Mango pulp drying by refractance window method

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Abstract: Mango pulp (2 mm thickness) was dried by Refractance window (RW) technique using Mylar sheet. Drying kinetics, water activity and color change were determined and the results were compared between mango pulp dried on Mylar sheet (MS), aluminum sheet (AS) and aluminum foil (AF), all placed on the top surface of hot water. The recommended moisture content of 18%-33% (db) for intermediate moisture food like mango leather, was achieved within 12 minutes using RW dryer with Mylar sheet. A final moisture content of 2.5% (db) was achieved in RW drying after 35 minutes. After 25 minutes of drying, water activity of the product was 0.4 with corresponding equilibrium moisture content (EMC) value of 0.25 kg water kg^{-1} dry matter at 30.2ºC. The maximum moisture diffusivity of RW dried sample on Mylar sheet was $(9±2)\times10^{-9}$ m^2 s^{-1}. The same values for drying on the aluminum sheet and foil were $(1.05±0.25)\times10^{-8}$ m^2 s^{-1} and $(1.2±0.4)\times10^{-8}$ m^2 s^{-1}, respectively. Measurement of color values L^*, a^* and b^* revealed that around 20 minutes time there was a distinct break in the ΔL^*, Δa^* and Δb^* values indicating the pulp layer going through darkening to reach mango leather properties.

Keywords: refractancewindow, moisture content, drying rate period, moisture diffusivity

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1 Introduction

Mango leather is a traditional product prepared from firm ripe mango. Traditionally, sun drying is the process employed for preparing mango leather from ripe fruit pulp but the sun dried product is discoloured and the process is unhygienic and long. Refractance Window Technology is a novel drying system, developed by the owners of MCD Technologies, Inc., Tacoma, Washington. The technology is relatively inexpensive and the equipment is simple to operate and maintain. It is a unique, self-limiting dehydration method that uses infra-red wave, rather than direct extremes of temperature, to remove water from food. Infra-red light is permeable through polyester film, trade named Mylar (Dupont Inc.) (https://www.mtcapra.com/refractance-window-drying-technology/). Relying on the thermal conductivity of water together with the properties of infrared electromagnetic wave and the refractance of light, this is the preferred method for preserving the precious nutrients found in whole foods. In this process, important sensory qualities of the fresh whole food, such as color, aroma, taste and nutritional value are retained (Nindo and Tang, 2007).In addition, energy demand of Refractance Window drying method compares favorably with other conventional dryers (Abony et al., 2002).

Refractance Window (RW) drying is inexpensive and simple in operation when compared to freeze drying, (Nindo et al., 2006). Quality and colour of RW products dried on Mylar sheet are comparable to freeze dried products (Abony et al., 2002). Short drying time is essential in countries where energy cost is very high. Refractance window drying is energy efficient and has a good capacity for microbial reduction (Nindo et al., 2003a). Several works have been reported on RW drying of agricultural products to compare drying characteristics and quality with other drying techniques. These include strawberry and carrot puree (Abony et al., 2002), tomato puree (Abul-Fadl et al., 2011), mango puree (Caparino et al., 2012), pumpkin puree (Nindo et al., 2003a), asparagus puree (Nindo et al., 2003b), cranberry and

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blueberry (Nindo et al., 2006), acai juice (Pavan et al., 2012) and paprika (Topuz et al., 2009). Dried mango contains polyphenolic compounds, which have powerful antioxidant and anticancer abilities. It can be consumed as snack or added as ingredient in bakery and confectionary products. Nutritional benefits of the product calls for moderate temperature drying for preservation of nutrients. This leads one to investigate the efficacy of RW drying over conduction or convection drying processes (Nindo and Tang, 2007; Abony et al., 2002). The objectives of this work therefore is to study the drying kinetics of RW drying for mango pulp, and to estimate the mass transfer parameters from the data in mango leather production .

2 Materialsandmethods

2.1 Preparation of samples

Mangoes were procured from a local market in Kharagpur. The fruits were selected according to degree of ripeness by visual inspection. The fruits were washed and peeled by hand. Fruit was made into pulp by using a kitchen blender for one minute. Potassium-meta-bisulphite (1000 ppm) was used as preservative (Akhtar et al., 2010). The pulp was filled in pre-cleaned and sterilized glass bottles and they were sealed with metal caps. The bottles were put into a metal bucket and kept in boiling water at temperature of 110°C for 30 minutes. After the heat treatment, the bottles were left for cooling and when they were at room temperature, they were placed inside refrigerator for yearlong preservation. This step was necessary to ensure mango pulp supply around the whole calendar year, since mango is a seasonal product in India and available only during the months of May - July.

2.2 RW Drying Apparatus

The RW dryer consisted of thermostatic water bath (SD Instruments and Equipments, Kolkata, India), which was filled with tap water and on the surface of water Mylar plastic or aluminum float was put to dry the mango pulp. Water bath was operated by helical coil electrical heating mechanism. Mylar plastic float was made out of Mylar plastic sheet (2 mm thickness and 10×10 cm^2 area) for conducting the experiments in batch mode and at laboratory scale for convenient drying process. Mango pulp was spread over the floats with uniform thickness of 2 mm. The temperature of water bath was set at 95± 1.5°C, chosen on the basis of preliminary tests. Hot water acted as IR source to the plastic. Higher temperature created turbulence and air bubbles in the water bath, which interfered with energy transfer through the float, as mentioned by (Clarke, 2004). All experiments were carried out at ambient conditions.

2.3 Conduction Drying

Aluminum float, identical to Mylar float in thickness and area was used for conduction drying. Aluminum foil tray of 1mm thickness and 8.5 cm diameter was also used for comparison. Mango pulp was spread over the float/sheet with uniform thickness of 2 mm.

2.4 Spreader

It was necessary to apply the mango pulp of uniform thickness over the surface of the base of the float. So for this purpose a spreader was made. The main structure was made with ‘Perspex’, or acrylic glass (polymethyl methacrylate) which was transparent, tough and lightweight and that was cut according to size and then joined by chloroform. There were two screws at the two ends. By rotating the bolts on two sides the clearance could be adjusted between plate surface and spreader. Thus, in this way a pulp layer of uniform thickness could be obtained at the pre-set value.

2.5 Temperature measurements

Thermocouples were used for measurement of temperatures. The tip of the thermocouple wire was inserted into 2 mm thick pulp layer to observe the temperature. At regular intervals of 1 minute the temperature of the pulp was checked at five locations.

2.6 Moisture content determination

An oven was used for the estimation of total moisture content of the product. In oven drying the samples were kept at 105°C for 3 h following AOAC (2000) method. The moisture loss was determined by weighing the plate using digital balance (Model DC-170 electromagnetic scale) with 0.01 g precision. All the weighing process was completed in 10-12 s within the duration of the drying process. The drying process continued until the moisture content reached 0.025±0.005 kg waterkg^{-1} dry matter.

2.7 Water Activity measurement

Water activity of the pulp was measured by water activity meter (AQUALAB CX-2 of Pullman, Washington, USA) with ±0.003 accuracy with respect to temperature. Equilibrium moisture content was measured every 5 min by removing small samples from the pulp being dried using air oven drying. High water activity was associated with microbial/fungal spoilage of food. Hence,water activity was monitored during the drying process.

2.8 Color measurement

Color parameters were measured by Chromameter (model no. CR-400, maker Konica Minolta, Inc., Japan). The color parameters lightness (L*); red-green (a*); yellow-blue (b*) of the sample were estimated. The total color difference (TCD) was a parameter that quantifies the overall color difference of a given sample compared to that of the reference sample (sterilized stored mango pulp, L_o^*, a_o^*, b_o^*). Color was measured initially and after every 5 min during drying process up to 35 min. Equation (1) as follows:

$$\mathrm{TCD} = \sqrt{(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2} \quad (1)$$

2.9 Theory

To compare the drying kinetics of RW dryer with Mylar plastic, aluminum Sheet and aluminum foil, the drying rate was calculated by Equation (2) as follow:

$$\text{Drying rate (kg water m}^{-2}\text{ s}^{-1}) = -\frac{W_s}{A} \times \frac{dX}{dt} \quad (2)$$

where, W_s = mass of oven dry sample in kg; A = area of sample being dried in m^2 and $\frac{dX}{dt}$ = slope of the graph between free moisture content and drying time at various points of time in units of kg water per kg dry sample per second. Unaccomplished (or remaining) moisture change (X/X_c) versus respective time in minute during the falling rate period onlyhas the following relationship, based on the solution of Fick’s second law, neglecting higher order terms (Geankoplis, 1997). Equation (3) was as follow:

$$\frac{X}{X_c} = \frac{8}{\pi^2} \exp\left(-\frac{D_f \pi^2}{L^2} t\right) \quad (3)$$

where, X is free moisture content, dry basis at time t_f, s; X_c is the free critical moisture content on dry basis; D_f is constant moisture diffusivity in m^2 s^{-1}; L is the depth of mango pulp layer, m

Values of instantaneous moisture diffusivities respective points of time are to be obtained from Equation (4).

$$D_{eff} = \frac{\left(\frac{\partial MR}{\partial t}\right)_{\exp} * L^2}{\left(\frac{\partial MR}{\partial F_0}\right)_{Th}} \quad (4)$$

where,

$$\left(\frac{\partial MR}{\partial F_0}\right)_{Th} = -(\pi^2) * \frac{X}{X_c}$$

F_0 = Fourier number in mass transfer = $\frac{D_{eff}}{L^2} t$.

3 Resultsand Discussion

3.1 Drying curves

Figure 1 shows the temperature of the product during RW drying, which varied from 71ºC to 75ºC on Mylar sheet. For drying on aluminum sheet and aluminum foil the temperature of the pulp reached 80ºC. This indicates lower heat transfer resistance of aluminum compared to Mylar (polyester). There is great increment in temperature as drying starts, due to small thickness of Mylar, aluminum sheet and aluminum foil. At the start the initial moisture content of mango pulp was measured as around 6.135 kg water kg^{-1} dry matter. For prolonged shelf life of intermediate moisture foods the moisture content needs to be in the range of 15% to 25% (wet basis) or 17.65% to 33.33% (d. b.). Expected shelf stability at ambient condition for mango leather is three to six months. In this drying process moisture content of this range was obtained after only 10 minutes of RW drying. Moisture loss is very intensive during the first few minutes of RW drying, and the partial pressure of oxygen near the product becomes very low due to the high local vapor pressure created by moisture evaporation (Abony et al., 2002). Results obtained from this study are similar to previous studies done for mango slices of 1 and 2 mm thickness with water temperature of 92ºC (Martínez et al., 2012). In RW drying, the drying rate value was high comparatively because radiation heat transfer took place through Mylar sheet and the product dried up to nearly zero free moisture content, if drying process continued as shown in Figure 2. Figure 3 shows the plots of drying rate as function of drying time. As evident, the peak drying rates are not conclusively established from this figure. Plotting the drying rate as function of moisture content (dry basis) in Figure 4 reveals the maximum drying rates of 0.0024 and 0.0029 kg water m^{-2} s^{-1} for Mylar sheet and aluminum sheet, respectively. No constant rate of drying could be identified from the data for aluminum foil. The larger value of maximum drying rate for aluminum sheet is justified as the thermal conductivity value for aluminum is of the order of 200 W m^{-1} K^{-1} as compared to the same value for Mylar of 0.2 W m^{-1} K^{-1}. The drying rate values also confirm that nearly equal level of drying rates for Mylar sheet through IR radiation and for aluminum sheet by conduction. These values of drying rates for Mylar sheet and aluminum sheet correspond to dry basis moisture content of 3 and 4.5 kg water kg^{-1} dry matter, respectively.

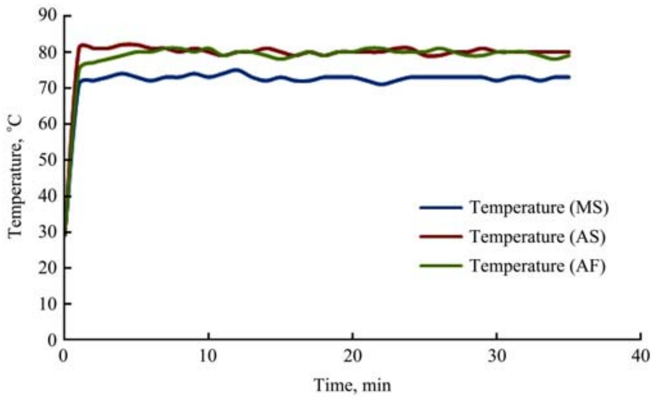

Figure 1 Temperature curves of mango pulp in Refractance Window and conduction dryings

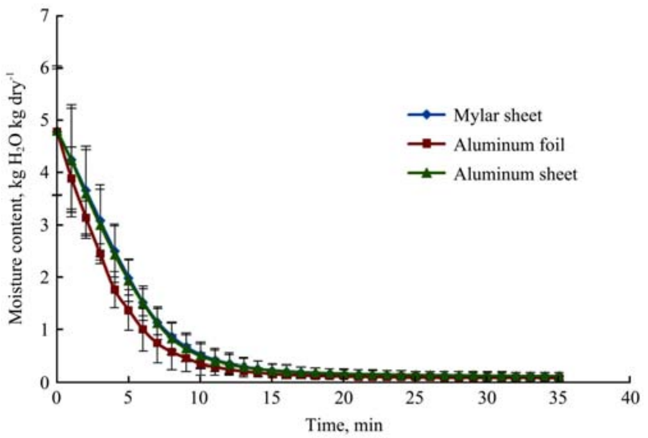

Figure 2 Moisture content of product versus time of drying

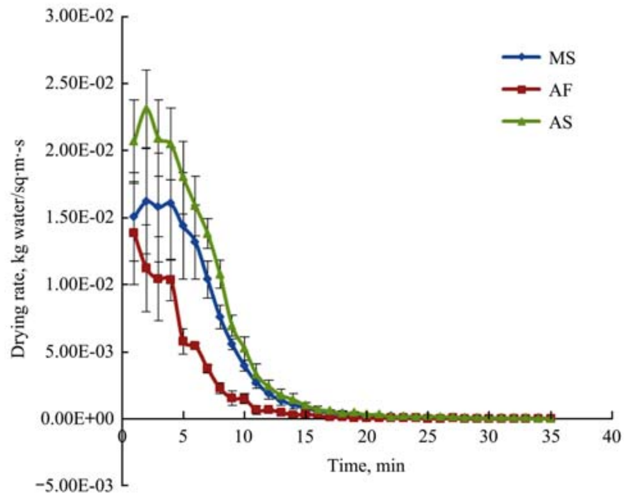

Figure 3 Drying rates of product versus time of drying

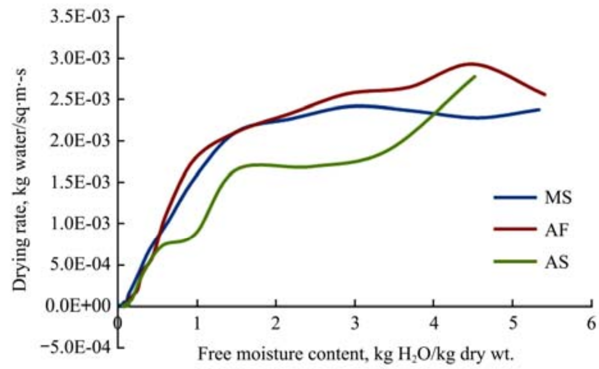

Figure 4 Drying rate vs. Free Moisture content (db)

3.2 Falling rate period

In RW drying of mango pulp on Mylar sheet the falling rate period started at around six minutes. In order to calculate the effective moisture diffusivity, free moisture content and ln(*MR*) data were plotted against the drying time for RW drying as shown in Figure 5 and Figure 6, respectively. From the instantaneous slopes of each line in Figure 6, using Equation (3), instantaneous D_{eff} values were calculated. The dotted lines in Figure 6 are representation of Equation (2), which assumes constant moisture diffusivity value of D_f. The sample temperature for RW drying on Mylar sheet was close to 75ºC (according to Figure 1), whereas for aluminum sheet, the sample temperature was around 80ºC. This temperature effect on the diffusivity has also been reported by (Dissa et al., 2008; Corzo et al., 2008). Figure 7 shows the resulting instantaneous moisture diffusivity values for drying operations carried out on Mylar and aluminum sheets and aluminum foil. As evident, instantaneous moisture diffusivity values increase with decreasing unaccomplished moisture ratio values up to a point in all three cases. This increase in instantaneous effective moisture diffusivity at relatively higher moisture content is likely to be due to increase in product temperature during the falling rate of drying. Escaping moisture may also have had to travel shorter length of path due to continual shrinkage. At the free moisture content of around 0.25 kg water kg^{-1} dry matter peak values of moisture diffusivity are attained for Mylar and aluminum sheets. Below this unaccomplished moisture ratio, the instantaneous moisture diffusivity values sharply descend, probably due to hardening of the layer through conversion from pulp to leather and residual moisture getting bound to sugar present in the pulp. Confirmation of this postulate was sought from Figure 8 and Figure 9. In Figure 8, water activity of drying mango pulp is plotted against duration of drying. In Figure 9, the same values are plotted against dry basis free moisture content. Figure 9 shows that there is a sharp decrease in water activity at the end of the drying operation in all three cases. This sharp decrease corresponds to the same unaccomplished moisture ratio value as mentioned earlier (0.25 kg waterkg^{-1} dry matter) for the case of Mylar sheet drying.

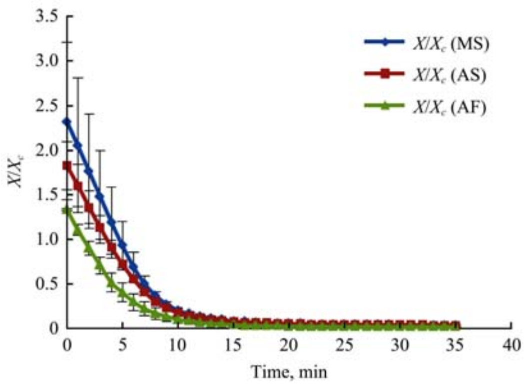

Figure 5 Variation of moisture change with time in RW drying during the falling rate period.

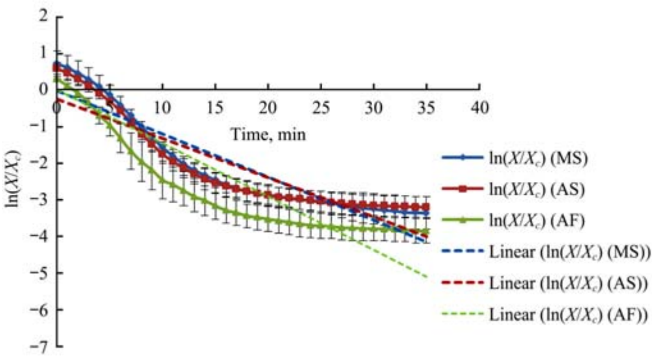

Figure 6 Variation of natural logarithm of unaccomplished moisture change with time in RW drying

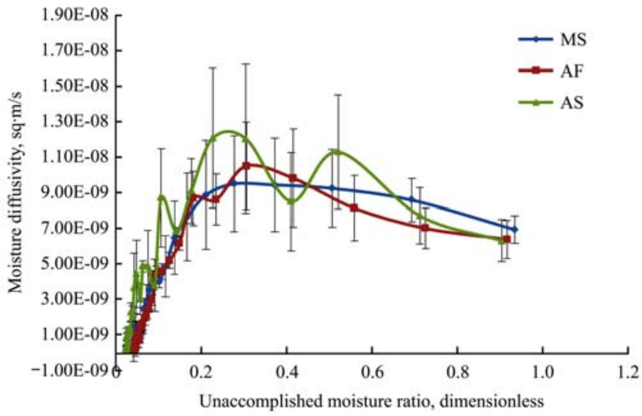

Figure 7 Effective moisture diffusivity vs. MR during the falling rate periods for Mylar, aluminum sheets and aluminum foil

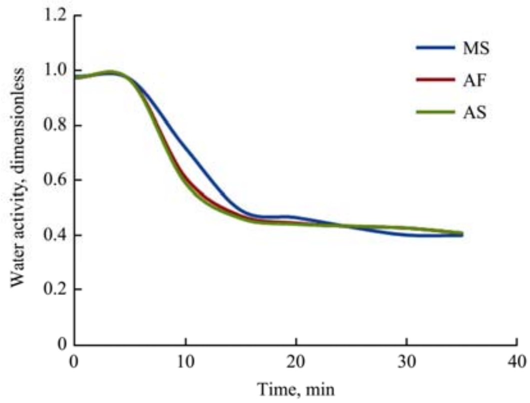

Figure 8 Water activity as function of time

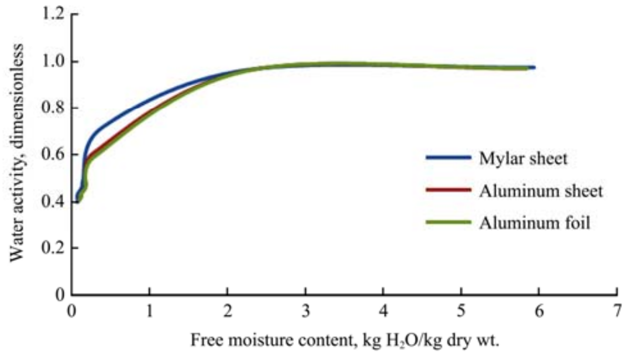

Figure 9 Water activity as function of free moisture content (db)

3.3 Colour change in the mango pulp layer

From Figure 10 to Figure 12, it can be observed that L* (lightness), a* (red-green) and b* (yellow-blue) values of product vary with drying time. Figure 10 shows the variation in change of lightness (ΔL^*) compared to the sterilized stored sample. As evident, the change in color increases with drying time up to 20 min of drying. This increase is reflected by the positive values of ΔL^*. However, after 20 min of drying a breakdown takes place in ΔL^* values showing a complete reversal of the rising trend and the negative values of ΔL^* for all three sheets and foil, indicate visible darkening of the sample within a short period of five minutes (from 20 to 25 minutes of drying), which may be attributed to conversion of mango pulp to mango leather. Finally from 25 to 35 minutes there is another steady increase in the values of ΔL^* for all three cases.Refractance window dried sample ends up being lightness neutral (value near about zero of L^* axis) where as conduction dried samples stabilize after 35 min of drying at –2. Red-green color (parameter a^*) changes (Δa^*) were not large for both drying methods, as demonstrated in Figure 11. The first set of observations of red-green color change indicates a negative value between –3 and –4, which means the samples were not red but brownish orange. After 35 minutes of drying the corresponding values of Δa^* stabilize around –7. On the other hand, there was a considerable increase of yellow color (parameter b^*) for all three cases. Figure 12, similar to Figure 10, showing a steady increase in yellowness difference (Δb^*) up to 20 min of drying, following which there is a steep decline in Δb^* which suggest darkening of the samples by a magnitude of 10 on the yellowness change scale. Ultimately for all three cases, the yellowness value stabilizes at around a magnitude of –7. Figures 11 and 12 also show that red and yellow color changes in mango pulp were minimal for Mylar plastic as compared to the same for aluminum sheet/foil.

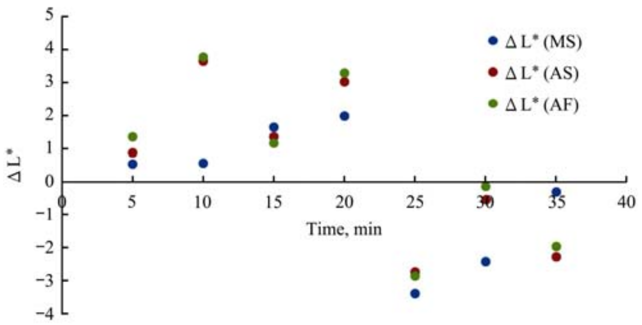

Figure 10 Change in L^* value for mango pulp dried on Mylar, aluminum sheets and aluminum foil

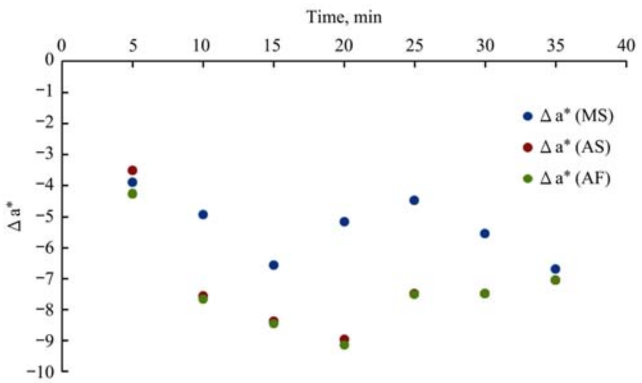

Figure 11 Change in red-green colour for mango pulp drying on Mylar, aluminum Sheets and aluminum foil

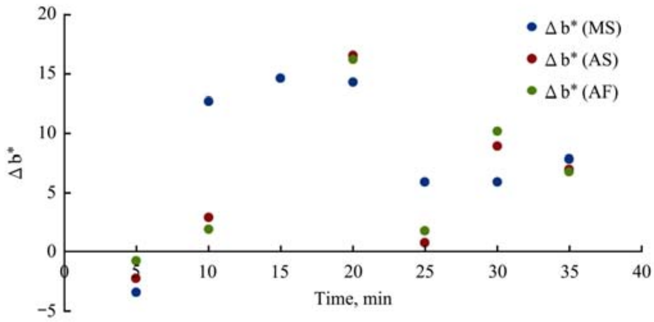

Figure 12 Change in yellow-blue colours in mango pulp drying on Mylar, aluminum sheets and aluminum foil

4 Conclusions

This study established the efficacy of RW drying using polyester (Mylar) sheet in a hot water bath. This method of drying is nearly comparable to conduction drying in aluminum sheet. However, the product reaches higher temperature in conduction drying, possibly resulting in enhanced aroma and flavor loss accompanied with nutrient degradation. Industrial application of RW drying can produce mango leather with high nutritive value and better visual appeal. RW drying requires minimal energy input in the state of 95ºC temperature maintained in water and for a very short duration of exposure. The recommended moisture content for intermediate moisture food like mango leather, which is 18%-33% dry basis (db), was achieved within 12 minutes using RW dryer with Mylar and conduction drying with Aluminium sheets and Aluminium foil this duration was only 10 minutes. A final moisture content of 2.5% (db) was achieved in RW drying after 35 minutes of drying for both sheets and foil, as well. After 25 minutes of drying, water activity of the product was 0.4 with corresponding equilibrium moisture content (EMC) value of 0.25 kg waterkg^{-1} dry matter at 30.2ºC. The maximum moisture diffusivity of RW dried sample on Mylar sheet was $(9\pm2)10^{-9}$ m^2 s^{-1}. The corresponding values for drying with aluminum sheet and foil were (1.05 ± 0.25) 10^{-8} m^2 s^{-1} and (1.2 ± 0.4) 10^{-8} m^2 s^{-1}, respectively. Measurement of color values L^*, $a^*$and b^* revealed that around 20 minutes time there is a distinct break in the ΔL^*, Δa^* and Δb^* values indicating the pulp layer going through darkening to reach mango leather properties.

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NOMENCLATURE

a* Red-green colour of sample, dimensionless

A Face area of dehydration surface, m^2

b * Yellow-blue colour of sample, dimensionless

D Mass diffusivity of water vapour, $m^2 s^{-1}$

ΔE^* Total colour difference, dimensionless

Fo Fourier Number in mass transfer, dimensionless

L Mango pulp thickness, m

L^* Lightness of sample, dimensionless

MR Free moisture ratio based on critical moisture content, dimensionless

t Drying time, s

W_s Dry matter mass, kg

X Free moisture content, kg water (kg dry matter)$^{-1}$

Subscripts

c critical condition

eff instantaneous effective value

exp experimental

f constant value

o sterilized mango pulp before drying

Th theoretical

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