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Rehydration kinetics of flour from dehydrated mango kernel

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Abstract

Mango kernel, a food waste with high nutritional values has been getting a significant focus in food processing, especially in powder form. The study was conducted to compare the rehydration kinetics of processed mango kernel flour (MKF) with wheat flour (WF). In Bangladesh, different mango varieties are available at different time of mango ripening season. Among them, four varieties (Baishakhi, Amrapali, Fazli and Ashwina) were selected to get their component percentage and kernels of the four varieties were analyzed to know about their nutritional values and drying behavior. It was found that mango varieties contained 8.4-12.4% kernels, 9.80-14.30% peel, 66.10-72.40% pulp and 7.50-9.30% seed coat. The chemical analysis of the kernels revealed that nutrient components varied due to varietal difference. The drying kinetics of the kernels showed that the drying rate constant increased with the increasing of kernels' moisture content, consequently decreased with increasing the duration of ripening season. A comparison of rehydration kinetics between the processed MKF from dehydrated mango kernel and WF at 40, 50 and 60°C showed that WF rehydrated quicker than MKF and the activation energy (Ea) values for rehydration were 9.544 and 7.532 KJ/mol for MKF and WF respectively. The research revealed that nutritious dried flour can be processed from mango kernel which needs more time to rehydrate than WF.

1. Introduction

Mango (*Mangifera indica* L.) belongs to the family Anacardiaceae, is one of the most common, popular and important tropical fruits in the world which is well known for its strong aroma, intense peel coloration, delicious taste, and high nutritive value as it has high amounts of vitamin C, β-carotene and minerals (Tharanathan *et al.,* 2006). They also reported that the composition of mango varies due to several factors such as cultivation area, maturity conditions, varietal differences etc. The main constituents of the mango pulp are moisture, sugar, vitamins, minerals, organic acids, color and flavor compounds.

According to FAOSTAD (2015), it is the second most traded tropical fruit in the world and also scored fifth among all fruits in terms of total production. From the statistical data of BBS (2015), total 10,18,112 metric tons mangoes were produced in Bangladesh from 61,997 acres land in the year of 2014-2015 which ranked seventh in terms of the highest mango production all over the world.

A full mango consists of its peel, pulp, seed coat, and kernel. The kernel with seed coat is known as seed which represents 10-25% of the total weight of the whole fruit and the kernel is around 45-85% or 20% of whole fruit approximately (Arogba, 1997; Solis and Duran, 2011) but this percentage can vary due to varietal variations, climatic condition, harvesting period etc.

Dhingra and Kapoor (1985) reported that mango kernel has 69.22%-79.78% carbohydrates, 8.35- 16.13% fat, 5.6-9.5% protein, and 0.35-3.66% ash. Mango kernel is a good source of carbohydrates (58-80%) and protein (6-13%) and has an attractive profile of essential amino acids and lipids (6-16%) with rich in oleic and stearic acids (Siaka, 2014).

Sultana (2013) mentioned drying as a modern method of food preservation and defined as a process in which moisture from products is removed to prevent the growth of spoilage microorganism is known for drying or dehydration. Also added that its success largely

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depends on the rehydration properties of the dehydrated products. According to Al-Amin *et al.* (2015), rehydration is an important process by which a dried material becomes refresh or wet by absorbing water.

Several researchers have reported about the utilization of mango kernel and its components in different foods (Nzikou *et al.,* 2010; Jahurul *et al.,*2015), however air-drying behavior of different kernels and rehydration kinetics of processed flour can be a matter of research interest.

From the above standpoint of view, the research was conducted to know the component percentage of different mango varieties, to asses to nutritional composition of different kernels, to study the mechanical drying behavior of different mango kernels and to compare the rehydration kinetics of mango kernel flour with wheat flour.

2. Materials and methods

2.1 Materials

Fresh mangoes (Ashwina, Baishakhi, Amrapali and Fazli) were collected from the mango garden of Chapai Nawabganj and the local market of Rajshahi. Chemicals and solvents used in the study were of AR grade and water was glass distilled unless specified otherwise. Cabinet dryer (Model No.:1816; Modern Laboratory Equipment Co., Inc. New York, U.S.A.) was used for the drying operation.

2.2 Preparation of mango kernel and component measurement

Collected mangoes were washed, peeled and pulped to get the mango seed and rinsed immediately. Then, the kernels of the mangoes were separated manually from seeds by cutting and removing the seed coat. The separated peel, pulp, seed coat, and kernel were measured by using the electric balance to know the component percentage of the kernels.

2.3 Chemical analysis of mango kernels

Moisture and crude fiber contents were determined according to the method of AOAC (2012). The ash, protein, and fat of the mango kernels were determined using necessary equipment according to the methods described by Ranganna (2005). The quantity of carbohydrate present in the samples was expressed as total carbohydrate and determined by subtracting the measured moisture, ash, protein, and fat from 100 (Pearson, 1976). The total body energy of a human is mainly provided by three groups of nutrients and they are protein, fat, and carbohydrate. Taking this into consideration, the energy content of the samples was calculated by multiplying the specific water factors for protein and carbohydrate as 4 and fat as 9 (Birch, 1980). Triplicate determinations were conducted and the results were presented as mean ± standard deviation (S.D).

2.4 Dehydration method

Cabinet dryer, in which air was blown by a fan passed over a heater was used for the dehydration of mango kernel. Trays of sample were placed in the chamber of the dryer. The moisture content of samples at each time interval was determined by gravimetric method from known initial moisture content. To know the effect of kernel variety on drying kinetics, mango kernels of different varieties were sliced by using slicer into 6 mm thicknesses and dried at a constant air velocity and specific temperature of 65ºC.

As food dehydration is most frequently assumed to take place by diffusion process, Fick's second law of diffusion can be applied for describing mass transfer during drying. The expression is:

$$\frac{\delta M}{\delta t} = \nabla^2 D_e M \quad (1)$$

where, M = Moisture content (dry basis); t = time; D_e = Effective diffusion co-efficient.

In order to solve the above unsteady state diffusion equation for one-dimensional transport for the case of initial uniform moisture distribution in the sample and negligible external resistance, appropriate boundary conditions were assumed. The solution for an infinite slab (with thickness = l) when dried from one major face (Islam, 1980 and Crank, 1975) is:

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\, exp\frac{-(2n+1)^2\pi^2 D_e t}{l^2} \quad (2)$$

For low M_e values and for moisture ratio, MR<0.6, equation (2) reduces to:

$$\frac{M_t}{M_0} = \frac{8}{\pi^2}e^{-\frac{\pi^2 D_e t}{l^2}} = \frac{8}{\pi^2}e^{-mt} \quad (3)$$

where, $m = \frac{\pi^2 D_e}{l^2}$ = drying rate constant ($sec^{-1}/min^{-1}/hr^{-1}$), D_e = Effective diffusion co-efficient and t = drying time. Rearranging equation (3) gives:

$$ln\, MR = ln\frac{8}{\pi^2} - mt \quad (4)$$

Consequently, a straight line should be obtained when plotting ln(MR) versus time (t) and the slope of regression line is the drying rate constant, m.

2.5 Rehydration kinetics

Kernels of Baishakhi mango were dried for about 15 hrs at 55-60ºC for complete removal of moisture and ground to obtain its flour form. The flour is sifted through a 30 mesh size to get fine mango kernel flour

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(MKF) and was compared with wheat flour (WF) to know the rehydration behavior. The rehydration behavior of WF and MKF was measured by combining and modifying the method described by Al-Amin *et al.* (2015); Apati *et al.* (2010); Doymaz and Ismail (2010) and Rastogi *et al.* (2000). Firstly, centrifuge tubes containing distilled water were heated in a controlled water bath up to desired rehydration temperature. When the rehydration temperature was attained, MKF or WF with known moisture content was poured into the centrifuge tubes and rehydrated in the water bath. To get the rehydration kinetic model, the flours were rehydrated at three different controlled temperatures of 40±1°C, 50±1°C, and 60±1°C. The sample and water ratio was maintained at 1:30. When rehydration time completed, the supernatant water of centrifuge's tube was drained off after centrifuging for 5 mins at 3000 rpm and the sediment was weighed again to get the moisture absorbed by the rehydrated materials. The moisture of the rehydrated samples was expressed as g water/g dry sample. The rehydration continued to 30 mins at an interval of 5 mins, then 15 mins interval up to 2 hrs and 30 mins interval up to 4 hrs.

2.6 Statistical analysis

The results were evaluated for standard deviation, single factor Analysis of Variance (ANOVA) by using Microsoft Office Excel 2013. Figures were prepared using Microsoft Office Excel 2007, Origin 8 and Microsoft Office Visio 2007. Fisher's Least Significant Value (LSD) multiple comparison test procedures were performed to know the significant difference among sample when the F-values of ANOVA reject the null hypothesis by taking 5% level of significance on accordance to Gomez and Gomez (1984).

3. Results and discussion

3.1 Component distribution of mango kernel

Components of collected mangoes were separated and the percent distribution of mango fruit component was studied and shown in Table 1. From Table 1, it is seen that kernel content varies from 8.40 to 12.40% and that early variety Baishakhi gave the highest percentage of kernel content (12.40%) as well as seed content (21.70%) among the samples (varieties) tested. It is also seen that Amrapali yielded the highest percentage of pulp (72.40%) and the Baishakhi gave the lowest percentage of pulp (66.10%). On the other hand, Ashwina gave the highest peel percentage (14.30%) while the lowest percentage of peel was given by Amrapali (9.80%). A similar study was conducted by Yatnatti *et al.* (2014) and they found 9.00% kernel in mangoes. The obtained results were more or less similar to those reported by Dhingra and Kapoor (1985), who reported the seed (seed coat and kernel) content as 18.00% and kernel content as 10.00% of total mango fruits. Thus, this study revealed that components of the mango vary from variety to variety.

3.2 Nutritional composition of mango kernel

Four types of kernels were analyzed for their nutritional composition and the results are shown in Table 2. Moisture, ash, protein, fat, fiber, total carbohydrate and energy content of four different mango kernels were in the range of 48.79-65.67%, 1.08-1.35%, 2.19-4.41%, 2.38-5.80%, 0.49-0.63%, 28.84-39.12% and 145.50-228.72 Kcal/100 g respectively in wet weight basis (wb) while the corresponding dry weight basis (db) values were 95.27-191.29%, 2.50-3.44%,6.38-8.86%, 6.93-11.33%, 1.23-1.46%, 77.44-83.25% and 420.89-446.65 Kcal/100 g respectively. The analysis revealed that early variety Baishakhi was rich in protein, fat and carbohydrate content while the latest variety (Ashwina) in moisture and ash content. Nzikou *et al.* (2010) reported that the moisture content of mango kernel as 45.2% (db) and Dhingra and Kapoor (1985) found the moisture content as 50.98% (db) for kernels of Dusheri mango in India. Nzikou *et al*. (2010), Dhingra and Kapoor (1985), Odunsi (2005) and Changso (2008) found the ash content as 3.2, 2.75, 2.23 and 0.83% (db) respectively, whereas in mango kernel, 6.36% (db) protein and 13.62% (db) fat was found by Nzikou *et al*. (2010) and Odunsi (2005) respectively. Legesse and Emire (2012) used mango kernel for biscuit production and found 2.51% (db) fiber and 67.25% (db) total carbohydrate, while Changso (2008) reported that the crude fiber content of 3.96% (db) and the carbohydrate of 48.79% (db) in mango kernel. The observed values are almost similar to that reported by the mentioned authors. The difference of composition among kernel sample and other authors might be due to varietal

Table 1. Component percentage of different mangoes

Component		% of whole mango*				LSD (P<0.05)
		Baishakhi	Amrapali	Fazli	Ashwina	
Peel (%)		12.20±0.95[b]	9.80± 0.78[c]	10.20±0.84[c]	14.30±1.03[a]	1.22
Pulp (%)		66.10±1.12[a]	72.40±1.53[a]	71.10±1.45[a]	68.6±1.32[a]	41.20
Seed	Seed coat (%)	9.30±0.63[a]	7.50±0.91[a]	8.10±0.87[a]	8.70±0.67[a]	4.74
	Kernel (%)	12.40±0.72[a]	10.10±0.93[a]	10.60±0.89[a]	8.40±0.61[a]	5.92

*Average± S.D.; n=5; Samples having the same superscript do not differ at 5% level of significance (α).

Table 2. Nutritional composition of mango kernels

Component	Baishakhi		Amrapali		Fazli		Ashwina		LSD (P<0.05)
	wb*	db	wb*	db	wb*	db	wb*	db	
Moisture (%)	48.79±1.26[d]	95.27	52.35±1.24[c]	109.86	62.76±2.49[b]	168.55	65.67±2.16[a]	191.29	3.53
Ash (%)	1.28±0.18[a]	2.50	1.35±0.22[a]	2.83	1.08±0.17[a]	2.90	1.18±0.18[a]	3.44	0.35
Protein (%)	4.41±0.31[a]	8.61	3.92±0.22[b]	8.23	3.30±0.13[c]	8.86	2.19±0.11[d]	6.38	0.39
Fat (%)	5.8±0.10[a]	11.33	5.11±0.12[b]	10.72	4.02±0.09[c]	10.80	2.38±0.06[d]	6.93	0.18
Crude fiber (%)	0.63±0.04[a]	1.23	0.59±0.06[ab]	1.24	0.49±0.05[b]	1.32	0.50±0.06[b]	1.46	0.10
Total carbohydrate (%)	39.72±1.47[a]	77.56	37.27±1.60[a]	78.22	28.84±2.26[b]	77.44	28.58±1.87[b]	83.25	3.44
Energy (Kcal/100g) (calculated)	228.72±4.04[a]	446.65	210.75±4.45[b]	442.28	164.74±9.07[c]	442.40	144.50±8.58[d]	420.89	13.06

*Samples having the same superscript do not differ at 5% level of significance (α); wb = wet weight basis (mean ± standard deviation); db = dry weight basis (values were calculated only by using the mean wb values).

variation, physicochemical and environmental difference, seasonal effect, harvesting period, pre-harvest and post-harvest condition of mangoes etc.

3.3 Effect of kernel variety on drying kinetics

To observe the drying behavior of different mango kernels, 6 mm kernel slices of four mango varieties were dried in a mechanical (cabinet) dryer at 65°C. The results were analyzed by using the semi-theoretical equation derived from Fick's law (equation 4) and thus, the values of moisture ratio (MR) versus drying time (hr) were plotted on a semi-log coordinate (Figure 1) and following regression equations were derived:

$MR = 0.908e^{-0.32t}$ (for Baishakhi) (5)

$MR = 1.030e^{-0.37t}$ (for Amrapli) (6)

$MR = 1.000e^{-0.42t}$ (for Fazli) (7)

$MR = 0.966e^{-0.50t}$ (for Ashwina) (8)

Where, t= time in hrs. From the above equations (5 to 8) and in Figure 1, it is seen that kernel variety had profound influence on drying rate and a general calculation reveals that Ashwina kernel required the lowest time of 4.54 hrs to dry to MR of 0.1, where Amrapali kernel required 6.23 hrs; Fazli kernels required 5.48 hrs while the highest time of 6.89 hrs was required by Baishakhi kernels to dry to MR=0.1 which is the end of first falling rate period. The observed differences in drying time to specific moisture ratio (MR = 0.1) may be due to differences in physiochemical properties (such as solid/solute, initial moisture content, structure etc.), weather conditions, varieties etc. It may be noted that Baishakhi mango becomes available in the market before the rainy season, Amrapali and Fazli are during the rainy season and Ashwina is after the rainy season. These four mango kernels had different initial moisture content which had an effect on drying rate constant as the higher the initial moisture content, the higher the drying rate constant due to having higher free water. The similar observation was made by Islam (1980).

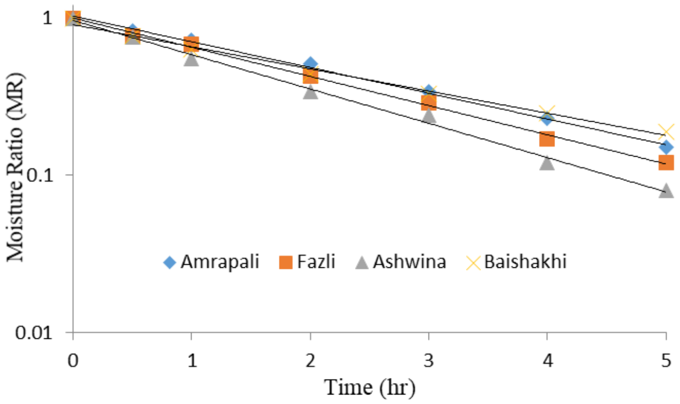

Figure 1. Influence of kernel variety on drying rate at 65°C with thickness of 6 mm

3.4 Comparison of rehydration kinetics between MKF and WF

3.4.1 Effect of temperature on rehydration behavior and rate constant

To analyze the effect of temperature on rehydration behavior of MKF and WF, both flours were rehydrated at 40, 50, and 60°C and by using Peleg (1988) model where absorption of moisture expressed as ratio (g water/ g dry matter) vs time (min) was plotted on linear coordinate (Figure 2 (a, b)) and revealed that uptake of the moisture of both flours increased with the increased temperature and time. Athanasia and Konstantinos (2009) observed the same effect in the case of rehydration behavior of dried tomato. As for WF, the increase in moisture content with temperature at each time interval was comparatively higher than MKF and at 60°C the degree of moisture uptake was even higher for the WF. This behavior again can be attributed to the difference in ratio of fat, protein, and carbohydrate of the samples and process of gelatinization.

To obtain the rehydration rate constant at different

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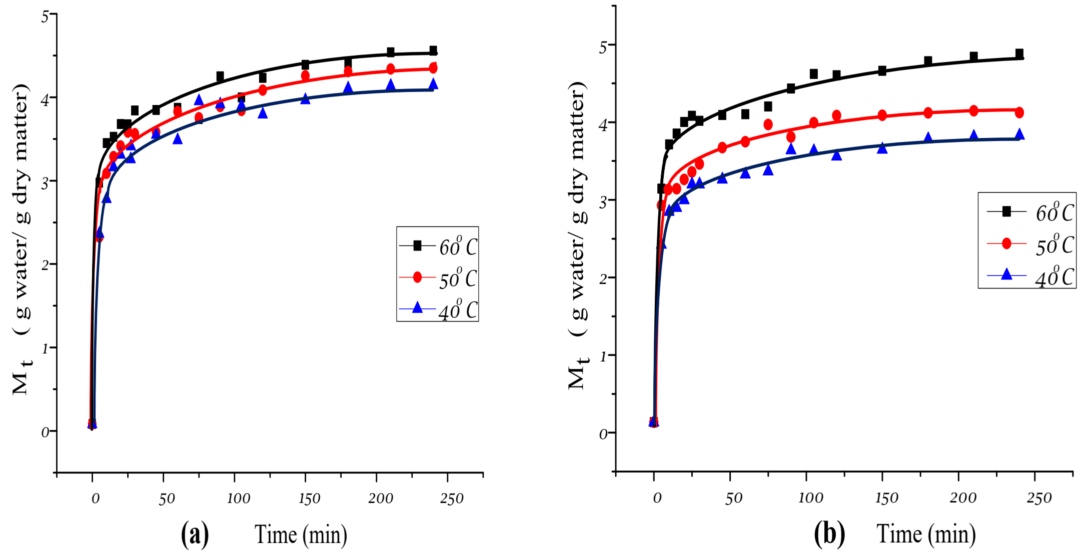

Figure 2. Effect of temperature on rehydration behavior of (a) MKF and (b) WF

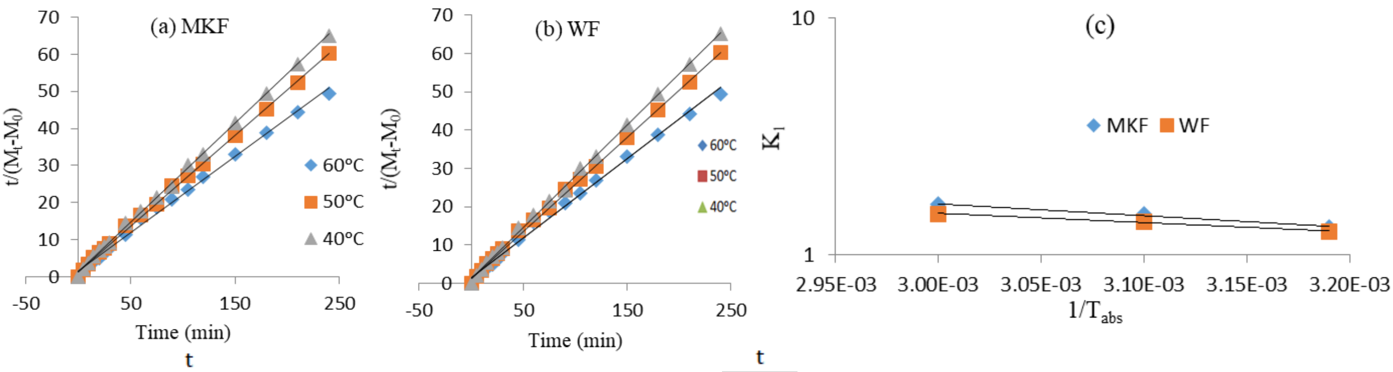

Figure 3. (a) $\frac{t}{Mt-M0}$ vs time plot for MKF using peleg model; (b) $\frac{t}{Mt-M0}$ vs time plot for WF using peleg model; and (c) Relationship between rehydration rate constant and inverse absolute temperature

temperature, rehydration model described by Peleg (1988) was used and Figure 3(a, b) was obtained for MKF and WF respectively where ($t/(M_t-M_0)$) vs time (t) was plotted on linear coordinate and regression analysis gave the following equations (9 to 14):

$$\frac{t}{Mt-M0} = 1.629 + 0.233t \quad \text{(for MKF at 60°C)} \quad (9)$$

$$\frac{t}{Mt-M0} = 1.476 + 0.232t \quad \text{(for MKF at 50°C)} \quad (10)$$

$$\frac{t}{Mt-M0} = 1.309 + 0.240t \quad \text{(for MKF at 40°C)} \quad (11)$$

$$\frac{t}{Mt-M0} = 1.486 + 0.206t \quad \text{(for WF at 60°C)} \quad (12)$$

$$\frac{t}{Mt-M0} = 1.383 + 0.245t \quad \text{(for WF at 50°C)} \quad (13)$$

$$\frac{t}{Mt-M0} = 1.250 + 0.267t \quad \text{(for WF at 40°C)} \quad (14)$$

From Figure 3 (a, b) and equations (9-14), it is seen that values of rehydration rate constant (min (g dry matter)/g water) of MKF were found to be 1.309, 1.476 and 1.629 at 40, 50 and 60˚C respectively while for WF, the corresponding values were 1.250, 1.383 and 1.486. The rate constant values (min. kg dry matter/kg H_2O) for rehydration of dried tomato were 4.157, 4.177, 4.319 and 4.491 for 25, 40, 60 and 80˚C respectively (Athanasia and Konstantinos, 2009). Souza *et al.* (2011) reported the values of rehydration rate constant as 2.73, 2.61, 1.67 and 1.76 for the powder of freeze-dried beaten pulp, disk, cube and slab sized avocado fruit respectively at room temperature.

3.4.2 Estimation of Activation energy for MKF and WF

To determine the activation energy for absorption of water by MKF and WF, the rehydration rate constant (k_1) values were plotted against inverse absolute temperature (1/Tabs) in a semi-log coordinate and regression lines were drawn (Figure 3 (c)) and the following equations (15 and 16) were developed:

$$K_1 = 51.27e^{-1148/Tabs} \quad \text{(for MKF)} \quad (15)$$

$$K_1 = 22.69e^{-906/Tabs} \quad \text{(for WF)} \quad (16)$$

Where, K_1= rehydration rate constant (min. g dry matter/ g water), T_{abs}= Absolute temperature, ˚K. From the above equations, the activation energy (Ea) for MKF was calculated as 9.544 KJ/mole which was higher than that of WF (7.532 KJ/mole) and the K_0 (min. g dry matter/ g water) values are 51.27 and 22.69 for MKF and WF respectively. The Ea value for rehydration of dried spinach was 23.84 KJ/mol (Dadali *et al.,* 2008). They also reported the K_0 value as 0.0075 (s (g db/g)). The

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relatively low Ea value (1.257 KJ/mol) was reported by Athanasia and Konstantinos (2009) for dried tomato.

4. Conclusion

Mango kernel, an important portion of the whole mango can be considered as a supplementary material for food processing. This study indicated that a mango contains around 8.40-12.40% kernel from the four mango varieties studied. The present study assists to suggest that early variety Baishakhi mango's kernel can be selected for processing into flour or other forms rather than other kernels because of its higher kernel percentage (12.40%). The nutritional analysis revealed that the mango kernel is a good source of protein and fat, and can provide a significant amount of energy. To dry faster, Ashwina's kernels are more suitable as this late variety had higher drying rate constant (0.50/hr) than other three samples. The comparison of rehydration kinetics between MKF and WF concluded that WF rehydrates quickly than MKF and comparatively more water will require for MKF than WF for a standard dough preparation.

Conflict of Interest

The authors declare no conflict of interest in this manuscript.

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