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Research Article

Thermal Performance Study of Solar Air Dryers for Cashew Kernel: A Comparative Analysis and Modelling Using Response Surface Methodology (RSM) and Artificial Neural Network (ANN)

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In this study, a new procedure for drying of cashew kernels is proposed. The new methodology involves the use of solar air dryers to remove the dark sticky coating called testa on the surface of the cashew kernel to get the final product. There are several challenges in the new procedures, especially with respect to the moisture level to be retained in the cashew kernel post drying for facilitating the optimal peeling activity. In this regard, thermal performance is carried out through a set of experimental and computational trials. The experiments have revealed that the natural and forced convection solar dryers with drying speeds of 1.0 kg/h and 1.66 kg/h, respectively, showed drying efficiencies of 51.7% and 50.9%, which is within the permissible acceptable limit, thus ascertaining a moisture reduction of 40 to 42% in each of case and keeping the moisture content within the band of approximately 5%, required for effective peeling of the testa from the cashew kernel to obtain the final product. This new method has resulted in batch drying of cashew kernels of up to 30 kg capacity in a time span of 360 minutes of solar irradiation with an average consumption of 255 kJ. The results of the experiments are also validated from the artificial neural network (ANN) and response surface methodology (RSM) modelling, resulting in better prediction and optimization of the performance parameters. The error between the actual and experimental values is well within the permissible limit of +/-5%, thereby correlating the experimental and statistical values for deriving an ANN model for predicting the results for different time duration and solar irradiation. In this way, the thermal analysis of the solar dryers for drying cashew kernels has resulted in findings, which shall be utilized to improve the overall performance efficiency and the methodology adopted for maximum yield.

1. Introduction

As a developing nation, India has achieved significant strides in agriculture, harvesting, and processing. India is the second biggest producer and consumer of cashew kernels, behind Vietnam. Cashew is a popular dry nut in India for health and a variety of other reasons. India has an 8.54-hectare cashew crop. The raw cashew nut output volume is 6.20 lakh tonnes per year, with average productivity of 820 kg/hectare. This is India's contribution to the extent of 17.3 percent of its area and 39.47 percent of raw cashew production with respect to the world. India processes 1.18 million metric tonnes of cashew kernels through 3650 cashew kernel processing industries spread across [1]. Energy is the most important and vital component of the drying process. Cashew drying is for its safe preservation and peeling of the brown coloured thin layer called testa. Removal of the testa is possible by drying the cashew kernels from their initial 13% to 5%. Process of drying requires energy in the form of heat supplied at 65°C to 70°C for 6 to 7 hours [2]. The heat energy for the drying process is supplied by other forms of energy like electrical energy, biomass, and steam. The other processes involved in cashew processing like cashew nut drying, nut steaming, and kernel drying include an energy consumption of 5000 to 6000 MJ for 1000 kg of raw cashew nuts [3]. The drying of cashew kernels within the stipulated time of six hours requires an energy consumption of 255 kJ with solar dryer and 251 kJ for industrial steam [3, 4].

Considerable efforts have been made to introduce solar dryers of various types for the drying process, especially for cashew kernel drying, to replace conventional systems. Design and testing of several types of single, double, and multipass solar air dryers are accomplished for evaluating their performance characteristics [5, 6]. Seshachalam et al. [7] constructed an indirect three-pass solar dryer for drying carrot pieces and examined its effectiveness. Eight mathematical models from the previous research were used to examine the drying properties. During the trial, they found the pick-up efficiency of the dryer to vary between 14 and 40%, with a mean air collector efficiency of 45%. Kareem et al. [8] examined the efficacy of a novel solar air heating collector in multipass configuration. They achieved the largest temperature difference between the ambient and the system collector of 30.42°C daily, and the sensible porous matrix resulted in a 9% increase in system heat delivery. To improve the energy output of the hot air, Shamekhi-Amiri et al. [9] used solar air equipped with a new counterflow two-pass packed-bed arrangement. They found an improvement in thermal efficacy with discharge for a certain range, and after that, the efficiency decreased even though the flow rate had increased. They also used mathematical models for predicting the drying behaviour of lemon balm leaves. The double pass air dryers are used to enhance the thermal efficiencies. The heated air passes down the bottom of the absorber surface and then in the opposite direction just above the absorber surface in a dual-pass arrangement and hence increases the efficiency of the system. It has been shown that dual-pass solar air heaters are 10–15% more efficient than single-pass systems [10]. Nowzari et al. [11, 12] studied the heat transfer performance of single- and dual-pass packed bed SAH's with regular glazing comprising a half perforated cover. The dual-pass air heater's efficacy was 22.7% higher than a single-pass air heater for the same discharge. Ravi and Saini [13] examined the outcomes of a dual-pass SAH with artificial roughness employing a mix of discrete multiple V formed and staggered ribs, and the results were compared to smooth ducts. The roughness geometry was shown to increase both frictional losses and the system's heat removal rate. A double-pass SAH with single glass was suggested for drying applications in a study by the same authors [14]. El-Sebaii and Shalaby [15] built an indirect dual-pass v-corrugated plate SAH for drying thymus and mint leaves. Midilli and Kucuk models were determined to be acceptable for mint, and Page and modified Page models for thymus, among 14 mathematical models of thin-layer drying. Gulcimen et al. [16] investigated thin layer sweet basil drying in a forced convection SAH and found the Page model to be the best for drying this medicinal crop. Multipass solar collectors are used for large-scale applications [17]. With a granite pebble bed, Kareem et al. [18] studied an improved multipass solar air heating collector (MPSAHC) system. The MPSAHC design was created without a transport pipe for moving hot air throughout the system to reduce heat and pressure losses of the heated air in the control volume. The MPSAHC system produced a specific energy demand of 11.51 kWh kg^1, with efficiencies of 73% for the maximum thermal collector.

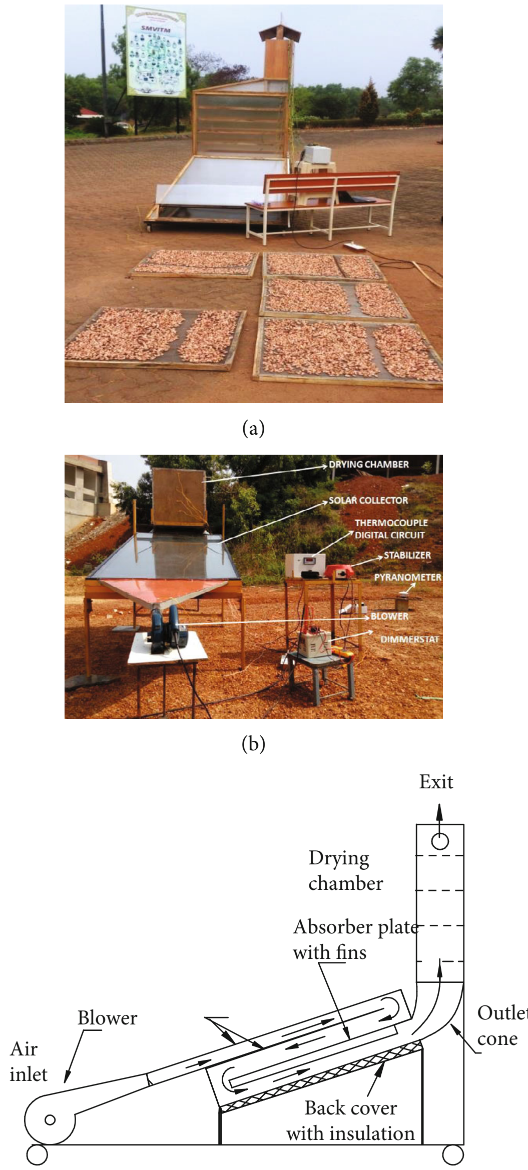
The proposed research is modeled on the lines of the works of Stalin and Barath [19]; they have considered the moisture removal by a hybrid combination of solar irradiation and capillary action and established a relation between the moisture removal rate and the drying capacity of the solar dryer. However, there is a lack of understanding of the effect of the solar irradiation angle and intensity on the drying of cashew kernels.

Further, Bouadila et al. [20] have reported that the condition monitoring of the solar activity is an important factor for any solar drying system. The solar activity depends on the intensity of solar irradiation, solar magnetism, and the solar irradiation angle, alongside the duration of the exposure of the solar dryer to the solar radiations. Their findings have given a motivation for formulating the problem statement for the current research along with the need based criterion assessment for faster and optimal drying of the cashew kernels.

Mahmoodi et al. [21] have worked on the ANN modeling of the conversion of biowastes into energy using mesophorous activated carbon systems. Their findings have ascertained the use of ANN modeling for validating the experimental outcomes.

Mahmoodi et al. [22] have reported on the modeling of the experimental outcomes and highlighted the significance of computational analysis of photocatalytic reactions and nanophotocatalysis process. The experimental outcomes are in close correlation with the computational results, and the errors between the values are within the admissible limit.

Thus, the review of the literature has yielded a research gap, which focuses on the thermal analysis of the solar dryer and its mathematical modelling for real-time applications in the field and faster adoption of the technology for greater yield of the dried and processed cashew nuts.



(a)

(b)

(c)

Figure 1: (a) Natural convection solar greenhouse dryer. (b) Forced convection FPC solar dryer. (c) Schematic view.

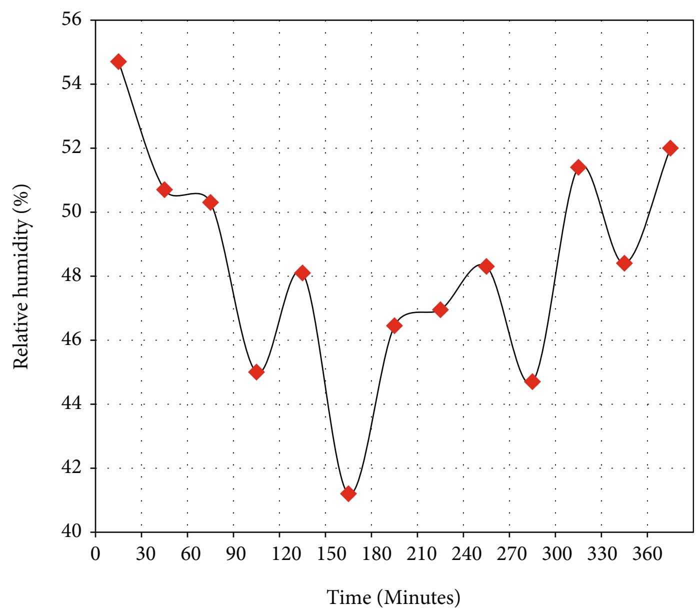
2. Materials and Method

Two solar dryers, one working on natural convection and the other on forced convection for drying cashew kernels, are considered. Figures 1 and 2 show the schematic and pictorial views of forced convection and natural convection flat plate collector and greenhouse dryers for cashew kernels, respectively. Test experiments were performed in the city of Udupi, Udupi district, in the state of Karnataka, India, with the following coordinates: latitude (Φ) $13°15'10''$N and longitude $74°47'39''$E in midsummer for a duration of one week from 25th April to 29th April 2021.

2.1. Natural Convection Solar Greenhouse Dryer. The dryer setup is tested under passive conditions in the southern orientation. The average solar radiation was $588.2\,\mathrm{W/m^2}$ and was in the close range of predicted value with a difference of less than 10%. The predicted value lies well within the acceptable difference of 10%. The experiments are accomplished at steady flow conditions. The empirical relations used for the thermal analysis are given in Table 1 [22, 23]. The calculations are done on an hourly basis.

The chambers' performance for the experiments was accomplished using energy balance equations [24–27]. The experiments were based on Duffie and Beckman [28]. The experimental setup comprises a greenhouse that eventually supplies the energy to the working fluid. It comprises horizontal and vertical absorber plates. The performance and the thermal properties of the PSGD are evaluated by considering the characteristics of the air at the drying chamber's film temperature.

The heat transfer values for the solar greenhouse dryer for natural convection conditions are found for Nusselt



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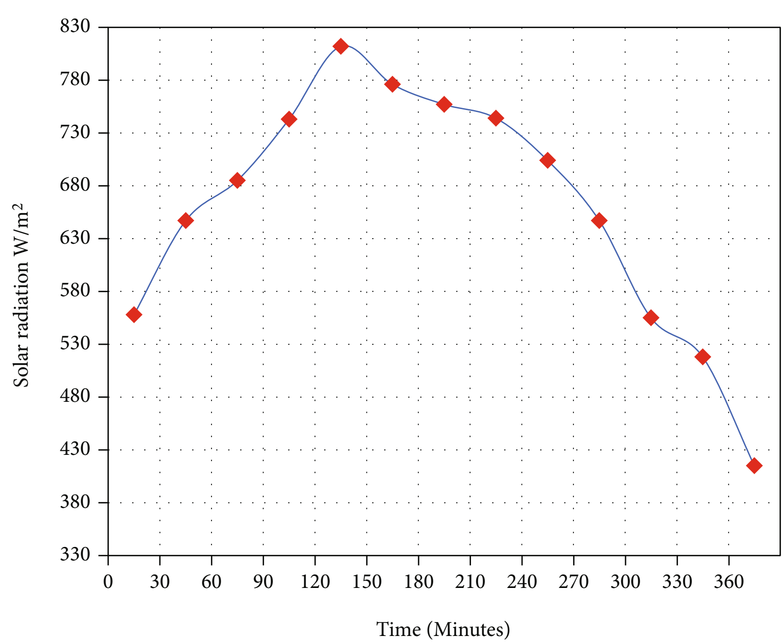

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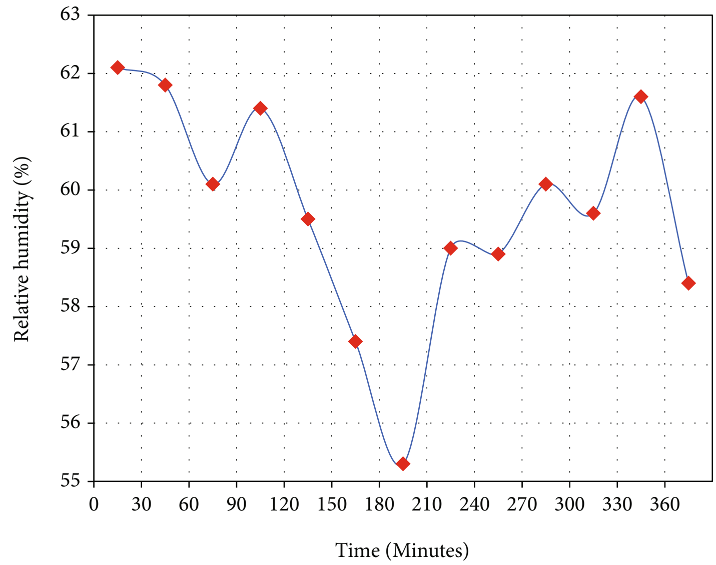

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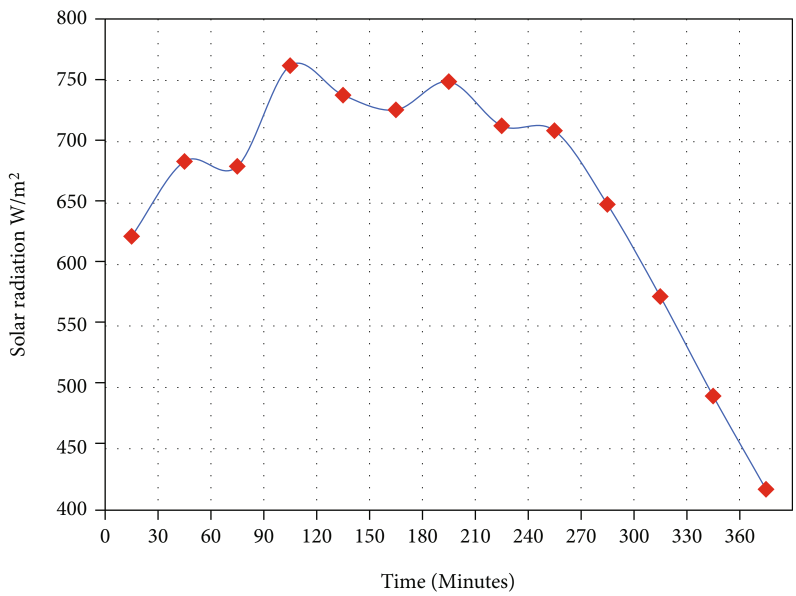


(d)

Figure 2: Variation of relative humidity and solar radiation (W/m^2) against time of the day in natural and forced convection.

number using appropriate Ra values. The following assumptions are made in the calculation.

(i) The surrounding environment is considered to be still

(ii) The heat transfer coefficient on the outside periphery of PSGD is considered to be constant (stagnant)

(iii) The exhaust opening is considered to have a cross-section area of 0.28 m^2 and 100% open

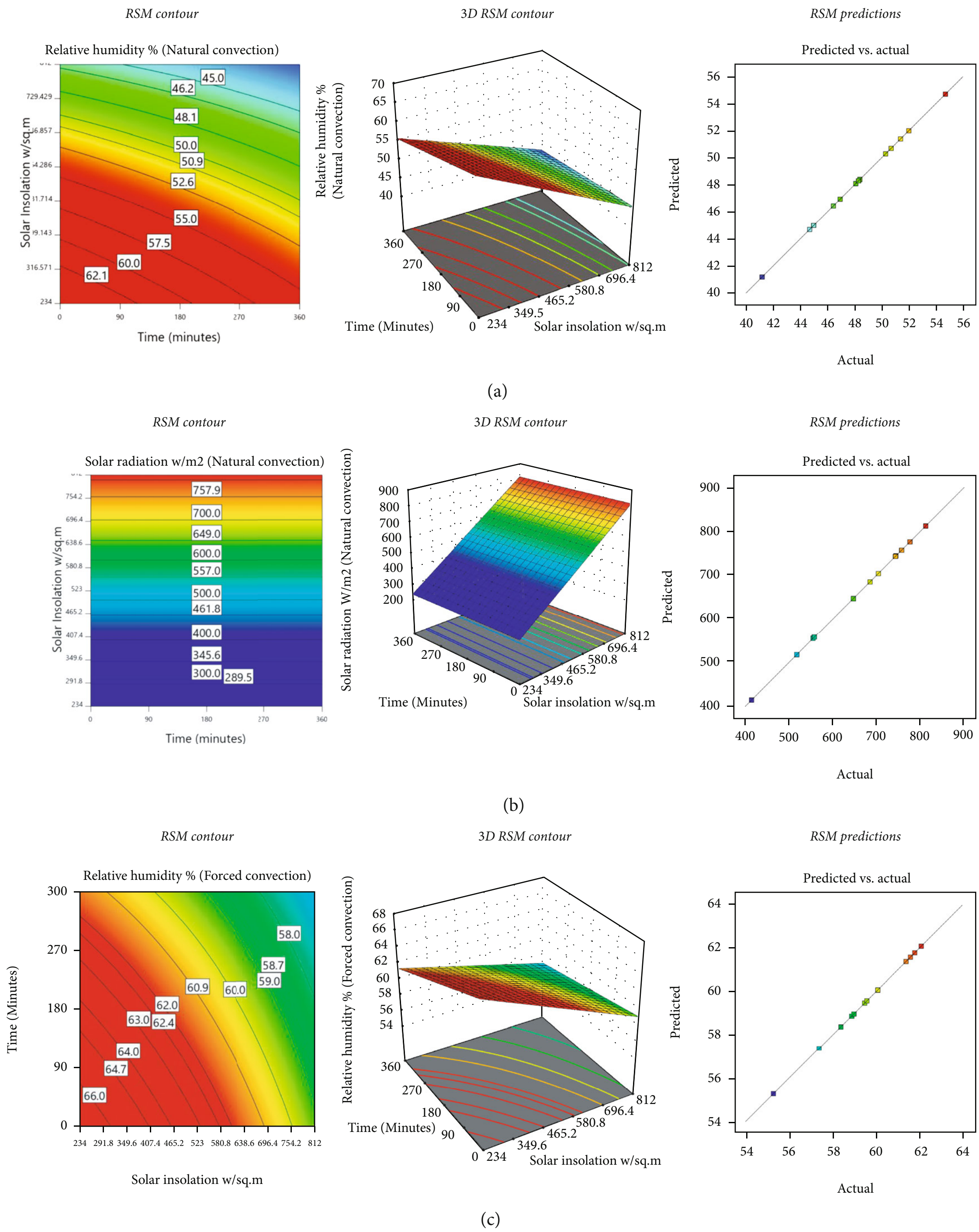
2.2. Forced Convection FPC Solar Dryer. The developed FPC solar dryer under active conditions is tested for its performance. Solar insolation on the day was predicted with a value of 588.2 W/m^2. The predicted value lies well within the acceptable difference of 10%. An average solar radiation of 615.15 W/m^2 was measured with a pyranometer with shade at the site on the day of test. Different test readings like air temperatures at inlet and outlet of cone, inlet, and outlet of drying chamber and at all four trays are recorded at an interval of half an hour. Air velocities at the points, along with relative humidity, are measured. Test measurements show exit temperatures of the collector in the range of 42-52°C. The heat transfer to the working fluid air is 3448 kJ. The drying process with forced convection FPC solar dryer for 6 hours ensures 5-8% removal of moisture from kernels with expected final moisture content ranging between 3 and 6%. An illustrative diagram showing the

Table 1: Empirical relations used for the thermal analysis.

Description	Equation	#
	(A) Greenhouse chamber analysis	
Input energy to solar greenhouse chamber	$Q_I = A_{gh} I$	(1)
Amount of energy gain	$Q_{\text{gain}} = \alpha \tau A_{gh} I$	(2)
	Energy loss by convection and conduction through horizontal and vertical walls (Q_{lost})	
Grasshoff number	$Gr = \frac{[(\beta.g.\Delta T).Lc^3]}{\mu^2} = \frac{[(\beta.g.\Delta T).V]}{\nu^2}$	(3)
Nusselt number for horizontal plate (according to McAdams for above heated)	$Nu = f\,(Gr.\text{Pr}) = C.(Ra)^m$ $Nu = 0.59.Ra_L^{0.25}$ for $10^4 \le Ra_L \le 10^9$ $Nu = 0.15.Ra_L^{0.333}$ for $10^7 \le Ra_L \le 10^{11}$	(4)
Nusselt number for vertical plate	$Nu = 0.68 + \left(0.67Ra_L^{0.25}/\left[1 + (0.492/\text{Pr})^{0.56}\right]^{0.45}\right)$ for $Ra_L \le 10^9$	(5)
Heat transfer coefficient h	$h = \frac{k.Nu}{L}$	(6)
Energy loss by convection and conduction through base and back wall	$Q_{\text{lost}} = \frac{\Delta T_{gh}}{\Sigma R_{gh}}$	(7)
Useful energy in the greenhouse	$Q_{uf} = Q_{\text{gain}} - Q_{\text{lost}} = \dot{m}.C_p.(T_s - T_a)$	(8)
Energy utilization ratio	$\text{EUR} = \frac{Q_{gh}}{Q_{uf}}$	(9)
Greenhouse dryer efficiency	$\eta_{gh} = \frac{Q_{uf}}{Q_{\text{gain}}} \times 100\%$	(10)
	(B) Drying chamber analysis	
Heat gain in drying chamber	$Q_{\text{in}} = Q_{gh} + Q_{\text{glaze}}$	(11)
Heat utilized for drying	$Q_u = m_w C_p \Delta T + m_w h_{fgw}$	(12)
Heat loss through drying chamber	$Q_{\text{con}} = \frac{\Delta T_{dc}}{\Sigma R_{dc}}$	(13)
Heat let out through exit	$Q_{\text{out}} = \dot{m} C_p \Delta T$	(14)
Drying chamber efficiency	$\eta_{dc} = \frac{Q_{\text{utilized}}}{\text{in}} \times 100$	(15)
Drying rate	$\text{DR} = \frac{(M_i - M_f)}{t}$	(16)
	Drying analysis	
Specific energy consumption	$\text{SEC} = \frac{E_t}{m}$	(17)
Percentage moisture removal from the cashew kernels	$\text{MR\%} = \frac{m_w - m_d}{m_d} \times 100\%$dry basis $\text{MR\%} = \frac{m_w - m_d}{m_w} \times 100\%$wet basis	(18)
Amount of moisture content removed	$m = \frac{m_w (m_i - m_f)}{100 - m_f}$	(19)
Average drying rate	$\text{DR}_{\text{av}} = \frac{m}{t}$	(20)

Table 2: Specifications of the equipment and the instruments used in the present work.

Instrument	Specifications	Make and model
Blower	1800 rpm, 5 hp stainless steel centrifugal air blower	Make: Airmass Engineers, India; model: AK401
Coil heater	Power input: 2000 W, 230 V, 50 Hz	Make: Airex, India; model: AX-S4
Anemometer	Resolution: 0.1 m/s; accuracy: +/-0.2 m/s	Make: Ace Instruments, India; model: ACE AM 4201
Temperature indicator	Resolution: 0.1°C; accuracy: +/-0.5°C	Selec TC544C digital temperature controller, India
Thermocouples	K type, range 0-180°C	Japsin Instrumentation, Jl-155
Pyranometer	Sensitivity: 10 μV (W/m^2), 2-wire RTU interface	Make: EKO, China; model no.: ML-02
Hygrometer	Resolution: 0.1% RH; accuracy: +/-3% RH	Make: R-Tek Instruments, India; RT-083 hygrometer



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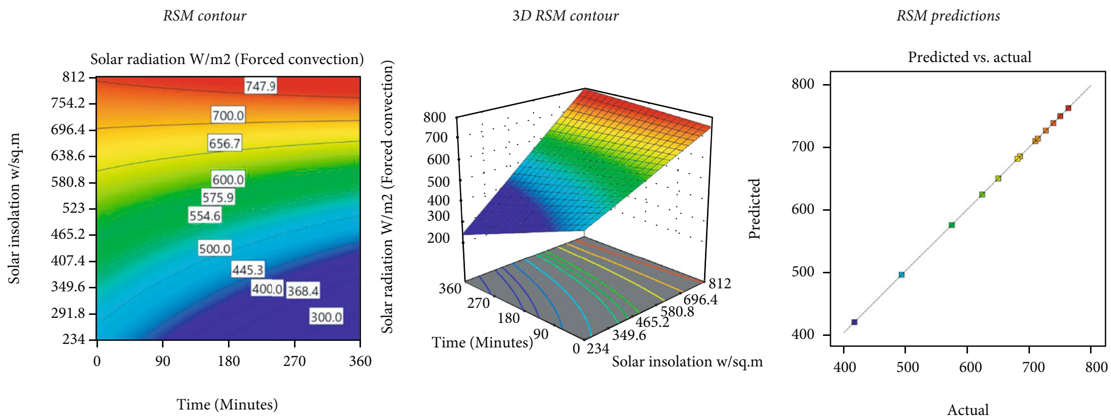
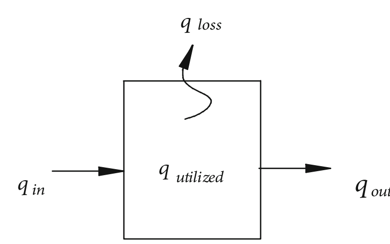


(d)

Figure 3: Variation of relative humidity and solar radiation (W/m^2) against time of the day in natural and forced convection (using RSM)..

Table 3: Important results of greenhouse dryer analysis.

SN	Description	Symbol	Value
1	Greenhouse chamber Energy utilization ratio	EUR	1.15
2	Greenhouse chamber efficiency	η	87%
3	Drying chamber Efficiency of drying chamber	η_{dc}	50.0%
4	Drying rate	DR	1.03 kg/h
5	Greenhouse dryer system System efficiency	η_{system}	48.2%
6	Specific energy consumption	SEC	12.42 Wh/kg
7	% moisture removed from product	MR	5.26%
8	Amount of moisture content removed	m	1.27 kg



Energy balance for drying chamber

experimental setup of the active solar air dryer system is shown in Figure 1.

The dryer unit was fabricated in house at Sri Madhwa Vadiraja Institute of Technology, Udupi District, in Karnataka State, India. The specifications of the equipment used in the present work are given in Table 2.

2.3. System Modelling Using Response Surface Methodology (RSM). RSM, fuzzy modelling, and other modelling methods are used to evaluate problems wherein one or more outputs are affected by various input factors to determine the mathematical relation between the output responses and the corresponding input variables. They are also used to create mathematical models to identify the major effect of each element on the response factor and to locate the best conditions. Many researchers used the RSM method to improve the drying effect of different dryers, such as fluidized bed dryers, on agricultural products like Coriandrum sativum leaves, kefir powder, Ganoderma lucidum slices, olive leaves, and soya bean, among others. RSM uses a set of statistical and mathematical methods to measure the relationship between output responses and input variables, which is influenced by various factors. The RSM strategy was first used to fit models to physical investigations, but it is now used to design

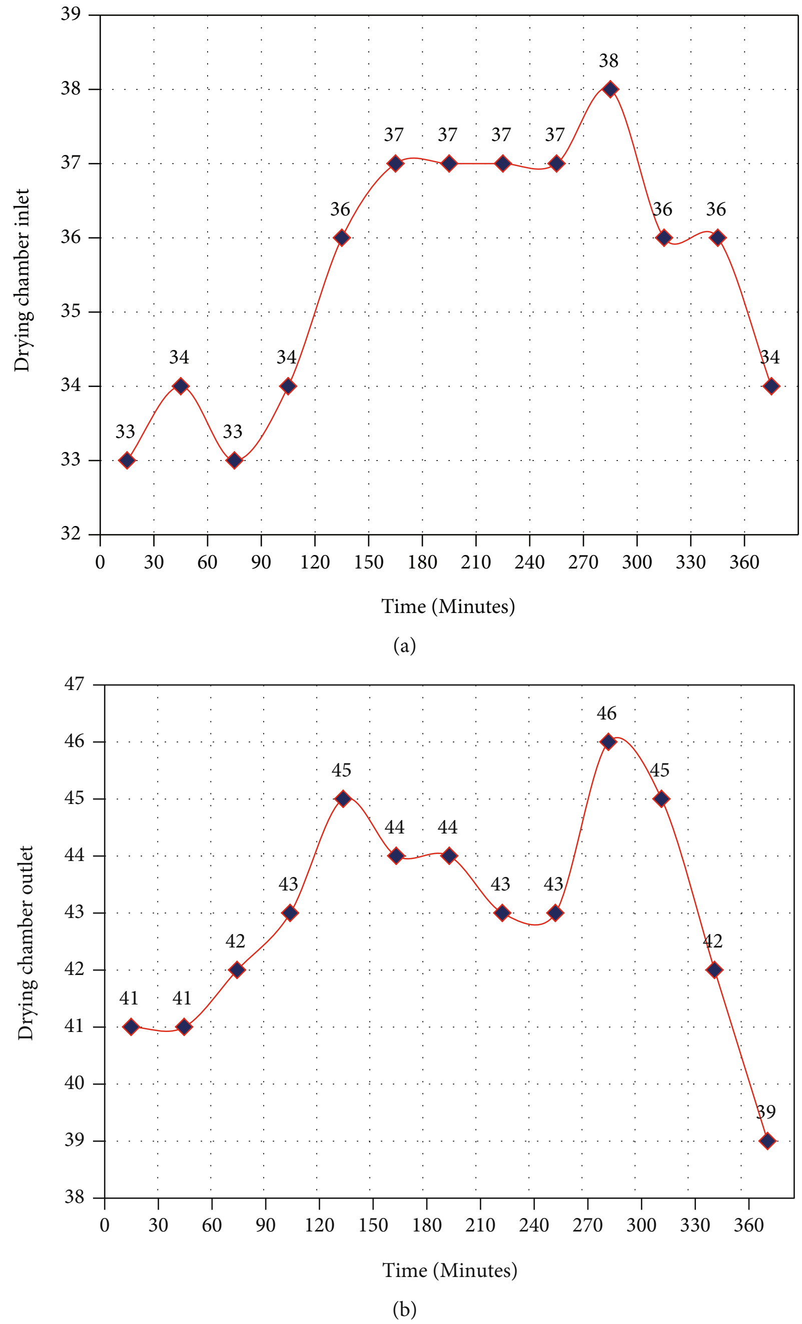
Table 4: Important results of forced convection FPC solar dryer.

SN	Description	Symbol	Value
1	Solar flat plate collector-input energy	Q_I	4716.9 kJ
2	Energy received	Q_{gain}	3447.93 kJ
3	Efficiency	η_{FPC}	71.84%
4	Drying chamber-energy entering	q_{in}	501.31 kJ
5	Energy utilized	$q_{utilized}$	255.18 kJ
6	Efficiency	η_{dc}	50.89%
7	System ASAD-instantaneous efficiency	η_i	26.24%
8	Drying rate	DR	1.65 kg/h

performance improvement experiments. RSM estimates a response function using statistical data that were collected at different design stages [29–31]. Equation (1) describes the relation between the control factors and the responses

$$Y = f\left(X_1, X_2, \cdots X_k\right) + \varepsilon, \tag{1}$$

where Y is the response variable and $X_1, X_2, \cdots, X_k$ are the input variables. The letter f denotes the true response function. The experimental error is measured by the residual "ε."



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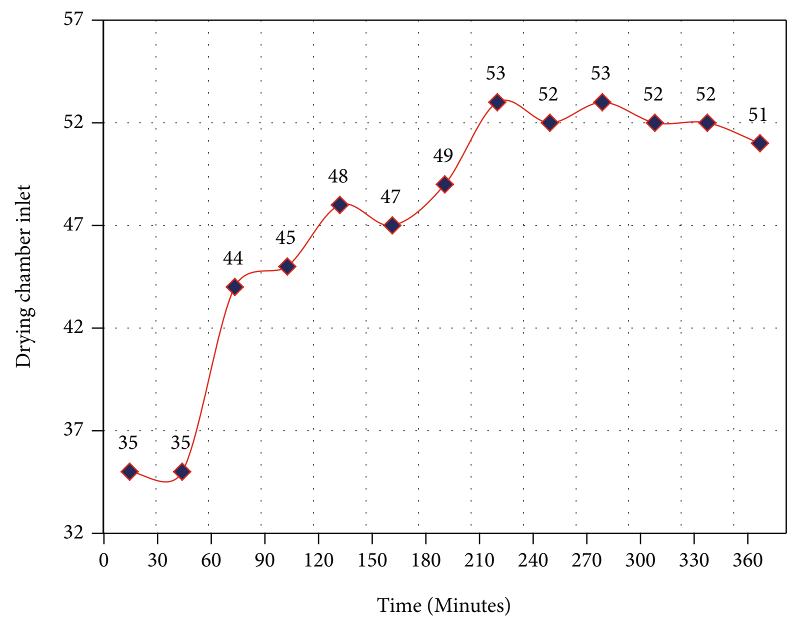

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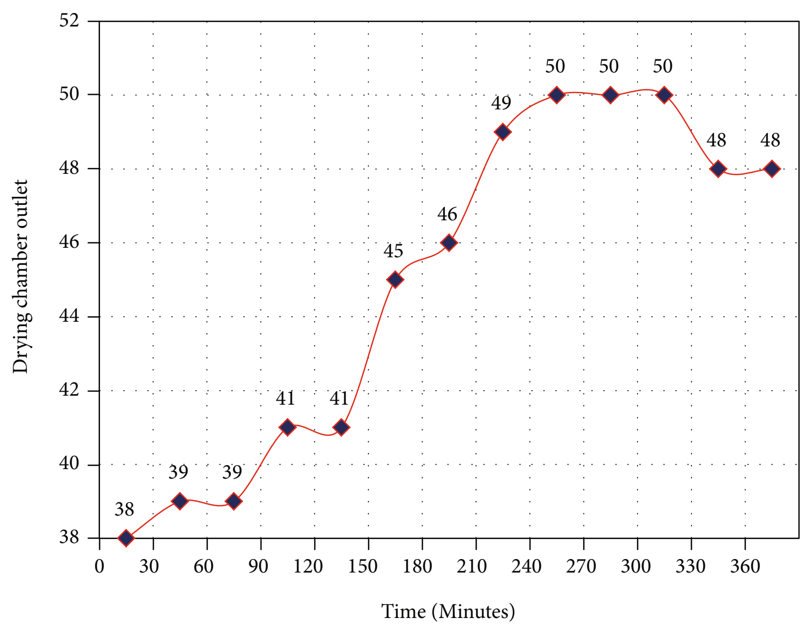


(d)

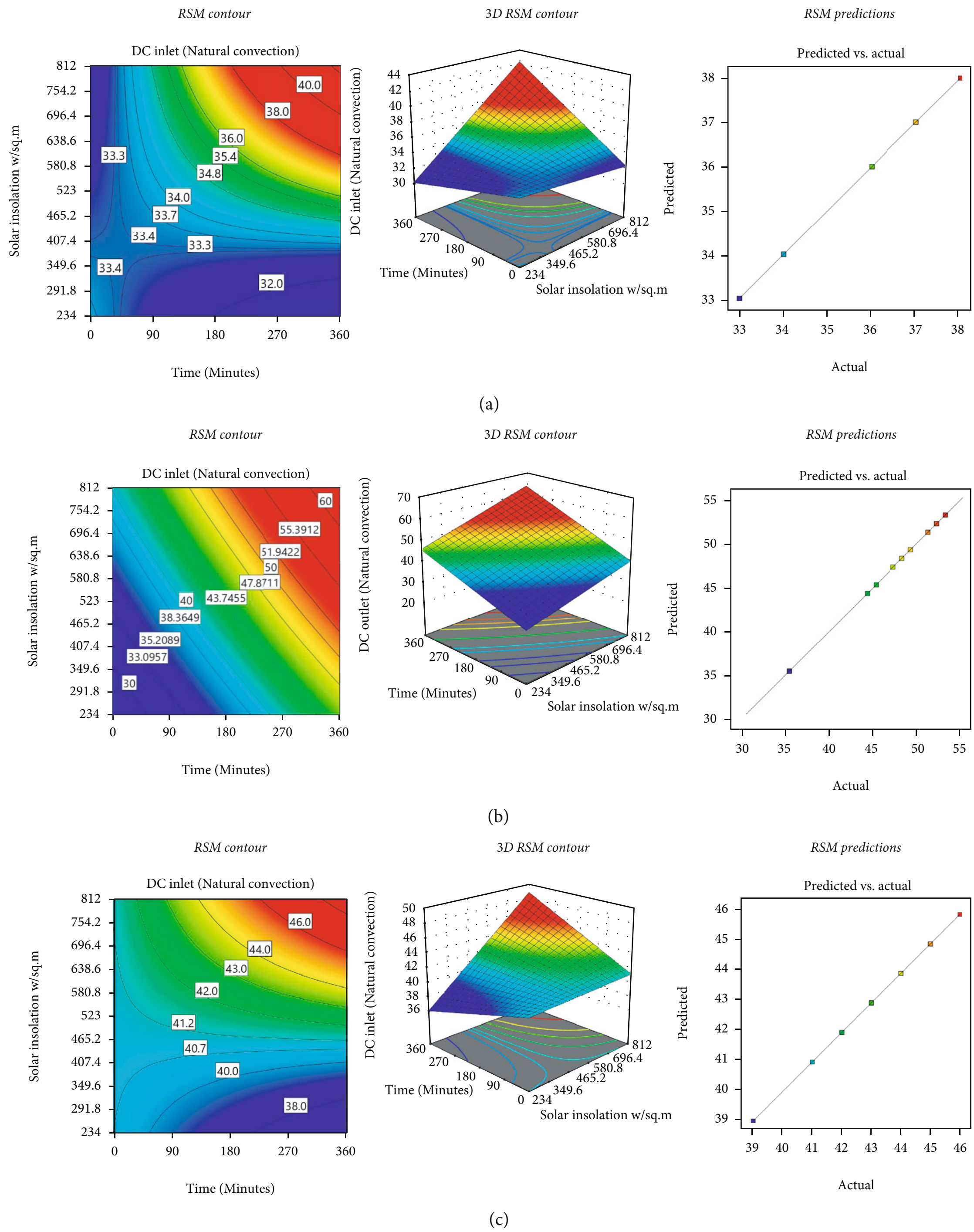
Figure 4: Variation of temperature in drying chamber in natural and forced convection.

The model is evaluated using the coefficient of determination (R-square).

3. Results and Discussions

3.1. Performance Investigation of Cashew Kernel Drying. Drying is the process of removing moisture through vaporization from the materials. This moisture is swept away from the material surface by means of hot air flowing over the material. For this, moisture has to travel from the inner layers of the materials to surface. Thus, it is a heat and mass transfer process. For drying of cashew kernels, experiments were conducted in the developed setups equipped with various advanced facilities. The experiments of drying cashew kernels were carried out in the month of April and May, where the solar radiation was 613.15 W/m^2 and 615.15 W/m^2, respectively, for natural convection and forced convection experimentations. In late summer, the experiments were conducted at Udupi, Karnataka, India, with the following coordinates: latitude (φ) $13°15'10''$N and longitude $74°47'39''$E. Both the greenhouse and forced convection FPC solar dryer were kept facing due south. Both the experiments were conducted on a clear sunny day.

The natural convection greenhouse dryer experiment was conducted in summer during April month on 25-4-



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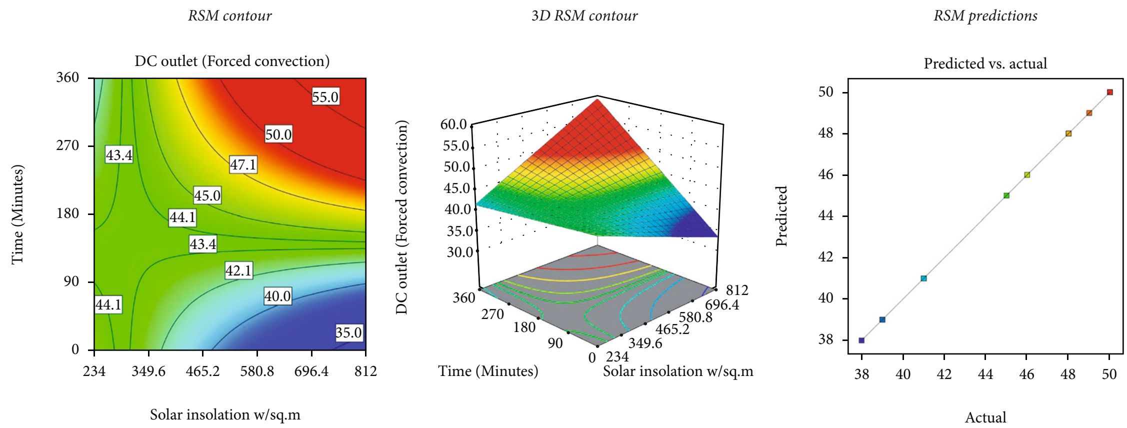


(d)

FIGURE 5: Variation of temperature in drying chamber in natural and forced convection using RSM..

2021. The average solar radiation measured was found to be 613.15 on the day the experiment was conducted at the geographical location. This value was more than the predicted solar insolation of 588.2 W/m^2 for the day, with the temperature considered to be in the range of 28°C to 34°C for the day, while the humidity varies in the range of 45% to 55% for a normal summer day. It can also be observed that the relative humidity was maximum in the morning and decreased with time due to solar radiation. While the solar radiation was least in the morning and increased with time, it reached a maximum in the forenoon and again decreased. The drying was effective in that period.

The global radiation varies from 419 to 764 W/m^2 for the forced convection FPC solar dryer during the experimental trial period between 10:00 am and 04:00 pm. The relative humidity exhibits a minimum value during the afternoon, while the global radiation exhibits a maximum value, with the RMSE value of 59.65%. Further, the temperatures in the range of 35°C to 58°C across the trays comprising of cashew kernels also reduced the moisture content. Furthermore, the dried kernels of the cashew are tested and found complying for the subsequent peeling process. Also, the cashew kernels dried in the experimental setup are of superior quality. The RSM contours, 3D surface plots, and predictions are shown for each case in Figure 3.

3.2. Correlations Using RSM.

$$\begin{aligned}&\text{Relative humidity\%[Natural Convection]}\\&\quad = 72.91 - 0.032 * Time(\text{minutes}) - 0.033\\&\qquad * \text{Solar Insolation W/sq.m} + 2.78e - 05\\&\qquad * \text{Time (minutes)} * \text{Solar Insolation W/sq.m},\end{aligned} \tag{2}$$

$$\begin{aligned}&\text{Solar Radiation W/m}^2 \text{ (Natural Convection)}\\&\quad = 5.93e^{-14} + -2.25e^{-16} * \text{Time (minutes)}\\&\qquad + 1 * \text{Solar Insolation W/sq.m} - 5.05e^{-19}\\&\qquad * \text{Time (minutes)} * \text{Solar Insolation W/sq.m},\end{aligned} \tag{3}$$

$$\begin{aligned}&\text{Relative Humidity\%(Forced Convection)}\\&\quad = 70.16 - 0.019 * \text{Time (minutes)} - 0.013\\&\qquad * \text{Solar Insolation W/sq.m} + 1.5e^{-05}\\&\qquad * Time \text{ (minutes)} * \text{Solar Insolation W/sq.m},\end{aligned} \tag{4}$$

$$\begin{aligned}&\text{Solar Radiation W/m}^2 \text{ (Forced Convection)}\\&\quad = 378.2 - 1.01 * \text{Time (minutes)} + 0.46\\&\qquad * \text{Solar Insolation W/sq.m} + 0.0013\\&\qquad * \text{Time (minutes)} * \text{Solar Insolation W/sq.m}.\end{aligned} \tag{5}$$

Air being humid in coastal areas, the relative humidity varies between 40 and 55%. In the morning at 10:0 am and in the evening at 4:00 pm, the humidity was found to be maximum and minimum as recorded in the afternoon 12:30 pm, due to high solar radiation. Minimum solar radiation was found, respectively, at 10 am and 4:00 pm. During high solar radiation and low humidity naturally, the drying process will be more and effective. In both cases, there is a considerable weight reduction due to moisture loss. The cashew kernels lost nearly 60 g per kg weight. The moisture content reduction goes up to 5% which is most suitable for peeling action of the test. The important results obtained during the experimentation are given in Tables 3 and 4, respectively, for both the experiments.

Figures 4 and 5 show the variation of temperature in the drying chamber in natural and forced convection cases. It can be seen that for given solar insolation, drying chamber (DC) inlet and DC outlet increased almost linearly with time, reached a maximum, and then decreased almost linearly. It can also be noted that these values were high for forced convection compared to natural convection cases because of increased velocity, increased convection, and high heat dissipation. Both DC inlet and DC outlet decreased almost linearly with solar insolation at a given time. Again, the values were high in forced convection as compared to natural convection case.

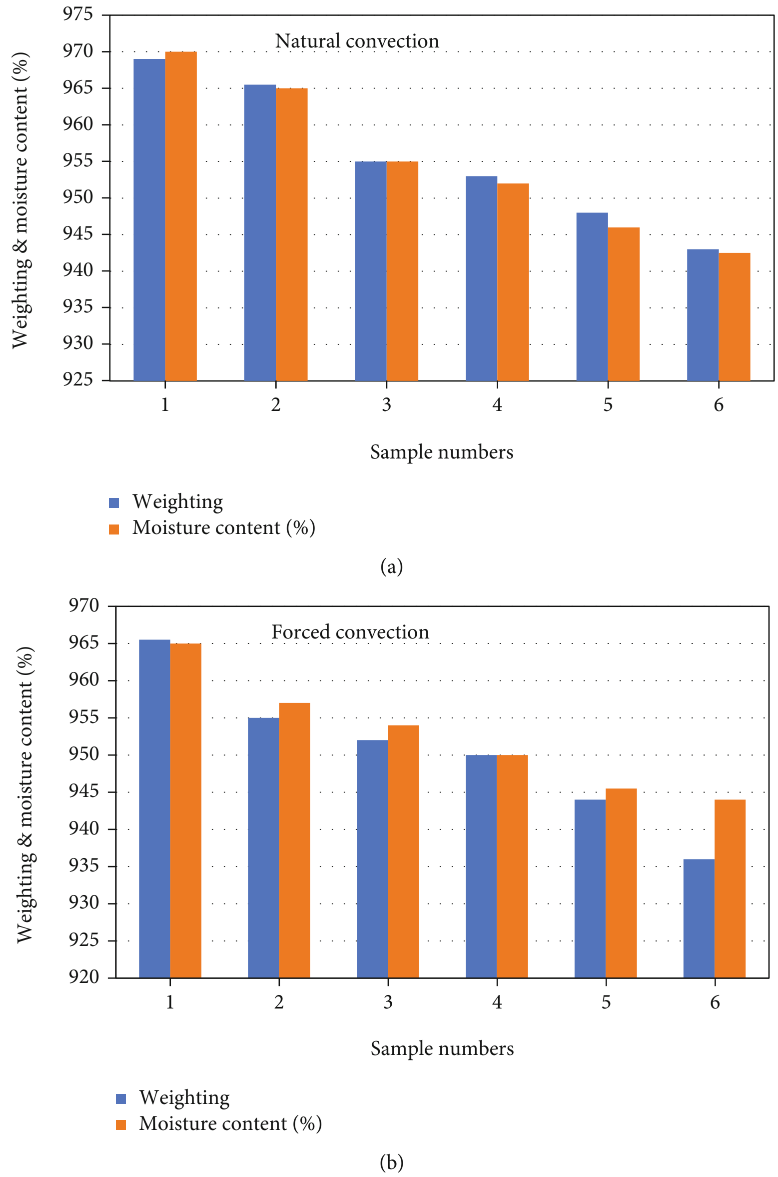


Figure 6: Variation of weight and moisture content in (a) natural and (b) forced convection.

3.3. Correlations Using RSM.

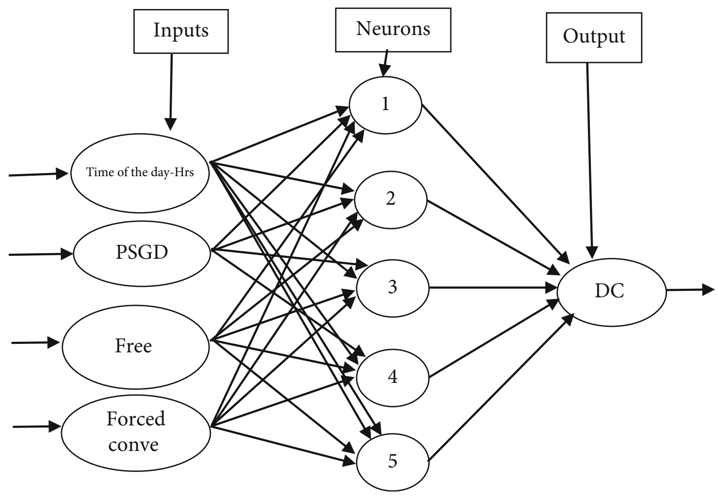
$$\begin{aligned}\text{DC Inlet (Natural Convection)} &= 34.3563 + -0.0254578 * \text{Time (minutes)} \\ &\pm 0.00246953 * \text{Solar Insolation W/sq.m} \\ &+ 6.56201e-05 * \text{Time (minutes)} \\ &* \text{Solar Insolation W/sq.m},\end{aligned} \quad (6)$$

$$\begin{aligned}\text{DC Oulet (Natural Convection)} &= 21.9476 + 0.0461958 * \text{Time (minutes)} \\ &+ 0.0223964 * \text{Solar Insolation W/sq.m} \\ &+ 2.10682e-05 * \text{Time (minutes)} \\ &* \text{Solar Insolation W/sq.m},\end{aligned} \quad (7)$$

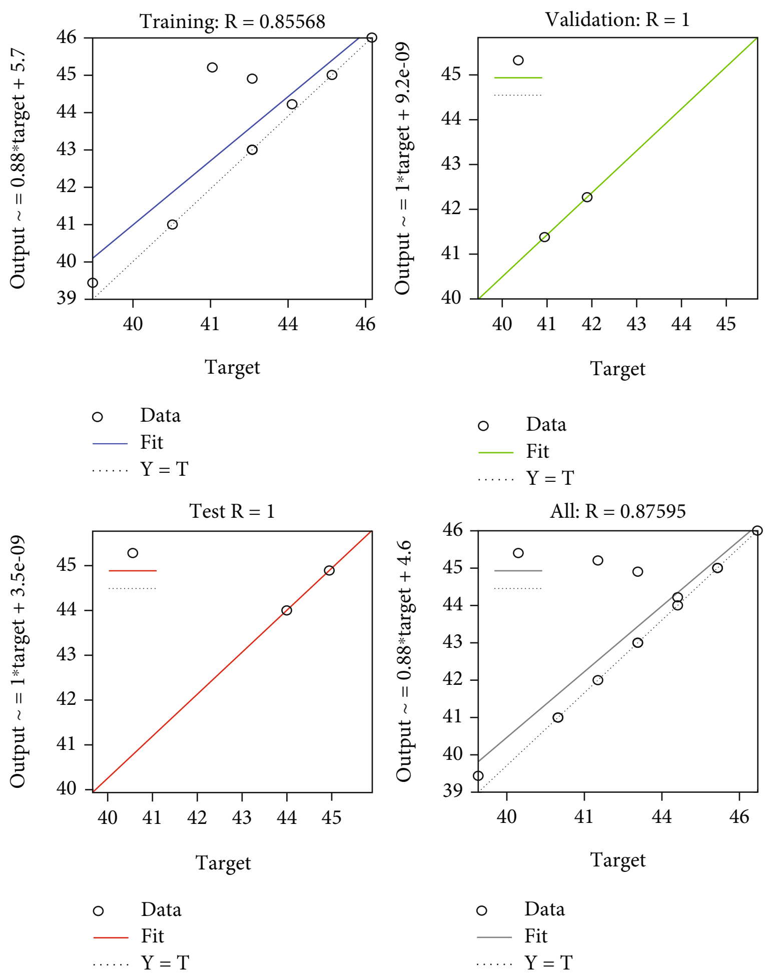
$$\begin{aligned}\text{DC Inlet (Forced Convection)} &= 40.4858 + -0.0264719 * \text{Time (minutes)} \\ &+ 0.000920563 * \text{Solar Insolation W/sq.m} \\ &+ 5.85624e-05 * \text{Time (minutes)} \\ &* \text{Solar Insolation W/sq.m},\end{aligned} \quad (8)$$

$$\begin{aligned}\text{DC Oulet (Forced Convection)} &= 49.5735 + -0.043235 * \text{Time (minutes)} \\ &+ -0.0198664 * \text{Solar Insolation W/sq.m} \\ &+ 0.000143962 * \text{Time (minutes)} \\ &* \text{Solar Insolation W/sq.m}.\end{aligned} \quad (9)$$

Figure 6 shows the variation of weight and moisture content in (a) natural and (b) forced convection for various

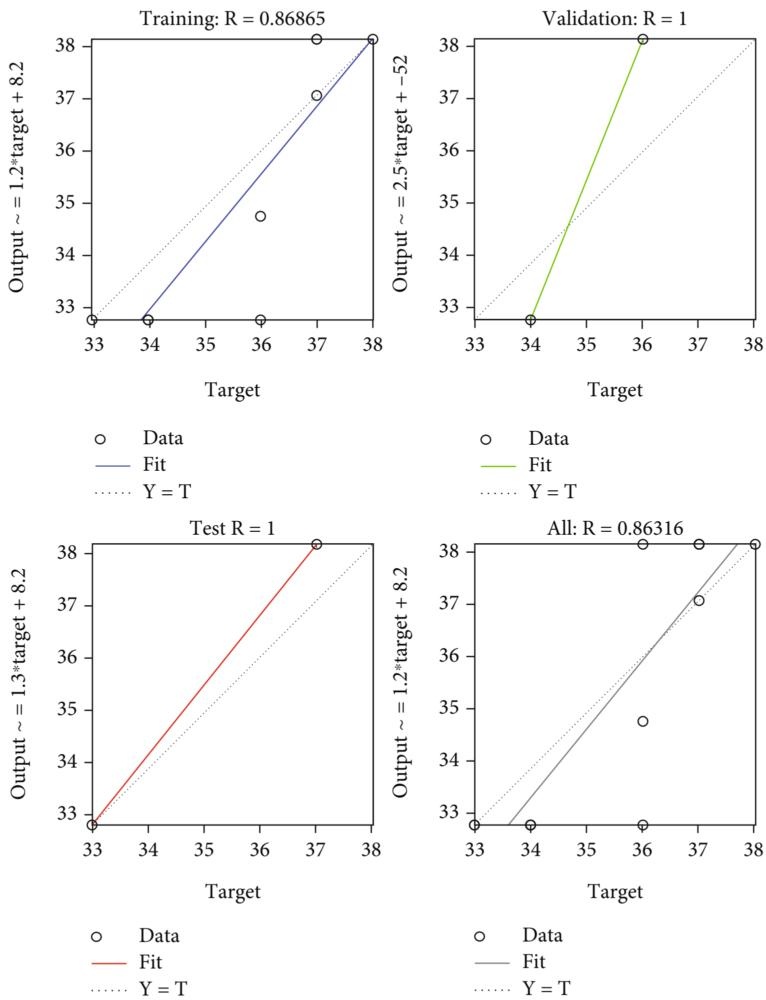


(a) General ANN structure



(b) Goodness of fit between predictions of ANN models and the experimental results (optimal performance at 30 neurons in hidden layer for DC Ti)

Figure 7: Continued.



(c) Goodness of fit between predictions of ANN models and the experimental results (optimal performance at 30 neurons in the hidden layer for DC T0)

Figure 7: Neural network training regression analysis.

samples. It can be seen that in both cases (natural and forced convection), there is a considerable weight reduction due to moisture loss. The cashew kernels lost nearly 60 g per kg weight. The moisture content reduction goes up to 5%, which is most suitable for the peeling action of the testa. It can also be observed that the weight reduction was high for the forced convection case compared to natural convection due to high flow velocity. The important results obtained during the experimentation are given in Tables 2 and 3, respectively, for both experiments.

The findings of the experiment are in line with the research outcomes of previous works, who have carried out work on the thermal analysis of forced convection and have reported that the heat transfer coefficient and thermal efficiency of the drying process can be enhanced by controlling the flow over the surfaces for optimal drying and heat transfer. Also, the previous work findings have ascertained the findings of thermal analysis; they have reported that the design optimization of conical draft tube and controlling the flow of hot air over the surfaces can significantly affect the boundary layer flow and thus influence the heat transfer rate. Thus, from the research findings of previous works, it is evident that the heat transfer rate is the major factor influencing the drying rate, which in turn is the major factor for optimizing the performance attributes of the solar dryers for cashew kernels [30, 31].

From the comparative evaluation (natural and forced convection) of the experimental outcomes, it is evident that the method offers quite a lot of inherent advantages, viz., the reduction in energy consumption by the drying chamber; since the energy consumption becomes almost constant, after the second hour of measurement, this is essentially due to the fact that the surface moisture is removed well within the first two hours of drying due to the efficient design of the drying chamber. After the first two hours, the rate of removal of moisture content almost becomes constant; however, the removal of moisture from inherent parts of cashew kernel is a continuous process throughout the day, and the energy consumption is monitored for a duration of 360 minutes, and the results are calculated. These experimental findings can be ascertained and validated from the RSM methodology and ANN modeling, which is a novel approach towards validation of the experimental results. Also, the results fulfill the objective of the research that the developed models provide sufficient room for the use of greenhouse dryers in the cottage and small industries. The method further provides an advantage with respect to the auto adjustment of the solar flat plate collectors to the angle of solar irradiation. The results provide a unique solution towards the use of solar energy for drying the cashew kernels which can effectively solve the problems of small scale industries who are dependent on conventional power sources for drying and processing nuts and raisins. The flat plate collector is designed to automatically adjust to the angle of solar irradiation, which is a novel method of harnessing the solar radiation for drying the cashew kernels. However, there are certain disadvantages with respect to the quantity of the cashew kernels that can be dried at a time and the dependency of the model on the solar radiations. These shortcomings can be overcome by enhancing the capacity of the solar dryer and incorporating a hybrid model of heat supply through biomass to augment the need for solar radiations during rainy season.

4. ANN Modelling

ANN is neurologically motivated; they are made up of segments that execute functions similar to those of a biological neuron at its most basic level. The artificial neuron is made to look like a biological neuron's first-order properties. In principle, a series of input data are provided, each of which defines the output of a different neuron. To assess the activation values of neurons, every insight is multiplied by the relevant weight; then, the weighted inputs are totaled. The biological cell body providing an outcome correlates to the summed body.

The drying system of cashew nut was modeled by an autonomous multilayer ANN model of the solar dryer. Though there is an equation for forecasting cashew nut drying rate [1], the ANN may not need it. The cashew nut ANN model has a 3-layered network with many simple processing units called neurons (Figure 7(a)). The model's input layer has 4 neurons related to the 4 input parameters, but the output layer only has a single neuron representing the DC Ti. The input parameters are time (t), sun radiation (It), free convection, and airflow rate. The values of these three variables were used as input data into the ANN.

The number of hidden layers in an ANN is determined by the extent of complexity of the problem and the network's applicability. There are no hard and fast criteria for figuring out how many hidden layers and nodes are to be used. A single hidden layer has been proven to be sufficient in most circumstances. As a result, a single layer is used. More hidden neurons can more accurately depict the system, but effective training is more difficult to achieve. The number of neurons in hidden layers of the model was determined to be 30 (Figure 7), after a significant number of ANN were evaluated. All of the inputs were normalised to a range of 0.00 to 1.00. The learning rate was previously set at 0.2 but dropped to 0.02, and the momentum was set at 0.90 to avoid overtraining. The models were trained for a specified number of 500 cycles, and the RMSE was always kept below a certain threshold. The RMSE was used to compare the results of the ANN models. ANN modelling gives a better prediction of the outputs, as shown in Figure 7.

5. Conclusions

The analysis of the results of the research has yielded some important inferences which are put forth pointwise accordingly in the conclusions.

(i) Natural and forced convection solar dryers with drying rates of 1.0 kg/h and 1.66 kg/h, respectively, demonstrated drying efficiencies of 51.7% and 50.9%

(ii) Each of the experimental case exhibits a decrease in the moisture content of up to 40 to 42%, resulting in an optimal moisture level of 5% for peeling

(iii) The required reduction in moisture content is accomplished, and the results help carry out the cashew kernels' safe peeling operation

(iv) Furthermore, the ANN and the RSM modelling provide improved prediction and optimization of performance parameters

(v) The variation between the experimental results and predictions of the ANN and RSM models are well within +/-5%

(vi) According to the research, the design is practical in small-scale and domestic sectors for batch drying of cashew kernels weighing up to 30 kg, where no external power arrangements are required

(vii) The experimental setups can be used during clear sunny days to dry cashew kernels and can be adopted for other varieties of nuts and raisins as well

5.1. Future Scope of Work

(i) The findings of the present work can be extended further to meet the requirements of the food processing industries, especially with respect to the drying of different varieties of nuts, raisins, fruits, and vegetables

(ii) The equipment can be modified by including a blow dryer setup and sieve dryer plates for adopting to sea fish processing plants

(iii) The computational fluid dynamics (CFD) studies can be carried out to further understand the flow characteristics for forced and free convection and adopt the findings for universalizing the equipment for multitude of applications

(iv) The use of heat storage materials in the system could be considered the scope of further research

Nomenclature

EUR: Greenhouse chamber energy utilization ratio
η: Greenhouse chamber efficiency
η_{dc}: Drying chamber efficiency of drying chamber
DR: Drying rate
η_{system}: Greenhouse dryer system efficiency
SEC: Specific energy consumption
MR: % moisture removed from product
m: Amount of moisture content removed
A_p: Heated plate surface area
f: Friction factor (dimensionless)
Q_I: Solar flat plate collector-input energy
Q_{gain}: Energy received
η_{FPC}: Efficiency
q_{in}: Drying chamber-energy entering
$q_{utilized}$: Energy utilized
η_{dc}: Efficiency of drying chamber
η_i: System ASAD-instantaneous efficiency
DR: Drying rate
m_a: Mass flow rate of air (kg/s)
Nu: Nusselt number (dimensionless)
K_a: Thermal conductivity of air (W/mK)
Re: Reynolds number of fluid (dimensionless)
V: Velocity of air (m/s)
SAH: Solar air heater.

Greek Symbols

ρ_a: Air density (kg/m^3)
υ_a: Kinematic viscosity of air (m^2/s)
η_p: Thermal hydraulic performance (dimensionless).

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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