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Performance evaluation of dual mode dryer for in-shell cashew nuts

D. Balasubramanian* and T.N. Sandeep

Directorate of Cashew Research, Puttur-574 202, Karnataka

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Abstract

Performance of a dual mode dryer developed to reduce the moisture content of in-shell cashew nut to improve its shelf life was evaluated. Dual mode dryer consisted of three major components *viz*., drying chamber, aspirator and heat exchanger. Its performance was evaluated by exposing in-shell cashew nuts at an average drying chamber temperature of 65 ºC for safe drying. Preliminary study on infusion of moisture into in-shell cashew nuts indicated that the moisture content of whole nuts and fractions *viz*., shell and kernel increased with increase in soaking period. Moisture reduction took place at faster rate in the case of electrical than thermal power which was used for the generation of heating media for drying moistened nuts. Average time required to reduce the moisture content of in-shell cashew nuts of small, medium and large size to safer level was worked out to be 4.41, 4.37 and 3.16 hrs in the case of electric power and 4.38, 4.28 and 4.11 hrs for thermal power respectively, indicating that the time taken for drying large size nuts was lesser than smaller size nuts. Drying rate among the size of the nuts varied mainly due to lesser nut count in a given mass for large size than small size nuts. Differential rate of drying was recorded for the nuts placed in different positions *viz*., top, middle and bottom of the drying chamber and it became non-significant after 4 hrs of drying. Drying of in-shell nuts followed falling rate period of drying and time required to reduce its moisture level from initial moisture content of 20.44 per cent to safer level of 8.00 per cent d.b was in the range of 2.84 to 4.51 hrs irrespective of source of power, size of the nuts and position of the tray. Energy required for desired moisture reduction was found to be in the range of 26.06 to 39.79 MJ for electrical system and 173.24 to 230.18 MJ in the case of cashew shell cake as biofuel.

Keywords: dryer, in-shell cashew nuts, moisture content

Introduction

Cashew (*Anacardium occidentale* L.), a native of Eastern Brazil was introduced to India by the Portuguese nearly five centuries back. Cashew nut 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. Cashew is presently grown in an area of 0.92 million ha with an annual production of 0.62 million MT of raw cashew nut in the country (DCCD, 2010).

Cashew nut is a seasonal crop and is harvested from March to June in the east and west coast of India. Certain cashew growing places like North Eastern Hilly regions, harvesting of cashew nuts coincides with monsoon rains, affecting its quality, if it remains in the field for longer period. Freshly harvested cashew nut can be successfully preserved by reducing their moisture content to a level that will discourage the activities of micro-organisms and fungi. Generally, microbes can be inactivated by reducing the moisture content of a agricultural produce to less than 10 per cent. Ohler (1966) reported that moisture content above 8.0 per cent (d.b) for in-shell cashew nut will result to deterioration. Hence, harvested cashew nuts either affected by rain or not, need to be stored in a dried condition holding moisture content less than 8 per cent level to prevent quality deterioration by micro organisms.

*Corresponding Author: bavika13@email.com

Drying agricultural produce to an optimum level prevents deterioration and preserves its nutritive value. Drying is a simultaneous heat and mass transfer process and the heat stirs up the moisture in the product by external medium usually air, in the form of vapour through the product tissue capillaries. Indirect methods of drying require the development of temperature differentials, which effects drying. The process is achieved by circulation of air directed through the drying trays to the products. Many dryers have been developed and used to dry agricultural products in order to improve their storage conditions (Mulhlbauer *et al*., 1996). Most of the dryers use either expensive source of energy such as electricity (Berinyuy, 2000) or a combination of solar and other forms of energy. The most common dryers for agriculture produce are continuous tunnel dryers, vacuum dryers or solar dryers. Huber and Menners (1996) found that out of over 200 different types of dryers that have different applications in industry, only about 20 basic types and their variants are commonly used in practice. This wide range is as a result of different physical forms of the products to be dried, desired rate of drying and quality constraints of the dried products.

Direct sun-drying and the use of solar driers depend on the intensity of the solar energy to heat up the air and effect drying. Most of the horticultural crops are usually at the peak of their yield when the rain has fully set. This period is characterized by low solar energy and high relative humidity and in turn prolongs drying period. Moreover, heating up the air using electricity, wood or fossil fuel for drying agricultural commodities are discouraged now-a-days.

Accounting the problems of certain cashew growing regions, wherein harvesting season coincides with monsoon rains, the present investigation was taken up to reduce moisture level of in-shell cashew nut to improve shelflife with the specific objectives of evaluating the performance of dual mode dryer wherein either byproduct of cashew nut processing *i.e.* cashew shell cake or electric coils are utilized to generate hot air for the purpose.

Materials and Methods

A dual mode dryer suitable for drying in-shell cashew nuts was developed at Directorate of Cashew Research (DCR), Puttur, Karnataka. Major components of the dryer are i) drying chamber; ii) heat exchanger and iii) aspirator assembly with electronic circuit. A schematic diagram of the developed dryer is shown in Fig.1. Drying chamber is cubical in shape having a total volume of 0.081 m^3 and provided with glass wool of 1 cm thick thermal insulation on all sides. It is designed to accommodate 20 numbers of wire mesh trays of size 0.30 x 0.24 m and about 5 kg of in shell cashew nuts can be loaded on each tray. Heating coils (2 sets) of capacity 3 kW are provided diagonally opposite inside the drying chamber. Two fans are also fitted inside the chamber adjacent to heating coil for the circulation of hot air generated and operated by $^1/_8$ hp single phase electrical motor. A circular c/s inlet of 0.01 m ϕ was provided at the rear bottom of the chamber to allow externally generated hot air in to the drying region. An outlet of 0.01 m ϕ was also provided on the back side at the top corner of the drying chamber to leave off humid air from the drying chamber to hot air generator through an aspirator. A thermocouple with electronic assemble was provided to control the temperature of hot air being circulated inside the drying chamber.

In-shell cashew nuts obtained from the farm of Directorate of Cashew Research, Puttur, Karnataka during the year 2011 was used in all the experiments. The collected cashew nuts were cleaned and graded manually into small, medium and large size nuts based on the major axis dimension. Initial moisture content of in-shell cashew nuts was measured using the standard toluene distillation method. Weight loss during drying is accounted as moisture evaporated from the sample and the moisture content is calculated using the following formula.

$$\text{Moisture content on wet basis, } Mw = \frac{v}{w}$$

Where,

v is the volume of water collected during toluene distillation, (ml)

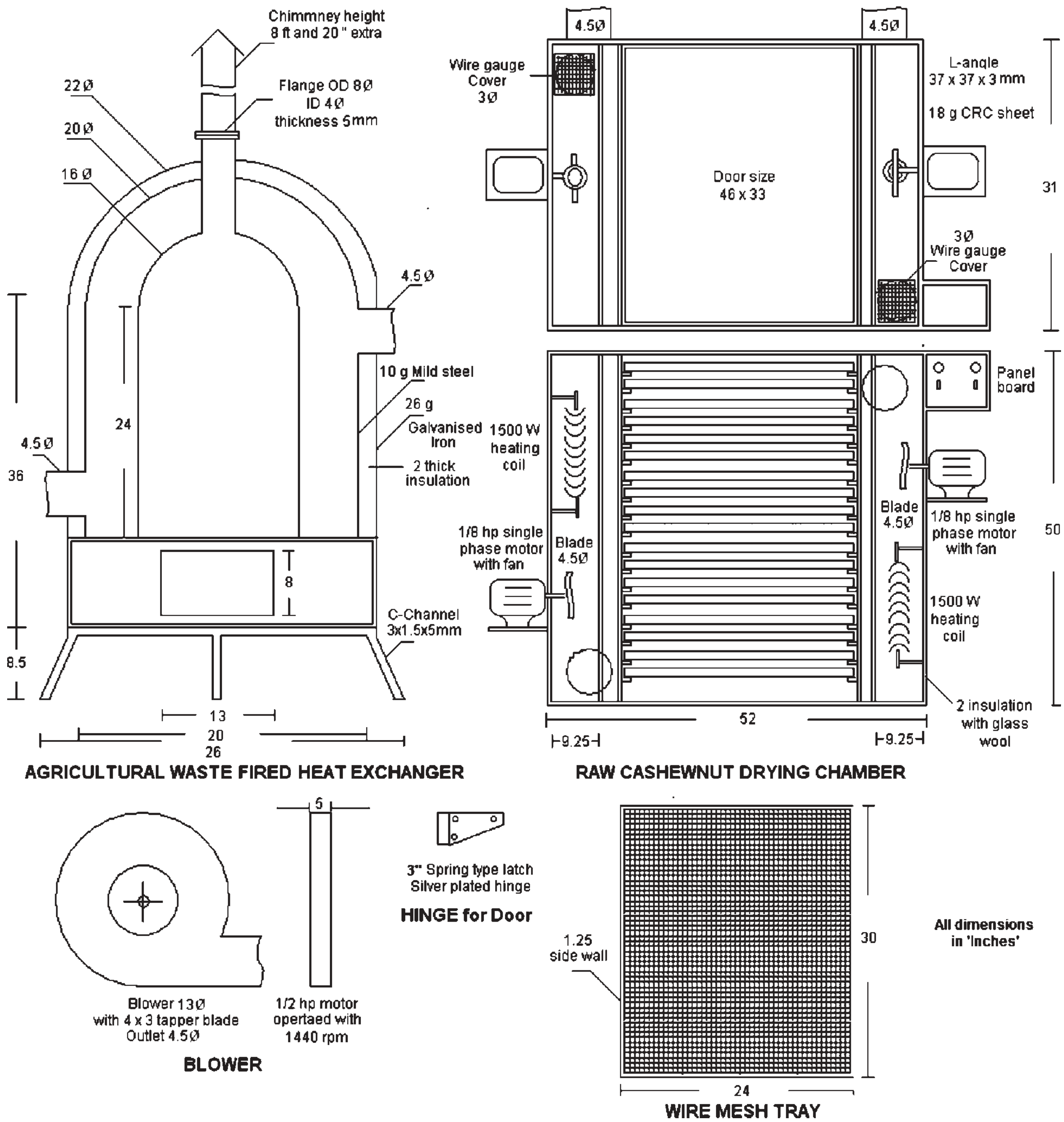

Fig. 1. Schematic diagram of dual mode dryer for in-shell cashew nuts

w is the weight of in-shell cashew nuts taken for toluene distillation, (g)

$$\text{Moisture content on dry basis, } Md = \frac{100 - Mw}{Mw} x\, 100$$

Weighed quantity of sample nuts were soaked in distilled water for a period up to 48 hrs and kept inside refrigerator for uniform distribution of moisture, to understand the moisture infusion mechanism in in-shell cashew nuts. Random samples were drawn at every 3 hrs interval and moisture content of whole nut, shell and kernel were determined using the standard toluene distillation method.

About 100 kg of graded nuts was soaked in distilled water for a specific period to uniformly distribute the moisture within the sample. Soaked nuts were uniformly spread on twenty wire mesh trays and loaded inside the chamber for drying. Temperature of hot air was set at 65°C and the fans on either side of the drying trays were switched on. Hot air was generated externally using thermal power *i.e.* using cashew shell cake as fuel and it was circulated inside the drying chamber with the aid of an aspirator. A sensor mechanism was provided in the electrical circuit to control the temperature of air inside the drying chamber to the set level. Graded cashew nuts placed on the wire mesh tray located at top, middle and bottom of the drying chamber were weighed at regular interval using a weighing balance (Sartorius, BS 124 S) and it was continued till moisture content of sample reduced below 8 per cent d.b. Experiments were conducted separately for small, medium and large size nuts. In order to compare the performance of the dryer, experiments were also conducted for graded nuts *viz*., small, medium and large size, wherein electric coils provided inside the drying chamber were operated for the generation of hot air. Energy consumed during drying process was calculated using the following relationship.

For electrical energy consumed during drying process: $E_p = \eta PTf$

Where, E_p is the electrical energy consumed, kWh

P is the rated horse power of motor, kW

T is the time of operation, hr

f is the power factor assumed to be 0.8

For thermal energy utilized during drying process: $T_p = CW$

Where, T_p is the Thermal energy utilized, J

C is the calorific value of the fuel used, J kg^{-1}

W is the quantity of fuel utilized, kg

All experiments were replicated three times and the data, thus obtained were analyzed statistically using 3- factor CRBD. The best statistical models were fitted to describe the drying characteristics of in-shell cashew nuts in dual drying system and drying time required for moisture reduction to safer level *i.e.* 8 per cent (d.b) was worked out.

Results and discussion

Moisture infusion in in-shell cashew nuts

Moisture absorption of various components of in-shell cashew nuts *viz*., whole nut, shell and kernel is presented in Fig. 2. Obviously, the moisture content of whole nuts and fractions of in-shell cashew nuts increased with increase in soaking period. Rate of infusion of moisture during soaking was higher in the initial period up to 6 hrs and its slope decreased irrespective of whole nuts or fractions. Moisture infusion was found to be higher for shell followed by whole nuts and kernel. It is clear that in-shell cashew nuts when exposed to rain, moisture infusion takes place at higher rate in the beginning and gradually reduces, but continues to absorb moisture even after 48 hrs. Therefore, moisture content of rain soaked cashew nuts need to be brought to safer level to improve its shelf life. Taking into account, the practice of harvesting nuts every day, initial moisture content of in-shell cashew nuts corresponding to 24 hrs of soaking *i.e.* 20.44 per cent (d.b) was considered in all the experiments.

Effect of source of hot air on drying characteristics of in-shell cashew nuts

Initial moisture content of in-shell cashew nuts used in all the experiments were maintained at 20.44 per cent (d.b) irrespective of the size and fuel used for the generation of hot air *i.e.* electrical or thermal. It was observed that the reduction in moisture content of in-shell cashew nuts showed falling rate of drying throughout the drying period. When electrical power was used for generating hot

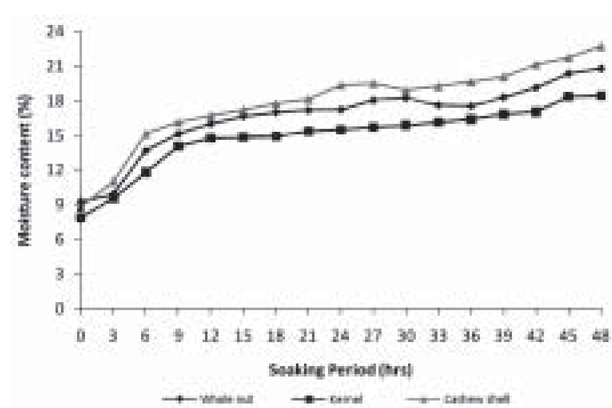

Fig. 2. Moisture absorbtion behaviour of in-shell cashew nuts

air, average moisture content of nuts reduced to 17.04, 12.71, 8.53, 5.80 and 3.96 per cent (d.b) after every 1 hr period of drying. But in the case of thermal power for generating hot air, moisture level of the nuts reduced to 17.29, 13.21, 8.32, 6.62 and 5.64 per cent (d.b) for the same period of drying. It clearly indicates that loss of moisture from in-shell cashew nuts is faster in the case of electrical than thermal power which was utilized for generating hot air.

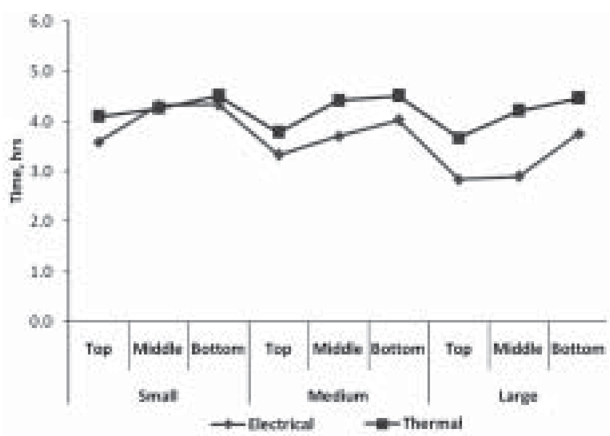

Fig. 3. Time required to reduce the moisture content of freshly harvested in-shell cashew nuts to 8% d.b. using dual mode dryer

Total time required to reduce the moisture content to safer level *i.e*. 8% d.b was found to be lesser while using electrical coils than biofuel as source for generation of hot air for drying (Table 1). In the case of electrical coils, required temperature could be reached shortly for better diffusion of moisture from in-shell cashew nuts. Owing to low heat transfer from exchanger to air being circulated inside drying chamber in the beginning, rate of moisture loss was recorded lesser in the case of thermal power in comparison to electrical power. But within a short period of 1 hr, heating media attained the required temperature as humid air within the chamber was taken away by the aspirator and reheated. Besides, hot air from heat exchanger was also forced at high velocity in to the drying chamber. In both cases, air temperature was controlled by heat sensor provided in the drying chamber. Falling rate period of drying is observed during drying of in-shell cashew nuts in dual mode dryer and the total time required to decrease the moisture content from 20.44 per cent d.b to safer level is in the range of 2.84 to 4.35 hrs for electrical power and 3.67 to 4.54 hrs for thermal power irrespective of size or location of nuts.

Table 1. Emprical equation representing the moisture diffusion in freshly harvested in-shell cashew nuts while drying in dual mode dryer

Source of fuel for the generation of hot air	Size of the in-cashew nuts	Position of tray inside drying chamber	Equation	R^2	Drying time to reduce M.C to 8% level
Thermal power	Small	Top	$y = 17.90x^{-0.63}$	0.974	3.591
		Middle	$y = 26.77e^{-0.28x}$	0.991	4.314
		Bottom	$y = -2.532x + 19.01$	0.998	4.348
	Medium	Top	$y = 32.15e^{-0.40x}$	0.987	3.477
		Middle	$y = 30.33e^{-0.36x}$	0.967	3.702
		Bottom	$y = -4.327x + 25.43$	0.983	4.028
	Large	Top	$y = 32.19e^{-0.49x}$	0.998	2.841
		Middle	$y = -11.1\ln(x) + 19.81$	0.995	2.898
		Bottom	$y = 27.62e^{-0.33x}$	0.994	3.755
Electrical power	Small	Top	$y = 24.50e^{-0.34x}$	0.986	3.292
		Middle	$y = 23.78e^{-0.30x}$	0.978	3.631
		Bottom	$y = -2.717x + 19.97$	0.984	4.406
	Medium	Top	$y = -3.959x + 24.22$	0.992	4.097
		Middle	$y = -3.498x + 22.89$	0.989	4.257
		Bottom	$y = -3.608x + 24.27$	0.994	4.509
	Large	Top	$y = -11\ln(x) + 22.62$	0.981	3.778
		Middle	$y = -4.189x + 26.49$	0.984	4.414
		Bottom	$y = -4.126x + 26.6$	0.974	4.508

Effect of size of in-shell cashew nuts on its drying characteristics

Faster rate of moisture removal was observed for large size nuts than smaller nuts irrespective of source of thermal power utilized as far as size of the raw cashew nuts is concerned. On an average, time required to reduce the moisture content of in-shell cashew nuts of small, medium and large size nuts to safer level was worked out to be 4.41, 4.37 and 3.16 hrs in the case of electric power and 4.38, 4.28 and 4.11 hrs for thermal power respectively. It was inferred that time taken for drying large size nuts was lesser than smaller size nuts. Although surface area increased in the case of smaller nuts as quantity of nut sample spread on the wire mesh for drying remained same in all experiments, number of large size nuts was found to be lesser compared to small size nuts for the given mass. In addition, more void space in larger size nuts allowed hot air movement all over the surface and enhanced drying rate. Moisture loss recorded for medium size nuts at any position for both bio fuel and electric coils found to be in the limit of other two sizes used in the investigation.

Effect of position of nuts placed inside the dryer on drying characteristics of in-shell cashew nuts

In order to understand the uniformity in drying operation, moisture loss in in-shell cashew nuts placed in different positions *viz*., top middle and bottom tray were analyzed. Differential rate of drying was recorded up to 4 hrs of drying at different positions inside drying chamber and later it became non-significant irrespective of source of energy for the generation of hot air (Table 2). Rate of drying was found to be comparatively faster at the top position than middle or bottom positions irrespective of power source for the generation of hot air.

Externally generated hot air, while entering the bottom of the drying chamber, drifted to the top immediately due to high velocity. Later it passed through the trays positioned at the top in order to reach the aspirator for recirculation. In the case of electrical power, hot air generated internally and turbulent motion took place due to fans provided on either side. As the air outlet was provided at the top of the chamber, humid air from top most trays had more opportunity to leave the drying chamber than trays available at other positions. This upward movement of air and the trays at the top in close proximity to humid air outlet are the twin reasons for the rapid diffusion of moisture from the in- shell cashew nuts spread on the trays located at the top position followed by trays in middle and bottom positions.

Energy consumption during drying using dual mode dryer for in-shell cashew nuts

Total energy required to dry in-shell cashew nuts from an initial moisture content of 20.44 to 8.00 per cent d.b was worked out to be in the range of 26.06 to 39.79 MJ for electrical system and 173.24 to 230.12 MJ in the case of cashew shell cake as

Table 2. Anova for drying of freshly harvested in-shell cashew nuts in dual mode dryer

	After 1 hr drying period			After 2 hr drying period			After 3 hr drying period			After 4 hr drying period			After 5 hr drying period		
	P 1	P 2	P 3	P 1	P 2	P 3	P 1	P 2	P 3	P 1	P 2	P 3	P 1	P 2	P 3
F 1 S 1	16.234	18.019	17.030	12.875	13.574	14.284	8.414	8.819	9.744	5.977	6.658	7.014	4.824	5.717	6.071
F 1 S 2	19.055	20.456	19.971	12.148	13.425	14.078	7.842	8.473	9.270	5.658	6.398	6.915	4.820	5.561	5.669
F 1 S 3	16.072	16.440	16.723	11.708	12.399	14.015	7.491	8.323	8.637	5.043	6.225	6.599	4.745	4.883	4.973
F 2 S 1	9.699	13.143	15.171	8.640	10.676	12.704	6.101	8.419	9.431	5.811	5.971	7.975	4.703	5.139	6.073
F 2 S 2	12.463	12.152	14.607	6.587	8.448	11.207	5.773	7.070	8.469	5.052	6.604	7.252	4.145	4.783	5.705
F 2 S 3	12.861	13.381	14.519	7.020	7.267	9.334	4.618	4.879	6.089	4.204	4.578	5.601	3.830	4.745	5.265
	SED	**CD (0.05)**	**CD (0.01)**	**SED**	**CD (0.05)**	**CD (0.01)**	**SED**	**CD (0.05)**	**CD (0.01)**	**SED**	**CD (0.05)**	**CD (0.01)**	**SED**	**CD (0.05)**	**CD (0.01)**
Source of power (F)	0.206	0.418	0.560	0.261	0.529	0.709	0.255	0.518	0.695	0.206	0.419	0.561	0.205	0.417	0.559
Size (S)	0.252	0.512	0.686	0.319	0.648	0.868	0.313	0.635	0.851	0.253	0.513	0.687	0.252	0.510	0.684
Position (P)	0.252	0.512	0.686	0.319	0.648	0.868	0.313	0.635	0.851	0.253	0.513	0.687	0.252	0.510	0.684
FS	0.357	0.723	0.970	0.452	0.916	1.228	0.443	0.898	1.204	0.357	0.725	0.972	0.356	0.722	0.967
SP	0.437	0.886	1.188	0.553	1.122	1.504	0.542	1.099	1.474	0.438	0.888	1.190	0.436	0.884	1.185
FP	0.357	0.723	0.970	0.452	0.916	1.228	0.443	0.898	1.204	0.357	0.725	0.972	0.356	0.722	0.967
FSP	0.618	1.253	1.680	0.782	1.586	2.127	0.766	1.555	2.085	0.619	1.256	1.683	0.616	1.250	1.676

bio-fuel for generating thermal power (Table 3). Energy requirement was found to be higher for smaller size nut than the larger size nuts for the given quantity. As the hot air was generated externally, due to energy loss by conduction and transfer through conduit, cashew shell cake found to consume 6.12 times more energy than electrical power as thermal source. Cost of drying in-shell cashew nuts using dual mode dryer was worked out to be Rs 0.44 per kg.

Table 3. Energy consumption (MJ/kg) during in-shell cashew nuts using dual mode dryer

Size	Position	Electrical	Thermal
Small	Top	32.937	230.18
	Middle	39.569	177.96
	Bottom	39.792	175.19
Medium	Top	30.561	212.32
	Middle	33.957	184.51
	Bottom	36.950	175.13
Large	Top	26.062	206.36
	Middle	26.581	175.98
	Bottom	34.442	173.24
	Min	26.062	173.24
	Max	39.792	230.18

Conclusions

Following conclusions were drawn while evaluating the performance of the dual mode dryer developed for in-shell cashew nuts.

i. A dual mode dryer which could be operated by utilizing either electrical or thermal power or both is developed for in-shell cashew nuts to preserve its quality.

ii. This developed dryer is very much suitable for cashew growing regions wherein harvesting of in-shell cashew nuts coincides with monsoon rains.

iii. Rate of infusion of moisture during soaking was higher in the initial period up to 6 hrs and decreased subsequently irrespective of whole nuts or its fractions. Moisture absorption was found to be higher for shell followed by whole nuts and kernel.

iv. Falling rate period of drying is observed during drying of in-shell cashew nuts in dual mode dryer and a total time required to decrease the moisture content from 20.44 per cent d.b to safer level is in the range of 2.84 to 4.54 hrs irrespective of the power used and size or location of nuts.

v. Average time required to reduce the moisture content of in-shell cashew nuts of small, medium and large size to safer level was found out as 4.41, 4.37 and 3.16 hrs in the case of electric power and 4.38, 4.28 and 4.11 hrs for thermal power respectively. Nut count in the given mass was the due reason for the variation in drying time w.r.t size of the nuts.

vi. Differential rate of drying was recorded at selected locations of the drying chamber, but it became non-significant after 4 hrs of drying period irrespective of source of power utilized for generation of hot air.

vii. Energy utilized during drying operation to reduce moisture to safe level on an average was worked out to be 32.93 MJ for electrical power and 201.71 MJ for thermal power.

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