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RESEARCH PAPER

Rapid Conditioning of Cashew Kernels by Infrared Heating

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ABSTRACT

Conventional hot air method of cashew kernel conditioning is time consuming besides other limitations, hence rapid infrared conditioning was tried as an alternative conditioning method. Comparative study of different temperature levels of infrared conditioning was carried to determine the effects on quality parameters of cashew kernel conditioning before peeling were compared with hot air conditioned kernels. Second level of infrared conditioning i.e., 160 °C for 8 minutes was found to the best conditioning treatment out of all infrared heating levels tried, yielding kernel quality comparable to conventional hot air conditioning. Moisture removal during infrared conditioning was analyzed using different established drying models. Page model was found to fit well in all three selected infrared conditioning levels. Diffusion coefficients during infrared and hot air conditioning were found to be 1.40×10^{-08} and 9.00×10^{-10} m^2/s respectively.

Keywords: Cashew kernels, infrared heating, drying kinetics and modelling, quality analysis

Processing of cashew nut involves roasting, shelling, conditioning, peeling, grading and packing. Kernels obtained after shelling of cashew nuts contain a thin testa layer which is removed to make kernels edible (Ali and Judge, 2001). Prior to peeling, conditioning is done to make the peel fragile to reduce damages of kernel during peeling, because broken or damaged kernels has low consumer acceptability. Balasubramaniam (2006) optimized conditioning of cashew kernels at 70 °C for a period of 6 hours followed by cooling for 24 hours at room temperature which makes peels fragile enough to get peeled off easily without damaging the kernel. Moisture content of the kernel after the conditioning treatment gets reduced to 3% (Ali and Judge, 2001). For hot air treatment, cashew kernels are kept in a cross flow type of dryer known as Borma dryer, whose estimated capacity varies from 4-12 kg per person per day (Ohler, 1979). Tirawanichakul *et al.* (2011) reported two stages drying of cashew kernels, i.e. by hot air and microwave method and studied the drying characteristics and quality of conditioned kernels.

However, some problems are associated with the hot air conditioning i.e. high processing time of 6 hour heating followed by 24 hour cooling. Besides, hot air in Borma dryer is generated by burning cashew shells or fuel woods, creates serious environmental pollution.

Infrared heating is much better than conventional hot air conditioning method, which is also used for several applications in food industries for thermal processing. Infrared radiation is electromagnetic in nature that when exposed to material surface, gets penetrated in the material surface and the radiation energy gets converted into heat. Advantages offered by infrared drying over existing hot air drying methods include higher moisture removal rate and reduced processing time. Uniform heating of product occurs during infrared heating along with efficient product heating without heating the surrounding and better control of product temperature. Infrared heating has reported as environmental friendly process and causes no air pollution (Grdzelishvili and Hoffman, 2013; Narang, 2005 and Nindo and *Mwithiga* 2010).

Many studies have been done with promising future applications regarding drying of fruits, vegetables, grains and others with the help of infrared dryer (Afzal and Abe, 1997; Nathakaranakule *et al.*, 2010; Nindo and *Mwithiga*, 2010; Doymaz, 2012). Mass transfer during infrared drying of cashew kernels was studied by Hebbar and *Rastogi* (2001). Process of infrared conditioning of cashew kernels was optimized by response surface methodology (RSM) and best results were obtained at 55 °C of infrared drying of cashew kernels with peels for 55 min (Hebbar and Ramesh, 2005). To modernize and automate cashew nut processing, there is a need of short time and environment friendly cashew kernel conditioning method. Although no literature was found reporting high temperature-short time conditioning of cashew kernels before peeling and its qualitative comparison with that of conventional hot air conditioning.

The objectives of the present work were to (1) identify a rapid environmental friendly conditioning method for cashew kernels and to assess its quality in terms of texture, colour and browning index with that of conventional hot air conditioned cashew kernels at 70 °C for 6 hours and (2) determine diffusivities and developing mathematical model during identified method of conditioning.

MATERIALS AND METHODS

Raw cashew nuts were procured from local cashew nut processing units in Kharagpur, India. Nuts were cleaned and sun dried for 3 days and subsequently, were roasted. Roasted nuts were cooled for overnight in normal room temperature (27-29 °C), followed by shelling of roasted cashew nuts by hand operated cashew nut sheller. After shelling of the roasted cashew nuts, raw cashew kernels with reddish-brown coloured testa layer were obtained which were used for further experiments.

Dimensions of 50 cashew kernels were measured with the help of "travelling microscope" vernier calliper

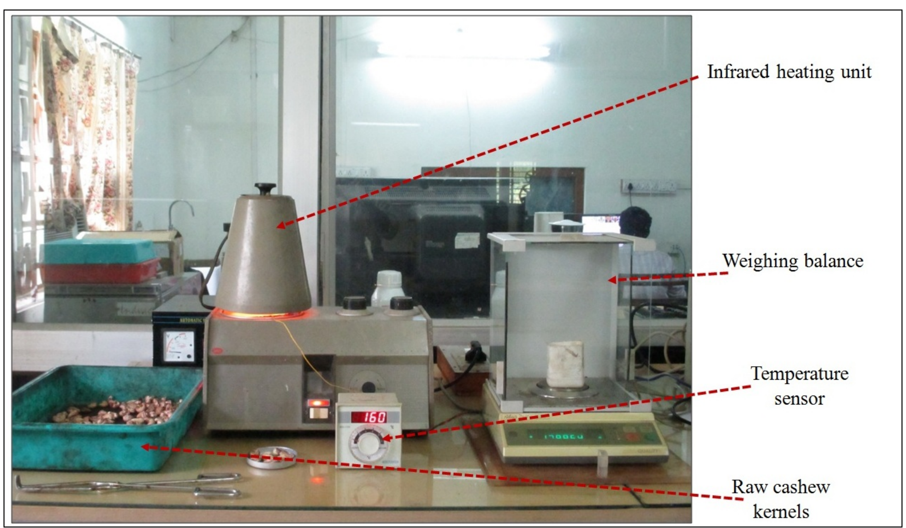

Fig. 1: Infrared conditioning setup

to determine average sphericity and equivalent diameter (Balasubramanian, 2001). Raw unpeeled cashew kernels were subjected to two different conditioning treatments, i.e. hot air conditioning at 70°C for 6 hours and infrared conditioning where time and temperature was varied. Hot air conditioning of cashew kernels was done in hot air tray dryer (S. D. Instruments and Equipments, Mohan Bagan Lane, Kolkata - India). Air temperature of the dryer was maintained at 70 (±1) °C. Air flow rate was 0.5 to 0.6 m/s. Product centre temperature varied between 69-70 °C.

Infrared conditioning setup consists of infrared heating bulb (Philips IRR, Specifications: 220-230 V & 250 W) which was enclosed in an insulated wooden box, with an attached variac to vary the intensity of infrared radiation by varying the input power level. Temperature was measured with the help of electronic temperature sensor with k type thermocouple. Infrared heating setup is shown in Fig. 1.

Infrared treatment was varied in 9 different temperature levels. For this experimental study, 9th level represents highest temperature of 450 °C and 1st level represents 135 °C. Conditioning of cashew kernels was continued till brown discolouration was seen.

As it have been already stated that the moisture content after conditioning treatment should be 3% for easy peeling, so the infrared levels that could not reduce the moisture content to 3% or below before discolouration were rejected. The infrared temperature levels which reduced the moisture content of cashew kernels near to 3% without brown discolouration were accepted.

Quality evaluation of conditioning treatment

After infrared conditioning at selected temperature levels, the conditioned kernels were peeled and obtained edible cashew kernels of different conditioning treatments were compared on the basis of quality. Quality parameters were colour, browning index and hardness.

Colour

Chromameter (Model CR-400) manufactured by 'Konica Minolta' was used to measure L*, a* and b* values of kernels. Colour difference (ΔE) values of individual samples were calculated using market samples as reference. The sample with lowest ΔE value, being closest to the market sample in terms of colour, was desirable.

Browning Index (BI)

During heating of cashew kernels, non-enzymatic browning was observed. Browning index (BI) was determined according to the method adopted by Hebbar and Ramesh (2005) and Maskan (2001). In the method, BI was calculated from the equation based on L*, a* and b* values obtained from Chromameter is shown in Eq. (1) and (2);

$$BI = \frac{100(x - 0.31)}{0.17} \quad (1)$$

$$x = \frac{a + 1.75L^*}{5.645 + a^* - 3.012b^*} \quad (2)$$

Hardness

Hardness was determined by Texture analyzer (Texture technologies Corp., Stable Microsystems Ltd, UK Model: TA-XT2i), with cylindrical aluminium probe of 25 mm diameter.

Comparing these quality parameters with market available cashew kernel samples, best conditioning treatment was identified.

Conditioning of cashew kernels by infrared and hot air conditioning methods

Moisture removal characteristics during best infrared and hot air conditioning were studied. Based on the moisture loss results, equilibrium and moisture content were predicted (Hebber *et al.*, 2001) and diffusivity was calculated based on Fick's solution of unsteady state diffusion equation for sphere (Eq. 3) as stated by Crank (1975). Neglecting the higher

Table 1: Established Mathematical Drying Models

Model name	Equation	References
Henderson and Pabis	$MR = a \times e^{(-k\times t)}$	Togrul 2005, Ozdemir and Onur Devres 1999.
Lewis	$MR = e^{(-k\times t)}$	Doymaz and Ismail 2011, Ozdemir *et al.* 1999
Page	$MR = e^{(-kt^n)}$	Celma *et al*. 2008, Togrul 2005
Wang and Singh	$MR = 1 + at + bt^2$	Togrul 2005, Ozdemir *et al.* 1999
Midilli	$MR = ae^{(-k\times t^n)} + (b\times t)$	Celma *et al*. 2008., El-Beltagy *et al*. 2007

Note: a, b, c and k are empirical constants; MR = Moisture ratio; t = time

order terms by taking 1st term of the equation and simplifying it Eq. (4) was obtained as.

$$M_R = \frac{m_t - m_e}{m_0 - m_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}e^{\left(\frac{-n^2\pi^2 D_{eff} t}{R^2}\right)} \quad (3)$$

By considering first term of the equation (i.e. n = 1), we got,

$$\ln\left(\frac{m_t - m_e}{m_0 - m_e}\right) = \ln\left(\frac{6}{\pi^2}\right) - \frac{\pi^2 D_{eff} t}{R^2} \quad (4)$$

where, M_R = Moisture ratio

m_e = Equilibrium moisture content [By the method of extrapolation, (Hebbar and Rastogi, 2001)]

m_t = Moisture content (at t = t)

m_o = Initial moisture content (at t = 0)

D_{eff} = Diffusion coefficient

t = time

R = Equivalent radius of the sphere

Fourier number for mass transfer (Fo)

$$(F_O) = \frac{D_{eff} \times t}{R^2} \quad (5)$$

Putting Eq. (5) in Eq. (6) we get,

$$\ln(MR) = \ln\left(\frac{6}{\pi^2}\right) - \pi^2 \times F_o \quad (6)$$

By plotting Fo with time, the straight line equation was to be obtained. From the straight equation [y = mx + c], m value (slope) would be:

$$m = D_{eff} / R^2$$

$$\text{or, } D_{eff} = m \times R^2 \quad (7)$$

From Eq. (7) diffusivities of cashew kernel during hot air and infrared conditioning were determined.

Model fitting

For developing mathematical model of moisture removal process during infrared conditioning, empirical thin layer drying models were fitted in the moisture ratio (MR) and time (t) data obtained during infrared conditioning of cashew kernels. Following thin layer drying models, shown in Table 1, were tried to be fitted with Origin® software, to select the best model describing the thin layer drying equation.

For determining the goodness of fit, three statistical methods were selected, namely adjusted R^2, reduced χ^2 and residual sum of square (RSS) which are defined in Eq. (8), (9) and (10).

$$Adj.R^2 = 1 - \frac{RSS / df_{Error}}{TSS / df_{Total}} \quad (8)$$

$$RSS = \sum_{i=1}^{n}\left(MR_{\exp,i} - MR_{pre,i}\right)^2 \quad (9)$$

$$\chi^2 = \frac{1}{N-n}\sum_{i=1}^{n}\left(MR_{\exp,i} - MR_{pre,i}\right)^2 \quad (10)$$

Adjusted R^2, reduced χ^2 and Residual Sum of Square (RSS) were the criteria used for selection of the best model. RSS is a measure of the discrepancy between the data and an estimation model. Higher Adj. R^2, smaller RSS and lower reduced χ^2 value indicates better goodness of fit and vice-versa (El-Beltagy *et al.*, 2007, Hosainpour *et al.*, 2012).

RESULTS AND DISCUSSION

Proximate composition of raw cashew kernels as determined by standard methods is shown in Table 2.

Table 2: Composition of Raw Cashew Kernel

Composition	% Value
Moisture	8.45 ± 0.01
Fat	45.49 ± 0.30
Protein	38.24 ± 0.29
Ash	2.24 ± 0.02
Crude fiber	3.35 ± 0.31
Carbohydrate	2.05

Dimension of raw cashew kernels with peel was shown in Table 3 for determining sphericity and equivalent diameter of cashew kernel.

Table 3: Raw Cashew Kernel Dimensions

Parameters	Dimension (cm)
Length	2.22 ± 0.20
Width	1.49 ± 0.26
Thickness	0.96 ± 0.16
Sphericity	0.66
Equivalent diameter	1.47

Infrared conditioning of cashew kernels

Table 4 shows different infrared heating temperature done during infrared conditioning of cashew kernels.

Table 4: Infrared Drying Levels

IR level	Approx. Temperature (°C)	Final MC (g/ g of dry solid)	Status
9	450	0.08	Reject
8	400	0.08	Reject
7	380	0.08	Reject
6	330	0.08	Reject
5	280	0.07	Reject
4	250	0.04	Reject
3	200	0.03	Select
2	160	0.02	Select
1	135	0.02	Select

Temperature of the specific level (450 to 135 °C) with final moisture content that could be achieved before occurrence of brown discolouration of cashew kernel under infrared treatment was mentioned. Status of selection, i.e. acceptance/ rejection of infrared level was also mentioned in the same Table.

As mentioned earlier that, the moisture content of conditioned kernels should be reduced to 3% for good peeling without affecting the quality parameters (Ali and Judge, 2001). Treatment temperature levels which have discoloured kernels before achieving moisture content of 3% (db) were rejected (i.e. 450, 400, 380, 330, 280, 250 °C) and treatment levels that conditioned kernels with desired moisture content was selected (i.e., 200, 160 and 135 °C). From Table 4, it is could be seen that, the levels from 9 to 4 were rejected, because due to high temperature, before the moisture could be removed to 3%, the kernels were getting burnt. Hence, three infrared conditioning temperature levels, i.e. 3rd, 2nd and 1st levels were selected (i.e. 200, 160 and 135 °C).

Table 5: Quality Parameters of Various Treatments

IR level	Approx. Time before browning (min)	Approx. Temperature (°C)	ΔE	BI	Hardness	Remark
Hot air	360	70	0.00	36.30	50.90	Conventionally used
1 (135°C)	12	135	5.67	40.20	41.97	
2 (160 °C)	6	160	5.14	34.22	43.07	Selected treatment
3 (200 °C)	5	200	12.00	34.87	30.78	

Effects of infrared conditioning on quality parameters

Determined quality parameters are presented in Table 5. Browning index was calculated by using Eqn. 1 and 2. Samples of cashew kernels obtained after each selected infrared treatments, were analyzed to determine the quality parameters based on which the best conditioning treatment is to be selected. Hot air conditioning which is widely acceptable conditioning treatment is taken as a bench mark to compare the infrared treated samples.

As from the data shown in Table 5, colour difference (ΔE) and browning index (BI) are found to be dependent on time and temperature of the conditioning treatment. From the result it can be concluded that for longer duration and higher temperature treatment, greater would be the colour difference and vice versa. These results agree with the studies reported by Masken (2001) and Titawanichakul *et al.* (2011) where they have reported that with rise in treatment time and temperature respectively, significant increase of ΔE and BI value was recorded. For 2nd level infrared treatment (at 160 °C – 8 min infrared treatment) lowered value of colour difference and browning index indicates the increase of temperature but with reduction of treatment time. L*, b* and a* values of hot air conditioned samples were taken as control value based on which ΔE of other conditioned cashew kernels were calculated. But at 3rd level of infrared treatment, i.e. at 200 °C, rise of temperature was too much to cause sufficient change in colour and increasing browning index to significant level instead of lowering of treatment time. Higher the temperature, higher the moisture removal rate but greater will be the chances of browning.

Hardness is related to moisture content of the product which changes with change in moisture content. Out of three different conditioning treatments, it was found that 2nd level of infrared conditioning was providing the hardness nearer to that of hot air conditioned cashew kernels. From the results shown in Table 5, it is clear that the treatment received by 2nd level is the best conditioning treatment was three infrared treatments. Keeping in mind other attributes, 2nd level (160 °C – 8 min infrared treatment) was selected as best conditioning treatment.

Moisture diffusivities of cashew kernels during infrared and hot air conditioning

Variation of moisture content with conditioning time is shown in Fig. 2. From the figure, it can be seen

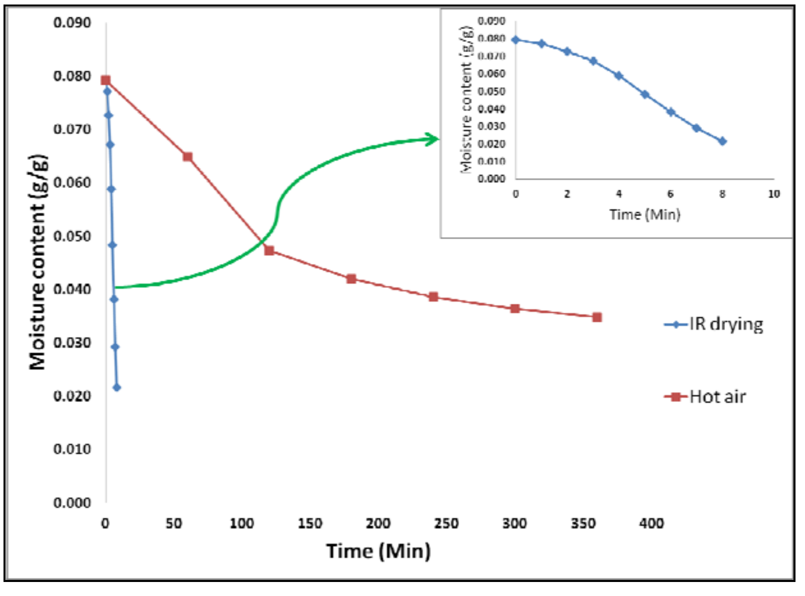

Fig. 2: Variation of moisture content with time during different conditioning treatment

that the moisture removal with time during infrared conditioning is much faster than hot air conditioning.

It was found that the extent of moisture removal obtained during hot air at 70 °C in 6 hours can be attained in only 8 minutes by infrared conditioning method (160 °C). Moisture removal rate from infrared heating is better depicted in a magnified view in-set in the figure and indicated by an arrow. Higher moisture removal rate by infrared treatment compared to hot air drying without compromising the quality of the dehydrated products was earlier demonstrated by of Togrul (2005) and Celma *et al.* (2008).

As described by Hebber *et al.* (2001) and Hosainpour *et al.* (2012) equilibrium moisture content and diffusion coefficients were determined using Eq. (7) and are presented in Table 6.

Table 6. Diffusion Coefficient Values

Drying mode	Temp. (°C)	Equilibrium moisture content (g/g)	Diffusion coefficient (m^2/s)
Hot Air	70 (69-70)	0.032	9.00×10^{-10}
Infrared	160 (158-162)	0.016	1.40×10^{-08}

Diffusion coefficients during infrared and hot air conditioning were found to be 1.40×10^{-08} and 9.00×10^{-10} m^2/s, respectively. It was found that with a rise in temperature, diffusion coefficient increased with lowering of equilibrium moisture content. If the conditioning temperature is too high, then it is possible to nearly bone dry the kernel which theoretically gives 0% moisture content (bone drying condition).

Infrared heating at higher temperature is used for rapid determination of moisture content, which justifies near to zero equilibrium moisture content during infrared conditioning treatment. It was observed that diffusivity was less for hot air conditioning and much high for infrared conditioning. Reason for this is, higher the temperature, more would be the moisture diffusion. Similar effect was observed in Hebbar and Rastogi's work (2001) where it was reported with the rise in temperature, equilibrium moisture content reduces and but diffusivity coefficient increases.

Modelling of infrared conditioning

Change in moisture ratio with time during different levels of infrared conditioning was shown in Fig. 2, which is a typical drying curve. To understand the moisture removal pattern, it was important to model the mass transfer process occurring during conditioning. The moisture content data at different levels of infrared conditioning temperatures were converted to more useful moisture ratio expression and then curve fitting computations with conditioning time were done by using five established drying models. Model fitting was done with the help of Origin® software. Selection criteria were based on highest adjusted R^2 value, along with lowest RSS and reduced χ-square value, which were determined as measures of goodness of fit. Results of model fitting are summed up in Table 7.

To select the best model, highest regression coefficient coupled with lowest reduced chi-square value was searched in Table 7 and Page model was found to suit the best as per the requirement. Therefore, Page model was used to evaluate the moisture ratio of cashew kernels during conditioning of cashew kernels for specified interval of conditioning temperature and time for this study.

The limitation of Page model is that it predicts the moisture ratio in relation to treatment time for a specific IR level and does not encompass the effect of varying temperature. Thus, the model coefficients were to be evaluated separately for each of the desired IR intensities or temperatures.

To accommodate the effect of IR level governing the treatment temperature a multiple regression analysis was performed which yielded a relationship expressing moisture ratio as a function of treatment temperature and time as shown in Eq. (11).

$$MR = e\text{\^{}}\ [\{-((1.19\times10^{-5}\times T^2)-(4.04\times10^{-3}\times T) + 0.36))\} \times \{t\ \text{\^{}}\ ((-7.06\times10^{-04}\times T^2) + (0.249\times T)-19.65)\}] \quad (11)$$

Table 7: Model Fitting of Cashew Kernels during Infrared Conditioning

Model name	Conditioning method	Model constants		Reduced Chi²	RSS	Adjusted R^2	Fit Status
Henderson and Pabis	1st Level IR	a	1.056	2.56E-04	0.007	0.996	Succeeded
		k	0.052				
	2nd Level IR	a	1.099	0.007	0.052	0.89	Succeeded
		k	0.124				
	3rd Level IR	a	1.123	0.007	0.065	0.925	Succeeded
		k	0.146				
Lewis	1st Level IR	k	0.048	7.18E-04	0.022	0.989	Succeeded
	2nd Level IR	k	0.105	0.009	0.072	0.867	Succeeded
	3rd Level IR	k	0.125	0.01	0.097	0.899	Succeeded
Page	1st Level IR	k	0.028	4.34E-05	0.001	0.999	Succeeded
		n	1.184				
	2nd Level IR	k	0.016	2.349E-4	0.002	0.997	Succeeded
		n	2.085				
	3rd Level IR	k	0.025	2.66E-05	2.39E-04	1.000	Succeeded
		n	1.874				
Wang and Singh	1st Level IR	a	-0.04	1.79E-04	0.005	0.997	Succeeded
		b	4.59E-04				
	2nd Level IR	a	-0.033	1.37E-04	9.61E-04	0.998	Succeeded
		b	-0.007				
	3rd Level IR	a	-0.066	0.001	0.012	0.986	Succeeded
		b	-0.002				
Midilli	1st Level IR	a	0.938	0.002	0.053	0.969	Succeeded
		b	-0.027				
		k	-0.003				
		n	1.03E-08				
	2nd Level IR	a	0.99	6.08E-4	0.003	0.991	Succeeded
		b	-0.166				
		k	-0.165				
		n	0.53				
	3rd Level IR	a	1	5.717E-4	0.004	0.994	Succeeded
		b	-0.098				
		k	-0.083				
		n	0.057				

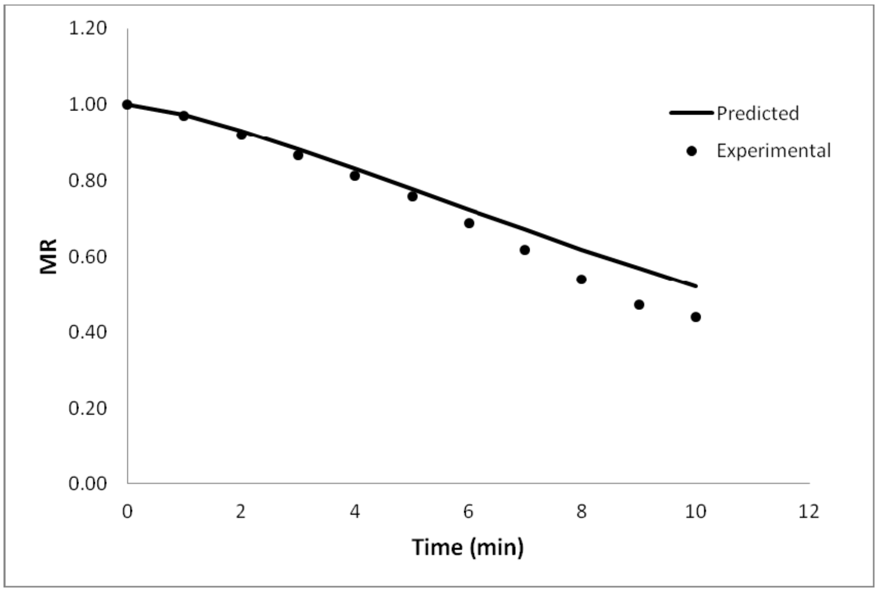

Fig. 3: Experimental and predicted MR with Time (min)

where,

T = Temperature below Infrared heat source (°C)

t = Conditioning time (min)

Developed model showed good fit at all three temperature levels of infrared conditioning treatments. Developed model was tested at another infrared conditioning level where temperature was 140 °C. Known amount of cashew kernels were placed below infrared heating source and the sample was weighed after every one minute interval. Total infrared heating was done for 10 min and then, moisture ratio (MR) was determined. Plotting was done to determine the deviation of experimental versus developed model predicted data with time, as shown in Fig. 3.

Fig. 3 showed good fitting of experimental values as predicted by the developed model. Coefficient of determination between experimental and predicted values was found to be 0.997. Developed model fits well with experimental data. High regression coefficient value also suggests a good fit in the range of 137 to 200 °C.

CONCLUSION

Cashew kernel conditioning before peeling by hot air method is a time consuming process which may vary between 6-8 hours. Hot air when generated by burning fuel wood or cashew shells promotes a serious risk of heavy environmental pollution. Study was conducted to reduce the conditioning time of cashew kernels without environmental pollution and quality degradation. Instead of hot air, infrared conditioning was used whose temperature could be varied from 450 to 135 °C in 9 different levels, where higher level indicating higher temperature and vice-versa. Levels 4 to 9 were rejected since these high intensity levels caused kernel browning before reaching desired conditioning stage and level 1, 2 and 3 were selected.

Infrared conditioned cashew kernels of these three selected levels were compared with hot air conditioned cashew kernels based on certain quality parameters, viz., colour difference, browning index and hardness. It was found that the cashew kernel conditioned with infrared level 2 (160 °C for 8 min) was the best out of the 3 treatments. Diffusion coefficients during infrared and hot air conditioning were found to be 1.40×10^{-08} and 9.00×10^{-10} m^2/s

respectively. Diffusivities were found to be higher for high temperature infrared treatment than hot air conditioning. Empirical model fitting was done and found that the Page's model fits well with the data with adjusted R^2 value of 0.99 and reduced χ^2 value of 2.35×10^{-5}.

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