameter Result for 4 mm Thin-Layer Mango Leather using RW Drying.

Layer	Model	Parameter	Value	CI (95%)	R^2	RMSE	χ^2
1	HPM	A_0	1.0790	1.004, 1.154	0.978	0.0494	0.0384
		k_0	0.0809	0.07182, 0.09013			
	LM	k_0	0.0749	0.06738, 0.08256	0.969	0.0563	0.0504
	PM	k_0	0.0272	0.02241, 0.03192	0.998	0.0147	0.0034
		N	1.3790	1.314, 1.444			
	MPM	k_0	0.8881	-2.122e+06, 2.122e+06	0.969	0.0583	0.0536
		N	0.0844	-2.018e+05, 2.018e+05			
2	HPM	A_0	1.0870	1.035, 1.139	0.978	0.0465	0.0736
		k_0	0.0428	0.03969, 0.04596			
	LM	k_0	0.0395	0.03688, 0.04204	0.969	0.0542	0.0999
	PM	k_0	0.0132	0.01001, 0.01645	0.993	0.0259	0.0229
		N	1.3230	1.251, 1.395			
	MPM	k_0	0.5352	-6.74e+05, 6.74e+05	0.969	0.0551	0.1031
		N	0.0737	-9.285e+04, 9.285e+04			
3	HPM	A_0	1.1080	1.052, 1.164	0.968	0.0576	0.1494
		k_0	0.0315	0.02906, 0.03389			
	LM	k_0	0.0285	0.02653, 0.03046	0.955	0.0673	0.2040
	PM	k_0	0.0054	0.004063, 0.006824	0.993	0.0264	0.0315
		N	1.4480	1.379, 1.517			
	MPM	k_0	0.0502	-4.446e+04, 4.446e+04	0.955	0.0681	0.2087
		N	0.5674	-5.025e+05, 5.025e+05			

HPM= Henderson and Pabis model, LM= Lewis model, PM= Page model, MPM= Modified Page model, k_0= drying constant (min^{-1}); A_0 = drying coefficient, n = drying coefficient, R^2 = coefficient of determination, SSE= sum square error, RMSE= root mean square error and χ^2= chi-square.

Table 3: Colour Parameters of Mango Puree and RW Dried Mango Leather

	Thickness (mm)	L^*	a^*	b^*	ΔE	C^*(Chroma)	h(Hue)
Mango Puree	-	77.62±0.54	-2.82±0.32	51.33±1.21	-	51.41	92.41
Mango leather of 2 mm Layers							
1	0.66±0.02	65.35±0.38	0.45±0.21	49.91±0.92	12.92	48.91	85.48
2	1.24±0.09	61.36±3.66	2.76±1.12	46.47±1.39	17.86	46.55	78.99
3	1.83±0.04	55.79±0.92	7.42±0.68	44.87±1.03	24.96	45.48	74.60
4	2.56±0.04	52.71±1.05	12.64±0.46	38.41±1.12	32.04	40.43	72.34
5	2.97±0.02	49.95±0.63	13.44±0.35	36.61±0.43	35.31	38.99	67.52
6	3.76±0.05	47.33±0.89	14.70±0.54	35.09±0.35	38.58	38.04	63.64
Mango leather of 4 mm Layer							
1	1.41±0.04	57.54±0.47	6.71±0.31	49.84±3.77	22.89	50.28	68.15
2	2.54±0.07	48.70±0.68	12.91±0.26	37.11±0.99	35.86	39.29	65.06
3	3.41±0.04	46.32±0.77	15.33±0.38	30.79±0.71	41.61	34.39	61.43

ΔE is calculated using L^*, a^* and b^* values of mango puree as reference.

Table 4: Mango Leather Texture Profile Analysis

Property	2 mm 3 Layer	4 mm 3 Layer
Hardness (N)	6.53	7.24
Fracturability	0.00	0.00
Cohesiveness	0.41	0.86
Springiness, mm	1.58	7.84
Chewiness Index, N	2.83	3.94
Gumminess, N	3.34	5.87
Resilience	0.18	0.27

The values indicate mean standard deviation from three replications