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INTERMITTENT DRYING OF GUAVA FRUIT USING SOLAR PHOTOVOLTAIC ASSISTED DRYER

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Abstract
The intermittent drying behaviors of guava were experimentally studied using a Solar Photovoltaic assisted dryer. This research aimed to investigate the performance of dryer for drying applications utilizing a Taguchi design of experiment (DoE), ANOVA analysis. The drying experiments was carried for drying guava fruit of varying thickness from 2 to 7 mm and with different intermittent ratios ($\alpha = T_r/(T_t)$), where T_r and T_t are the rest time and total (heating and tempering) time for each 60 minutes' duty cycle α=0, 0.25, 0.5 and 0.75, respectively. The drying regime was observed all through a major falling rate. The study articulates that intermittent ratio and fruit thickness considerably effects dehydration process. The intermittency ratio of 0.25 resulted in optimum drying rate, reducing the effective drying time. Solar radiation is measured was ranged from 251 to 956 W/m^2. The maximum collector & dryer efficiency was 70% & 18% respectively. The biological test resulted showed the suitability of safe consumption. The statistical analysis shows, that the Henderson & Pabis and logarithmic model is a preferred to explain intermittent drying nature of Guava fruit.

Keywords: Intermittent Drying, intermittent ratio, Guava fruit drying. Antioxidant activity.

1. INTRODUCTION

Guava is a "super-fruit" of a Myrtaceae fruit family owing to its antioxidant and phenols virtue [1,4]. India leads guava production, followed by China [2, 3]. The purpose of dehydration is to remove water content to an optimal value such that no degrading microbial reactions are encouraged. In conventional drying continual heat is delivered throughout the dehydrating resulting in surface hardening of the product owing to less moisture at surface. Thus, it causes quality degradation by reducing drying rate and wastage of high-grade heat energy. The strategy of intermittent drying permits enough time for the moisture to mitigate at the surface from the center through the tempering period. The antioxidant properties and quality of dried guava slices strongly depend on pre-treatment and drying methods adopted along with drying conditions like air quality, temperature, and velocity [6]. Several constraints like medium temperature, inlet air velocity, and relative humidity, and fruit thickness influence drying kinetics. Modern-day techniques for devising drying procedures consist of developing a numerical model of moisture transport in drying known as 'drying kinetics' [7]. Dehydration of agricultural produce is well-defined by thin layer drying mathematical models. Drying kinetics are normally evaluated experimentally by observation of drying sample mass over a period [8,9]. Dehydration process Mathematical models are employed in enhancing existing drying systems, devising new systems, and optimization of dehydration process [10]. Fick's law of diffusion is generally employed to explain the dehydration process. Moisture ratio models are used to study the drying curves to understand dehydration of agricultural produce. The dry basis Moisture content at varying temperatures and velocities is transformed into a Moisture Ratio to normalize the curves.

This research aimed to experimentally explore the effects of intermittent-ratio and thickness for guava fruit on the drying curves of guava (Sodium guajava L) fruit grown in the Ballari (15.1394 ^{0}N, 76.9214^{0}E) area of Karnataka state, India, utilizing developed Micro-controller-based solar photovoltaic assisted fruit dryer. The purposes of the study were to experimentally explore the Guava fruit drying kinetics for varying drying parameters via, the effect of intermittent ratio and fruit thickness upon drying characteristics and study the fitness of semi empirical models developed by Henderson - Pabis [11], Page [12], and Wang- Singh [13] for explaining the dehydration process.

2. MATERIALS AND METHODOLOGY

2.1 EXPERIMENTAL SETUP

The schematic of the solar photovoltaic assisted fruit dryer setup is shown in Figure1. The dryer was used for experimental work, which assured required drying environments over a range of operational conditions. The drier comprises of 2mx1msolar flat plate collector with integral fins on selectively black coated 1mm absorber plate on 25mm glass wool insulated base and a two-drying cabinet insulated wall, two stainless steel mesh trays arranged in a vertical row (length 0.45m x width 0.45m x height 0.009m), dc fans for air circulation, and auxiliary heaters of 100w power were housed in a common air handling unit duct with two times of drying chamber. A flow control valve is utilized to regulate the hot air to the drying chamber. The hot air supply switching approach was used with four intermittent ratio α for drying fruit in a hot air cabinet. Flow control vale was used to achieve the required intermittent ratios=0, 0.25, 0.5 and 0.75, respectively ($\alpha = T_r / T_t$) where T_r and T_t are the rest time and total time of each 60 minutes' duty cycle. Thus α= 0 indicates conventional continuous heating and 0.75 intermittency (α) refers larger rest period. Digital temperature indicator, air filter, Relay indicator (Automatic), auxiliary heater, a control panel was used to regulate the required temperature of air. Fruit mass and air flow were measured with Digital electronic balance (±0.1mg).

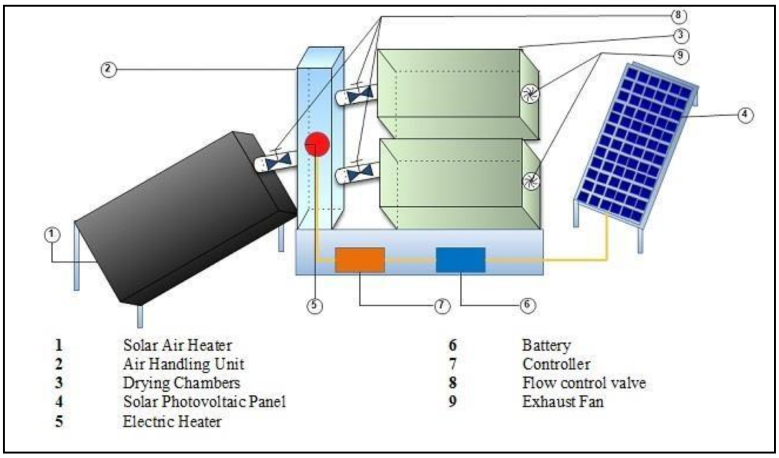


FIGURE1. Solar Photovoltaic assisted dryer Experimental setup

The trial runs were performed on 30mm fruit slice diameter guava fruit slices with thickness of 2 mm, 3 mm 5 mm, and 7mm mass of 120gms respectively. Drying experiments were performed for sunny days of May month. Solar Drier was run for 60 minutes to reach a steady-state condition Before drying experiments for the selected temperature of 64 ^{0} C hot air from 8 am to 5 pm each day. Drying chamber temperature is adjusted automatically with the help of auxiliary heater and relay. Air flows parallel through the stainless-steel wire mesh trays, on which the samples were arranged in a thin layer. The fruit samples during drying were weighed at every regular interval and later the readings were used for evaluation of drying curves. The process of drying was carried till the fruit reached equilibrium moisture content (EMC). The dry sample was cooled down till room temperature and packed in heat-sealed vacuum-packed LDPE (low-density polyethylene) bags. The final fruit mass was evaluated corresponding to a known initial mass, ahead of the experiment and the initial fruit moisture content, using equation (1) [14]

$$M_R = \frac{M_i - M_e}{M_o - M_e} \text{ ---------- } (1)$$

Where M_R is Moisture Ratio, M_i is Instantaneous Moisture content of the sample, M_e is Moisture content at equilibrium, M_o is Initial Moisture content.

2.2 TAGUCHI STATISTICALDESIGN

The guava dehydration process was carried out under different combinations of thicknesses and intermittent heating-tempering ratio, employing triplicate readings for each experiment, and averaged reading is used to calculate the effect. The Drying time and Equilibrium moisture content (EMC) were tabulated through weight lost by comparing initial and final fruit mass. The experimental combination of process parameter followed the Taguchi design using Minitab 17 software.

Table;1 Design matrix

Intermittent Ratio	Air Velocity	Air Temperature	Rh	Fruit Thickness	Intermittent Ratio	Air Velocity	Air Temperature	Rh	Fruit Thickness
	in m/s	in ^{0} C		in mm		in m/s	in ^{0} C		in mm
0	0.5	60	46	2	0.5	0.5	68	52	3
0	1	64	48	3	0.5	1	70	50	2
0	1.5	68	50	5	0.5	1.5	60	48	7
0	2	70	52	7	0.5	2	64	46	5
0.25	0.5	64	50	7	0.75	0.5	70	48	5
0.25	1	60	52	5	0.75	1	68	46	7
0.25	1.5	70	46	3	0.75	1.5	64	52	2
0.25	2	68	48	2	0.75	2	60	50	3

The design matrix provides the best probable combination of operational conditions of the model by decreasing total trial experiments. In this experimental work the dehydration process was carried out varying intermittent ratio, velocity, and fruit thickness, as they make a significant impact on the drying behavior of guava fruit. The 5 factors were coded at 4 levels of variation resulting 16 runs of experiments as indicated in fig 2. The curve-fitting is used to determine drying constants and coefficients for chosen empirical models. The results of the models were validated through commonly used statistical indicators for fruit drying models such as adjusted coefficient of determinant R^2.

In this experiment, the variables explored were intermittent ratio, temperature, air velocity, relative humidity, and fruit thickness, the possible combinations of exploratory variables with their ranges, and the experimental design is depicted in Tables 1 and 2.

TABLE:2 The Exploratory Variable

Exploratory Variable	Variable Ranges			
Intermittent Ratio	0	0.25	5	0.75
Air Velocity (m/s)	0.5	1	1.5	2
Temperature (°C)	60	64	68	70
Relative Humidity	46	48	50	52
Fruit Thickness in mm	2	3	5	7

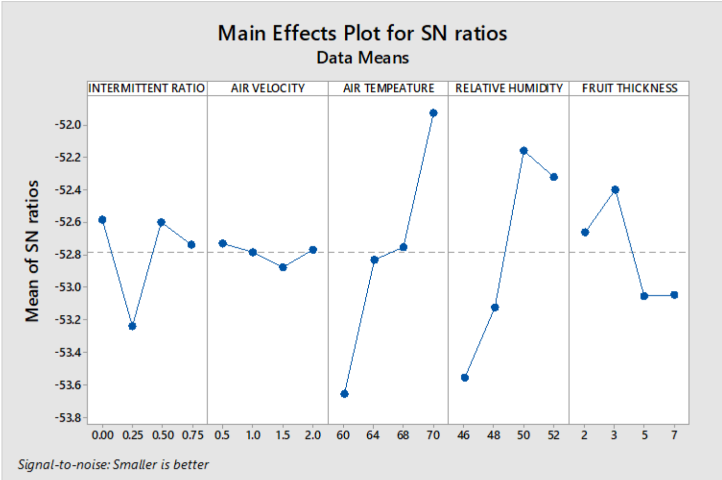


Figure 2: Signal to Noise Ratio plot

The figure 3 indicates the SN curve related to the selected parameter such as Intermittent Ratio and fruit thickness, the α=0.25 and thickness 5mm shows the optimum combination for the present study by considering least drying time as a response variable.

The thermal performance of collector and dryer was assessed utilizing the equations [15,16,] given below.

$$Q_u = A[S - U_L(T_{pm} - T_a)] \quad (2)$$

$$U_L = U_g + U_b + U_s \quad (3)$$

$$U_b = \frac{t_{bottom}}{K_i} \quad (4)$$

$$U_s = \frac{(L_1 + L_2) * L_3 * K_i}{L_1 * L_2 * t_s} \quad (5)$$

$$U_g = \left\{\frac{N}{\frac{C}{T_{pm}}\left[\frac{T_{pm}-T_a}{N+f}\right]^{e}}\right\}^{-1} + \frac{A_1}{B_1 + C_1 - N} \quad (6)$$

7

$$A_1 = \sigma(T_{pm} + T_a)\left(T_{pm}^{2} + T_a^{2}\right) \quad (8)$$

$$B_1 = \left(\varepsilon_p + 0.0591\,Nh_w\right)^{-1} \quad (9)$$

$$h_w = 2.8 + 3.0V_W \quad (10)$$

$$C_1 = \frac{2N + f - 1 + 0.0133\varepsilon_p - N}{\varepsilon_g} \quad (11)$$

$$f = (1 + 0.089 * h_w - 0.1166 * h_w * \varepsilon_p) * (1 + 0.07866 * N) \quad (12)$$

$$e = 0.430\left(1-\frac{100}{T_{pm}}\right) \quad 13$$

$$T_{pm} = T_{fi} + \frac{Q_u/A}{F_R U_L}\left(1-F_R\right) \quad 14$$

$$T_{fm} = T_{fi} + \frac{Q_u/A}{F_R U_1}\left(1-F''\right) \quad 15$$

$$F_R = \frac{\dot{m} \times C_p}{A_c \times U_L}\left[1-e^{-\frac{U_L A_c F'}{m^* C_p}}\right] \quad 16$$

$$F' = \left[1+\frac{U'_L}{h_e}\right]^{-1} \quad 17$$

$$h_e = h_{fp}\left(1+\frac{2\times l_f \times \phi_f \times h_{ff}}{W \times h_{fb}}\right) + \frac{h_r h_{fb}}{h_r + h_{fb}} = \quad 18$$

$$\phi f = \frac{\tanh^* mlf}{mlf} \quad 19$$

$$mlf = \left[\frac{2^* h}{K_{fin}{}^* t}\right]^{0.5} {}^* H \quad 20$$

$$h_{fb} = h_{fp} = \frac{N_u K}{d_e} \quad 21$$

$$d_e = \frac{4 \times (l1xl2)}{2 \times (l1 + l2)} \quad 22$$

$$U'_L = U_t + \frac{h_r U_b}{h_r + h_{fb} + U_b} \quad 23$$

$$h_r = F * 4 * \varepsilon_g * \sigma * \left[\frac{T_g + T_{sky}}{2}\right]^3 \quad 24$$

$$\eta_i = \frac{Q_u}{A_p \times S} \times 100 \quad 26$$

$$\eta_d = \frac{M_w * h_{fg}}{A_p * S * t_d} \times 100 \quad 27$$

Table 3 Selected thin layer drying models.

Sl. No.	Model name	Model
1	Page model (A)	$MR = \exp(-kt^n)$
2	Henderson &Pabis (B)	$MR = a * \exp(-kt)$
3	Wang & Singh (C)	$MR = 1 + at + bt^2$

Where a, b, k, and n, are drying coefficients k is the drying constant in min^{-1} and t is the drying time in min. The values of parameters for different models for thin layer drying at optimum temperatures, intermittent ratio, velocity, and fruit thickness utilizing the Analysis of variance method and presented in table 3

3.2 Biological analysis of sample

The dried guava slices were subjected to microbiological analysis to determine the product quality in terms of Antibacterial Activity, Antioxidant activity and Nutritional value. [17,18,19]

Determination of Antibacterial Activity

The bacterial colonies and fungal growth in dried samples were analyzed via pour plate method in two-stage that involving sample preparation and examination respectively. In first stage saline (Na Cl) solution was prepared in two separate beakers and mixed with dried fruit samples. The sterilized samples material was distributed on two Petri dish plates and then nutrient agar medium was added with to enable bacterial growth. The procedure for fungal growth analysis used 1 ml of sterilized sample poured on Petri-dish plates and added dextrose agar medium for enabling fungal growth during 3 to 4 days of solidification on Petri-dish placed in room temperature. After sample preparation the samples were examined for bacterial colony growth the microbial count in Quebec colony counter.

Determination of Antioxidant Content

Free radical scavenging ability of the methanol extract dried samples was tested by 1,1-diphenyl-2-picryl hydroxyl (DPPH) radical scavenging assay. The hydrogen atom donating ability of the dried sample extracts was determined by the de-colorization of methanol solution of (DPPH). 1 mL of different concentrations dried extract was added to 3 mL of 0.1mm methanolic solution of DPPH. The changes in absorbance of samples were measured at 517nm. A control reading was obtained using methanol.

Determination of Nutritional Composition

Nutritional value of the dried fruit was assessed by total fat, protein, carbohydrate energy and crude fiber was determined using respective standard protocol according to the standard procedure as mentioned in table 4.

Table:4 Nutrients analyzed

Sl No	Selected Parameter	Protocol
1	Total Fat	IS:12711: 1989
2	Total Protein	IS: 7219 : 1973
3	Carbohydrate	IS:1656: 2013
4	Energy	TAL/SOP/CM/122/00
5	Crude Fiber	IS: 10226 (Part 1) :1982

RESULTS ANDDISCUSSION

The variation of Moisture content (MC) reduction with a drying time is illustrated by figure 3. It is observed the drying time for intermittent drying is longer than the continuous drying. The moisture removal rate was faster at higher temperatures and the drying time shortened considerably as air temperature increased.

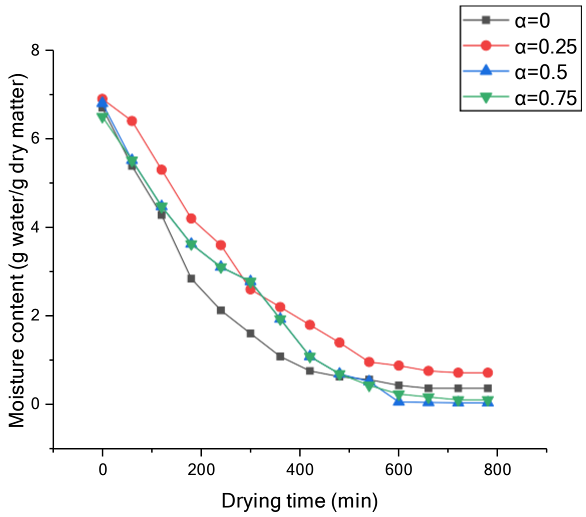


FIGURE 3 Variations of Moisture Content Vs Drying Time

It is observed that for a slice thickness of 5 mm, 1.5 m/s velocities, an intermittent ratio of 0.25 required 610 minutes, whereas 700 minutes was required for attaining EMC at 0.75 intermittent ratios. The soothing period substantially influenced the rate of drying as moisture mitigation from the center to the exterior controls the drying process. This agrees with the former research [20].

It is noted that intermittent ratio and temperature have a key influence on the drying rate. The increase of air temperature during the heating, increased the moisture removal rate. In Contrast increase in the tempering period in the heating cycle reduces the moisture removal as temperature difference at the surface of the fruit reduces.

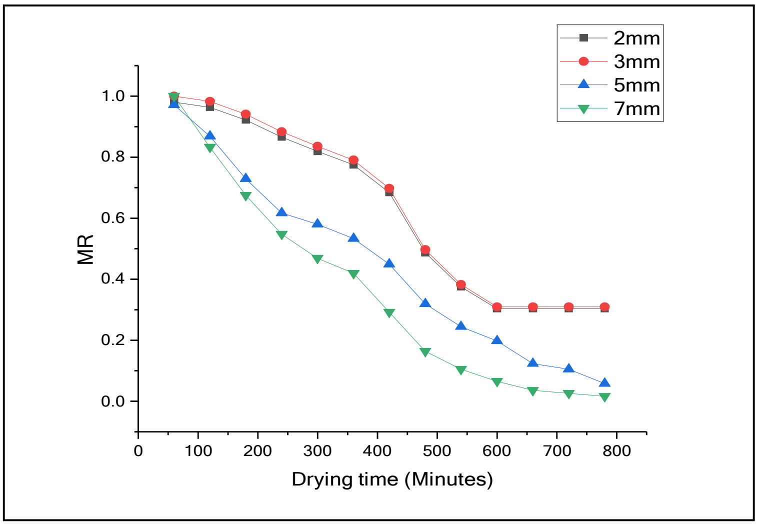


FIGURE 4 Variations of Moisture Ratio Vs Drying Time

Figure 4 Illustrates the change in Moisture Ratio with drying time for different thickness at 64°C air temperature. It is seen that a rise in slice thickness extends the total drying time. The total effective drying time reduces by 25% when compared with thickness from 7 mm to 2 mm, further thickness reduction from 3mm to 2 mm reduced the total drying time. It is observed that the moisture removal is faster during the start of the dehydration and reduces as the drying continues, indicating an exponential reduction of the moisture ratio along the drying time.

TABLE:5 Estimated Drying model parameters

Fruit	Fruit Thickness	Model	Constant	Drying coefficient			Statistical Indicator
	in mm		k (min^{-1})	a	b	n	R^2
Guava	3	1	0.00162	------	------	1.49	0.95
	5		0.00139	------	------	1.56	0.97
	7		0.00178	------	------	1.46	0.94
	3	2	0.00488	1.21	------	0.948	0.96
	5		0.00469	1.32	------	0.958	0.98
	7		0.0039	1.37	------	0.967	0.95
	3	3	------	0.0015	0.08	0.948	0.94
	5		------	0.0028	0.05	0.958	0.95
	7		------	0.0018	0.06	0.967	0.93

The selected model was fitted to the experimental data using the nonlinear regression. The higher the value of the coefficient of determination (R2) were chosen as the criteria for goodness of fit. The estimated parameters and results of the statistical analysis for the models are summarized in Table 5. It is observed from the tabulated results that high coefficients of determination were obtained for Henderson - Pabis gave higher values of R2 (0.98). The predicted and experimental values showed the suitability of the Henderson - Pabis equation in describing the intermittent drying behavior Guava Fruit.

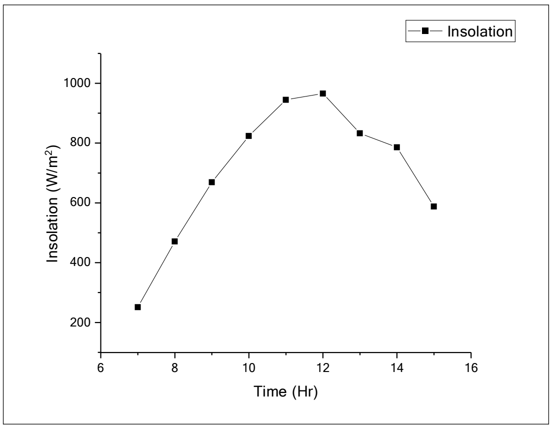


FIGURE 5: Variation of Insolation Vs Time

Figure 5 illustrates the variation of insolation along with time, it is observed that the solar insolation gradually increased in value till solar noon and remains constant with a value of 987 W/m^2 till 13:00 hrs. and reduces gradually to lower value by 17:00 hrs.

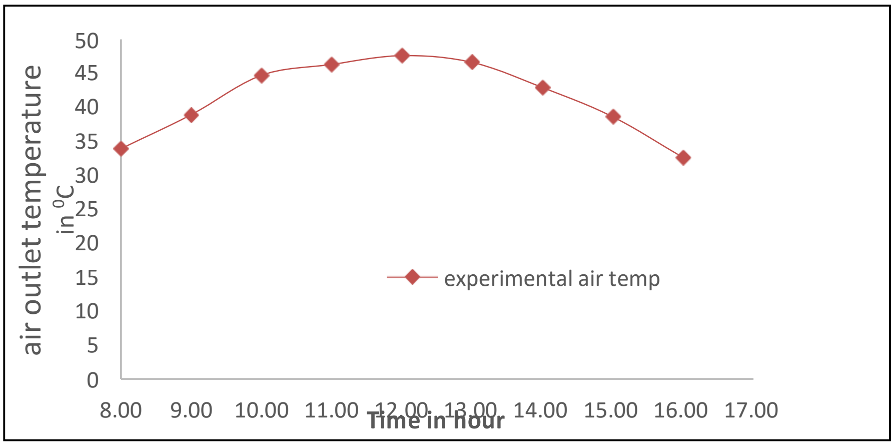
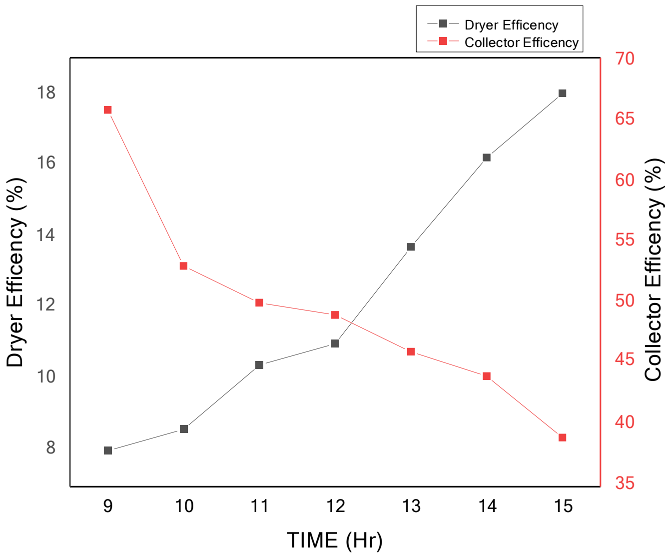


FIGURE 6. The Air outlet temperature Vs Time

Figure 6 depicts variations in exit air temperature of air heater with time for the month of June. The highest recorded air temperature was 48°C for a mass flow of 0.03 kg/s during the period close to solar noon.



Figure; 7 Variation of Experimental thermal efficiency

Figure 7 dipicts Variation of Experimental thermal efficiency of SPV assisted collector and Dryer efficiency along time. lower values during period close to solar noon owing to higher inlet air temperatures that contributed to enhanced heat losses. The earlier and later part of the day exhibited a better instantaneous efficiency due to lower thermal losses.The dryer effiency exibhited a reducing trend from 17 % to 8% as the available moisture to evaporate was reduced . The dependance of losses indicated that the efficiency of 68 percent for mass flow rate of 0.03 kg/s .

Biological analysis

The bacterial activity studies revealed that the microbial count on intermittently dried guava slice were within safe limit 2 log10cfu/g ((less than 8.0log10cfu/g)) for fruits [20], however fungal growth was visually not observed in 0.1ml samples through microscope.

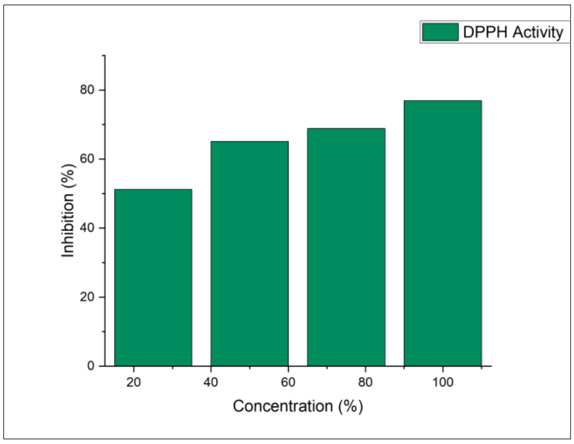


FIGURE 8: DPPH Percentage inhibition v/s sample solution concentration

The figure 8 Illustrates DPPH radical scavenging assay to determine antioxidant activity. The changes in absorbance of samples were measured. The tests were performed in triplicate and the graph was plotted with the mean values of inhibition percentage against the concentration of the sample solutions. The mean activity was found to begin at 48 % and showed maximum activity of 75%. The dried product had Antioxidant activity value of 51.2 mg/ml that amounted to less than 1% of fresh fruit value of chosen variety of guava fruit.

Table 6: Dried guava sample Nutrient contents

Sl No	Parameters	Units	Dried Sample	Fresh Fruit	Difference
1	Total Fat	G/100g	0.1	0.42	0.32
2	Total Protein	G/100g	3.1	2	-1.1
3	Carbohydrate	G/100g	78	81	3
4	Energy	K. Cal/100g	324.8	334.6	9.8
5	Crude Fiber	G/100g	1.1	2.9	1.8

The intermittently dried product nutritional value of the essential nutrients per 100 gram indicate an 0.32, 3, 1.8 grams' reduction of total fat, carbohydrate and crude fiber and 9.8 K Cal drop in Energy content in comparison with fresh guava fruit (allabhad safada variety). The microbiological analysis highlighted the suitability of Solar Photovoltaic assisted dryer for intermittent drying application.

4 CONCLUSIONS

The intermittent drying behavior of guava fruit was studied in the present experimental study as a function of varying drying conditions. Fruit slice thickness, as well as the intermittent ratio, was found to be a significant parameter affecting intermittent drying behavior of guava slices. A higher resting period resulted in a lower drying rate because of reduced air heat supply to the product besides the slower movement of moisture within the structure. The complete drying regime happened in the falling period. Fruit thickness, drying medium temperature, and intermittent ratio affect the total drying time predominantly.

In a heating cycle of 60 minutes, 45 minutes of heating and 15 minutes of resting period allows the moisture present in the fruit layer to mitigate to a surface which can be removed in the next heating cycle. The slice thickness of 5mm and intermittent ratio of 0.25 resulted in an increased drying rate consequently resulting in better moisture mitigation ratio during drying.

It was observed that the maximum collector thermal efficiency and Dryer efficiency were 65.7% and 18%, respectively. The dryer efficiencies improved with time as the moisture content of the produce reduced and it was found between 8 and 18.6% during day. The microbial count on intermittently dried guava slice is found to be within safe limit for fruits. The dried product had Antioxidant activity value of 51.2 mg/ml that amounted to less than 1% of fresh fruit value. The dried product nutritional value of the essential nutrients per 100 grams for Total fat, Total protein, Carbohydrate, Energy and Crude fiber were 0.1 g, 3.1,78 g, 324.8 kcal and 1.1 g respectively. The microbiological study highlighted the suitability of Solar Photovoltaic assisted dryer for intermittent drying application.

The statistical analysis indicates Henderson - Pabis model (R^2=0.982) as the most appropriate model to describe the defining guava fruit intermittent drying indicating the suitability of Solar Photovoltaic assisted dryer for intermittent drying application.

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NOMENCLATURE			
M_R	Moisture Ratio	h_w	Convective heat transfer coefficient between glass cover and ambient, W/m2K
M_i	Mi is Instantaneous Moisture content in kg H_2O/kg dry material	ε_p	emissivity for absorber plate
M_e	Me is Moisture content at equilibrium in in kg H_2O/kg dry material	ε_g	emissivity of cover
M_O	Mo is Initial Moisture in kg H_2O/kg dry material	m	Mass flow rate, m/s
Q_u	Useful heat gain	F_R	collector heat removal factor
A	Area of the collector in m2	F'	Efficiency factor of the solar air heater
S	Hourly insolation upon collector W/m2	FR	Heat removal factor for the solar air heater
T_{pm}	Mean Plate Temperature in 0C	hw	Convective heat transfer coefficient between glass cover and ambient, W/m2K
T_a	Ambient temperature 0C	hfp	Convective heat transfer coefficient between the absorber plate and the air stream, W/m2
U_L	overall loss coefficient	hfb	Convective heat transfer coefficient between the bottom plate and the air

			stream, W/m2
U_g	top loss coefficient	h	Convective heat transfer coefficient between the bottom plate and the air stream, W/m2
U_b	bottom loss coefficient	K_{fin}	Thermal Conductivity if fin in W/mK
U_s	Side loss coefficient	t	thickness of the fin
d_e	Equivalent diameter of the air tunnel, m	H	distance between the absorber plate and the glass cover
K_i	Thermal Conductivity if Insulation in	W	Distance between fins, m
N	number of transparent covers	N_u	Nusselt number
C	Specific heat of air at constant pressure, J/kgK	η_i	Efficiency of solar air collector
T_{pm}	mean absorber surface temperature	η_d	Efficiency of solar dryer
T_a	ambient temperature	M_w	Mass of water evaporated, kg
f	friction factor	h_{fg}	Latent heat of evaporation, J/kg
T_{fi}	Mean fluid temperature, K	t_d	Drying time, hour
T_g	Cover plate Temperature in 0C	α	Intermittent ratio
τ	Transmittance of glass cover	T_r	Rest time ,min
T_0	Fluid outlet temperature, K	T_t	Total time (in duty cycle), min
V_W	velocity of air, m/s		