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Drying behaviour of unpeeled cashew kernels in steam assisted cross flow dryer

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ABSTRACT : The performance of the steam assisted cross flow dryer employed in Indian cashewnut processing industry for drying unpeeled cashew kernels was assessed in terms of drying rate in relation to peeling efficiency. The rate of removal of moisture from unpeeled cashew kernels significantly varied with the location inside the dryer. Cashew kernels placed in close proximity to heat exchanger showed faster diffusion of moisture than other locations inside the dryer. Moisture content of unpeeled cashew kernels was reduced to less than 3.0 per cent (d.b) in the beginning *i.e.* first 3 hr of drying and reached below 1.0 per cent (d.b) after 9 hr of drying from the initial moisture content of 7.0 per cent (d.b). Movement of humid air towards outlet provided at the top of the dryer and circulation of hot air from bottom to top are the due reasons for the variation in the moisture from the unpeeled cashew kernels inside the dryer. Significant difference was found in the peeling efficiency of unpeeled cashew kernel dried up to 9 hr. Practically, moisture content of unpeeled cashew kernels reduced to 1.0 per cent after 9 hr of drying ensured manual peeling process better and kernels dried for 3 or 6 hr period could not attain the required moisture level to ease manual peeling. Total energy required to operate steam assisted cross flow dryer was found to be 16.49 per cent lesser than existing type of dryers in Indian cashewnut processing sector.

KEY WORDS : Drying, Moisture content, Unpeeled cashew kernels

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Cashew (*Anacardium occidentale* L.) a native of Eastern Brazil introduced to India by the Portuguese nearly five centuries back. Cashewnut is one of the important crops of the coastal region in India. India is the largest producer, processor, consumer and exporter of cashew in the World (Kumar *et al.*, 2002). Cashew is presently grown in an area of 0.92 million ha with an annual production of 0.62 million MT of in-shell cashewnuts in the country (DCCD statistics, 2010).

Shelling of cashewnut and removal of testa are the two major operations in cashew nut processing. The shell of the roasted / steam treated cashewnut is removed manually or with the help of a shelling gadgets. Shelled cashew kernels are dried in a convective dryer for 12±2h to loosen the testa layer which could be removed manually using special knives made up of metal or bamboo or wood (Mandal, 1992).

Thermal drying has been recognized as an important unit operation as it is energy intensive and has a decisive effect on the quality of many products. Escalating energy costs, demand for eco-friendly and sustainable technologies and demand for higher quality products are the principal reasons to develop higher performing dryers. Although the price of oil dropped subsequently, significance of improving the drying operation to save energy, improve product quality and to reduce environmental effect remained flourished over recent years. New drying technologies, better operational strategies and control of industrial dryers have contributed to better cost-effectiveness and quality dried products (Mujamdar, 2006 and Balasubramanian, 2007).

Drying has been reported to account for 12 to 20 per cent of the total energy consumption in the industrial sector. Majority of artificial drying operations are based on hot air drying, wherein air is heated up by the combustion of fossil fuels prior to forced application on the product. This type of drying requires high-energy inputs and more often, the exhaust air is simply released to the surrounding ambient air reducing its efficiency. Some systems allow recycling of exhaust heat to increase the overall energy efficiency of the dryer (Raghavan *et al.*, 2005).

Dryers employed in majority of the Indian cashewnut processing units have either natural or forced convective system. Accounting the problems of non uniform drying, high thermal energy loss, increased cost of drying, reducing environmental degradation etc., in the brick constructed drying system, a novel dryer which works on the basic principle of heat exchange of super heated steam through radiator and fins assembly is introduced in the Indian cashewnut processing industry. This scientific article reports the performance evaluation of the steam assisted cross flow dryer used to increase overall efficiencies, decrease energy consumption and uniform drying of unpeeled cashew kernels in the Indian cashew industry.

■ METHODOLOGY

The performance evaluation of steam assisted cross flow dryer was investigated for unpeeled cashew kernels. All the drying experiments were performed using steam assisted cross flow dryer available at M/S Kalbhavi Cashews, Baikampady Industrial Area, Mangalore, Karnataka, India. The steam assisted dryer is a forced convective type with blowers on either side providing total air circulation on double passing principle. This dryer has the capacity of about 800 kg of unpeeled cashew kernels per batch and consists of mainly three components *viz.,* steam generation unit, drying chamber with heat exchangers, blowers and electronic control unit.

The dryer is of double walled design with inner chamber made up of mild steel and finished with heat resistant aluminum paint. Annular space between walls is filled with glass wool for thermal insulation. Two steam heat exchangers *i.e.* radiators and fins assembly having capacity up to 7 kg cm^{-2} steam pressure are fitted diagonally opposite to each other as shown in Fig. 1. Externally generated steam is passed in to the heat exchangers to transfer heat for drying process inside the dryer. Inlet and outlet pipes are provided at appropriate locations to ensure supply of ambient air and removal of moist air from the dryer. Electric control panel consists of temperature indicator, on/off switches, indicator for fans and other safety features is also provided.

The drying system was run for few minutes in the beginning to ensure steady-state conditions. Later on, the unpeeled cashew kernels were spread on the trays in thin layers and placed at different positions of trolleys located inside dryer. Unpeeled cashew kernels were exposed to hot air maintained at 80±2^{o}C temperature for a total of 9 hr duration. The initial moisture content of unpeeled cashew kernels was around 7.00 per cent (d.b). Weight of the unpeeled cashew kernels placed at different locations inside dryer were recorded using an electronic weighing balance (Make: Essae, India with L.C of 0.001g) periodically. The moisture content was determined in triplicates samples following standard chemical distillation method (Suzanne Nielsen, 2003) and expressed in per cent dry basis using the formula :

$$M_w = \frac{V}{W} \qquad (1)$$

where,

M_w is moisture content wet basis, per cent

V is the volume of water collected during toluene distillation, ml.

W is the weight of in-shell cashewnuts taken for toluene distillation, g.

$$M_d = \frac{100 - M_w}{M_w} \times 100 \qquad (2)$$

where,

M_d is moisture content dry basis, per cent

M_w is moisture content wet basis, per cent.

Samples of unpeeled cashew kernels from various positions inside the dryer were drawn randomly at regular interval of 3 hr and manually peeled. Kernels, thus peeled were segregated in to different fractions *viz.,* whole kernels, broken kernels, unpeeled kernels, spoiled kernels and testa and weighed to work out peeling efficiency using following expression :

$$\eta_p = \left[1 - \frac{UK}{T - R}\right] \times \left[\frac{Pw}{Pw - Pb}\right] \times 100$$

where,

η_p - Peeling efficiency, per cent

UK - Weight of unpeeled kernels after peeling, g

T - Total weight of unpeeled cashew kernel, g

R - Weight of cashew kernel rejects, g

P_w - Weight of peeled whole kernels, g;

P_b - Weight of peeled broken kernels, g .

Data obtained with respect to moisture content per cent (d.b) and peeling efficiency per cent were transformed and analyzed statistically using 3-Factorial Randomized Block Design.

■ RESULTS AND DISCUSSION

Initial moisture content of the unpeeled cashew kernels was found out to be 7.0 per cent moisture content (d.b.) and it was exposed to hot air maintained at 80±2^{0}C for a period of 9 hr. Performance of the steam assisted cross flow dryer was evaluated in terms of rate of drying and peeling efficiency.

Effect of drying time on moisture content of unpeeled cashew kernels :

The effect of drying time on moisture content of unpeeled cashew kernels placed at different position of trolleys *viz.,* top, middle and bottom inside steam assisted cross flow dryer on front and rear side of the dryer is shown in Fig. 1 and 2, respectively. Initial moisture content of samples *i.e.* 7.00 per cent d.b. placed in trolleys T_1 and T_4 at different positions on front side of the dryer *viz.*, top (P_1), middle (P_2) and bottom (P_3) trays of dryer was reduced to 0.82, 0.36, 0.04 per cent and 0.07, 0.54, 0.61 per cent, respectively after 9 hr of drying. But the final moisture content of samples placed in adjacent trolleys T_2 and T_3 of front side of the dryer as shown in Fig. 1 was found to be 0.46, 0.18, 0.11 and 0.43, 0.46, 0.18 per cent at tray positions P_1, P_2 and P_3, respectively. Similarly reduction in the moisture content was observed to be 0.07, 0.04, 0.29 and 0.29, 0.21, 0.25 per cent for the samples placed at positions P_1, P_2 and P_3 in trolleys T_5 and T_8 at rear side of dryer, respectively as shown in Fig. 2. Moisture content of the samples placed in adjacent trolleys T_6 and T_7 located on the rear side of dryer decreased to 0.46, 0.25, 0.54 and 0.61, 0.25, 0.18 per cent at positions P_1, P_2 and P_3, respectively from an initial moisture content of 7.00 per cent.

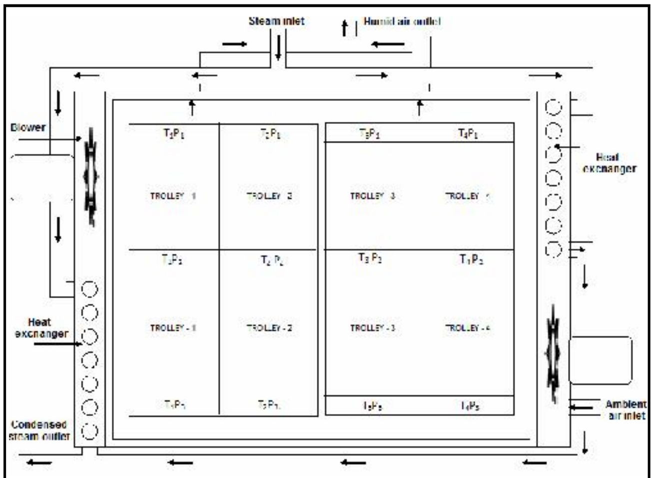


Fig. 1 : Vertical c/s of the steam assisted cross flow dryer (front side) showing the position of trays with unpeeled cashew kernels

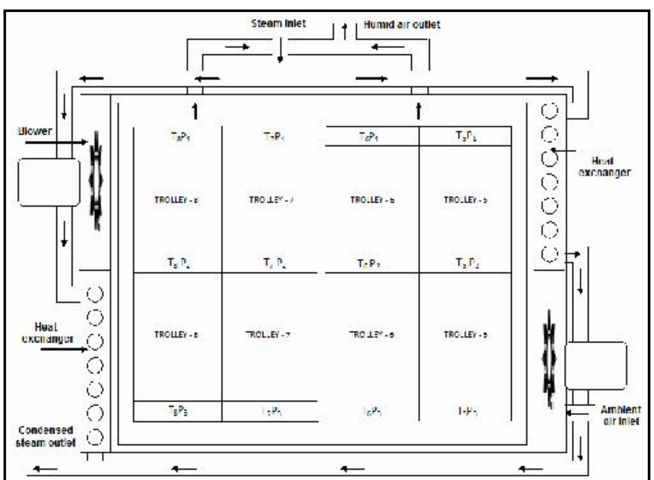


Fig. 2 : Vertical c/s of the steam assisted cross flow dryer (rear side) showing the position of trays with unpeeled cashew kernels

Final moisture content of the samples placed in trolleys on front side *viz.*, T_1, T_2, T_3 and T_4 ranged from 0.04 to 0.82 per cent (d.b.) and on the rear side *viz.*, T_5, T_6, T_7 and T_8 ranged between 0.04 and 0.61 per cent (d.b.) of dryer was at par with each other. This indicates that in spite of differential rate of drying recorded up to 6 hr, moisture loss from samples reached more or less uniform during 9th hr of drying irrespective of its position inside the dryer. The average final moisture content of samples placed in trolleys *viz.*, T_1, T_2, T_3, T_4, T_5, T_6, T_7 and T_8 was observed to be 0.41, 0.25, 0.36, 0.41, 0.13, 0.42, 0.35, and 0.25 per cent, respectively resulted to 94 to 98 per cent of moisture removal after 9 hr of drying.

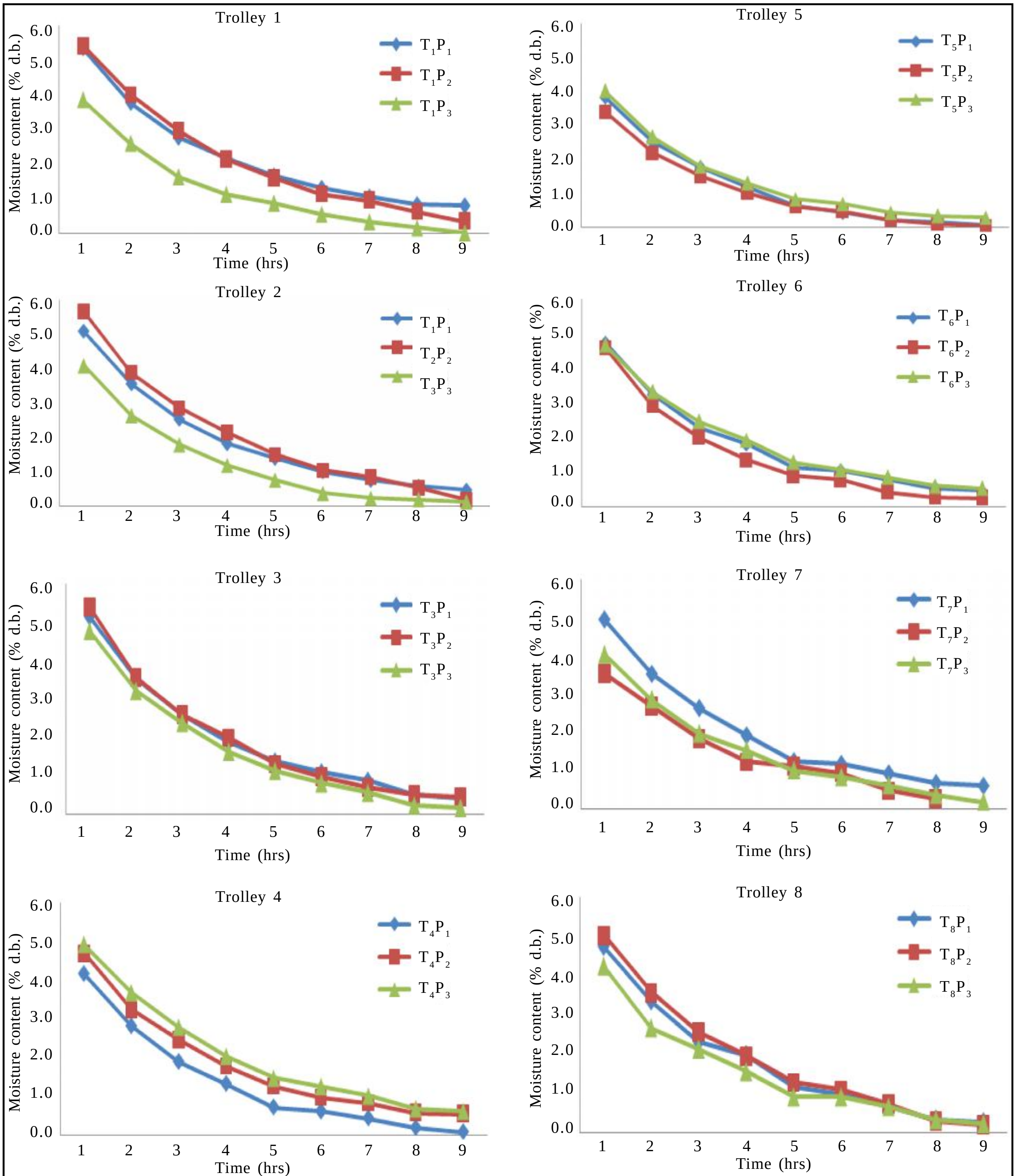
In general, the moisture content of unpeeled cashew kernels was reduced to less than 3.0 per cent in the first 3 hr of drying and below 1.0 per cent after 9 hr of drying. Movement of humid air towards outlet provided at the top of the dryer and circulation of hot air from bottom to top are the due reasons for the variation in the moisture from the unpeeled cashew kernels inside the dryer. The amount of moisture removed was found to be maximum from unpeeled cashew kernels placed at position P_3 *i.e.* at the bottom of trolleys T_1, T_2, T_3, T_7 and T_8, whereas higher rate of moisture removal was observed from unpeeled cashew kernels placed at positions P_1 and P_2 of trolleys T_5 and T_6 after 9 hr of drying.

Effect of drying time on peeling efficiency of unpeeled cashew kernels :

The effect of drying time on peeling efficiency of unpeeled cashew kernel placed at different position of trolleys in a steam assisted cross flow dryer is represented in Fig. 3. It is evident that peeling efficiency of unpeeled cashew kernels increased with drying time *i.e.* 1.95 to 88.43 per cent. It varied from 1.95 to 27.49 per cent and 30.29 to 79.38 per cent for unpeeled cashew kernels dried for 3 hr and 6 hr, respectively placed in various trays of different trolleys. But the values ranged from 72.22 to 88.43 per cent after 9 hr of drying for the unpeeled cashew kernels kept in different location inside the dryer.

A considerable variation was found in the peeling efficiency of unpeeled cashew kernel dried up to 9 hr. Peeling efficiency of samples placed in trolleys T_1, T_2, T_3 and T_4 on front side of dryer was found to be 84.95 (T_1P_1), 88.24 (T_2P_3), 85.04 (T_3P_1), and 81.44 (T_4P_3) per cent, respectively after 9 hr of drying which was found to be higher than unpeeled kernels dried for 6 and 3 hr. Practically, moisture content of unpeeled cashew kernels reduced to 1.0 per cent after 9 hr of drying ensured manual peeling process better and kernels dried for 3 or 6 hr period could not attain the required moisture level to ease manual peeling.

Similarly, the samples dried for 9 hr recorded maximum peeling efficiency of 86.21(T_5P_1), 84.68 (T_6P_2), 88.43 (T_7P_2) and 84.82 (T_8P_2) per cent in trolleys T_5, T_6, T_7 and T_8, respectively



T- Trolley; P- Position of Trays (P_1-Top; P_2-Middle; P_3-Bottom)

Fig. 3 : Variation in the moisture content (d.b) of unpeeled cashew kernels w.r.t drying period inside steam assisted cross flow dryer

on rear side of dryer too and the unpeeled cashew kernels dried for 3 and 6 hr recorded lower peeling efficiency.

The moisture content of samples kept at various location was found to be 0.36 to 1.32 per cent after 6 hr of drying during which the peeling efficiency varied from 30.29 (T_1P_1) to 79.38 (T_4P_1) per cent. But the peeling efficiency varied from 72.22 (T_4P_2) to 88.43 (T_7P_2) after 9 hr of drying during which the moisture content was ranged from 0.04 to 0.82 per cent as shown in Fig. 3 and 4.

Irrespective of position of trolleys, the peeling efficiency was recorded maximum for samples placed at position P_3 *i.e.* bottom of trolley followed by position P_1 and P_2 of trolleys after 6 and 9 hr of drying. The minimum peeling efficiency was recorded for samples placed at position P_2 as it was not in the close proximity to either heat exchanger or blowers. Interaction effect of unpeeled cashew kernels placed in the various trolleys and drying time (Table 1) and various positions and drying time (Table 2) in terms of moisture content and peeling efficiency showed significant difference at 5 per cent level.

Comparative energy utilization during drying process :

The total electrical, thermal and man power utilized

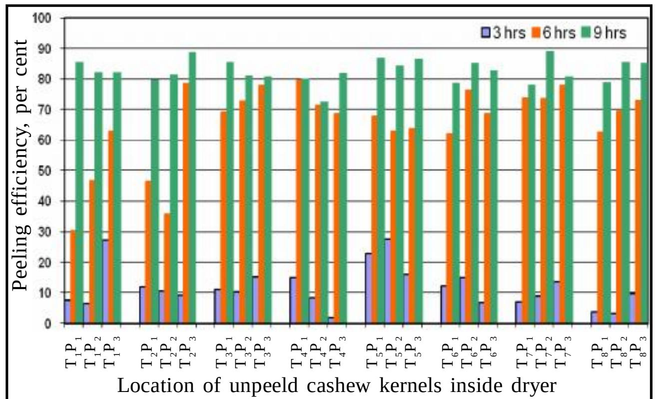


Fig. 4 : The effect of drying time on peeling efficiency of unpeeled cashew kernels placed inside steam assisted cross flow dryer

for drying unpeeled cashew kernels in steam assisted cross flow dryer having capacity of 800 kg $batch^{-1}$ was found to be 97.23, 3684.43 and 0.23 MJ, respectively. But the brick constructed dryer (Borma) utilized 106.92, 4421.32 and 0.23 MJ of electrical, thermal and man power for the drying operation, respectively. Overall, the total energy utilized

Table 1 : Anova for interaction between trolleys (T) and drying time (L) for unpeeled cashew kernels in steam assisted cashew kernel dryer

Trolley	Moisture content				Peeling efficiency			
	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
T_1	8.964	5.688	3.262	5.972	20.73	43.00	65.55	43.09
T_2	8.870	5.013	2.742	5.542	19.05	47.39	65.68	44.04
T_3	9.167	5.664	3.362	6.064	20.47	58.97	64.96	48.14
T_4	8.851	5.510	3.405	5.922	15.86	58.86	61.93	45.55
T_5	7.446	4.128	1.917	4.497	27.98	53.62	67.61	49.74
T_6	8.624	5.633	3.658	5.972	19.42	56.24	64.72	46.79
T_7	8.945	5.829	3.261	6.012	18.17	60.04	65.20	47.80
T_8	8.804	5.777	2.861	5.814	13.27	55.85	65.52	44.88
Mean	8.709	5.405	3.059	5.724	19.37	54.25	65.15	46.25
	S.E. ±		C.D. (P=0.05)		S.E. ±		C.D. (P=0.05)	
Trolleys (T)	0.15		0.43		1.46		4.22	
Levels (L)	0.09		0.26		0.89		2.59	
Interaction	0.26		0.74		2.52		7.31	

Table 2 : Anova for interaction between positions (P) and drying time (L) for unpeeled cashew kernels in steam assisted cashew kernel dryer

Position	Moisture content				Peeling efficiency			
	L_1	L_2	L_3	Mean	L_1	L_2	L_3	Mean
P_1	8.805	5.559	3.418	5.927	19.25	51.84	64.37	45.16
P_2	8.977	5.556	2.936	5.823	18.95	53.11	65.21	45.76
P_3	8.345	5.100	2.821	5.422	19.90	57.79	65.86	47.85
Mean	8.709	5.405	3.059	5.724	20.08	49.79	65.40	45.09
	S.E. ±		C.D. (P=0.05)		S.E. ±		C.D. (P=0.05)	
Positions (P)	0.09		0.26		0.89		2.59	
Levels (L)	0.09		0.26		0.89		2.59	
Interaction	0.16		0.45		1.55		4.48	

for drying 800 kg of unpeeled cashew kernels was found to be minimum *i.e.* 3781.86 MJ for steam assisted cross flow dryer than brick constructed dryer *i.e.* 4528.47 MJ. Better heat utilization efficiency is the due reason for minimal energy requirement for drying process in the case of steam assisted cross flow dryer than in brick constructed dryer. Further, attaining desired temperature within a short period of time and automatic control over air temperature inside are the principal advantages over existing brick constructed dryer.

Summary and conclusion :

The performance of steam assisted cross flow dryer for unpeeled cashew kernels was evaluated in terms of moisture loss and peeling efficiency. The rate of removal of moisture from unpeeled cashew kernels significantly varied with location of samples in the dryer up to 6 hr of drying. Moisture content of unpeeled cashew kernels reached = 1.0 per cent (d.b) during 9 hr of drying promoted peeling efficiency. Variation in moisture removal undoubtedly affected the peeling efficiency of the kernels after 3 and 6 hr of drying. Moisture reduction took place at faster rate for cashew kernels placed in close proximity to heat exchangers or blower than other location. Insignificant difference was observed between front and back side of the dryer and the total energy required for drying 800 kg of unpeeled cashew kernels per batch was worked out to be 3781.86 MJ, which is 16.49 per cent lower than existing dryers of bricks construction.

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