Indian Journal of Engineering & Materials Sciences
Vol. 29, April 2022, pp. 237-242

Experimental analysis and mathematical modelling of ginger using different solar drying systems

Bhomesh Singh[a], O P Jakhar[a], Ravi Kumar[a*], C S Rajoriya[a] , & Sathans[b]

[a]Government Engineering College, Bikaner, Rajasthan 334 001, India
[b]National Institute of Technology, Kurukshetra, Haryana 136 119, India

Received: 16 February, 2021; Accepted: 30 December, 2021

Fruits and vegetables are perishable; they don't have a shelf life. They contain so much water that their logistic become difficult. Drying is both heat and mass exchange energy activity, mainly utilized as a food preservation technique. Fresh collected ginger has effectively dried from starting moisture content of 86% wet basis (w.b.) to the safe storage moisture content of 13% - 14% (w.b.) in Open Sun Drying (OSD) and hot air oven solar dryers. It has been found that the hot air dryer of the glass-to-glass module took less time (8hrs) as compared to the hot air dryer of an opaque module (10hrs) and Open Sun Drying (OSD) (14hrs). The drying behavior of ginger slices have been analyzed using various mathematical models. Page model has explained the drying behavior of ginger precisely with maximum values of coefficient of determinationi.e.,0.996, 0.997, and 0.994for hot air dryer of glass-to-glass module, opaque module, and OSD respectively, and has minimum reduced chi-square, mean bias error, and root mean square error.

Keywords: Ginger, Moisture content, Wet basis, Open sun drying (OSD), Hot air oven solar dryer, Mathematical models

1 Introduction

Drying is a significant activity in ginger handling. In numerous spots all through the world, ginger is generally dried under Open Sun Drying (OSD) conditions (specifically, open environment). The OSD technique unfavorably influences the item quality as far as shading, sustenance, substance creation, and food cleanliness is concerned[1]. For food preservation, OSD is the best traditional method rehearsed in numerous metropolitan and provincial territories of agricultural nations. The significant drawback of OSD is the bad quality of the item. The item gets defiled from dust, creepy crawlies, and different creatures which truly corrupt the quality of the food and its impact on the price[2]. In India, more than 300 days are clear and sunshiny, and hypothetical solar-oriented power gathering, on its territory region, is around five trillion kWh/year. The day-by-day normal solar-oriented energy incident over India fluctuates from 5 to 7 kWh/m^2 with around 1500 to 2000 daylight hours every year relying on the spot, which is more than present energy utilization[3].

The examination shows that cost of drying with solar power is only 33% when contrasted with the cost of utilizing a dryer based on conventional fuels[4]. These solar dryers take into account managed drying by dealing with the drying such as dampness content, the temperature of air, stickiness, and wind speed. Sufficient drying assists with protecting the flavor, surface, also, the shade of the food, which prompts a superior quality item[5]. Zingiber aceae family utilized the ginger as a zest and home-grown medicine. It can be acquired around the world in its new or semi-processed structure. With the expanding attention to the relationship between dietary phyto chemicals and human wellbeing and prosperity, flavors and culinary spices have acquired the consideration of established researchers since they contain synthetic mixes that have cancer prevention agents, what's more, restorative properties[6].

The region under development in India is 108.6 thousand hectares and the complete creation of the nation is 517.8 thousand tons[7]. Ginger has many applications arrangement, pastry shop items, toiletry items, scent businesses, meat items, wine, and soda pops making. Dried ginger is utilized both as a zest and medication. In Ayurveda, it is termed 'eda' which is a significant medication to fix numerous illnesses, for example, ailment, throat issues, heaps, alcoholic gastritis, cholera morbus, texture illness, neuralgia, and aspiratory and catarrhal sicknesses[8]. The nature of

*Corresponding author (E-mail: er.ravi@gamil.com)

ginger created in India has a high substance of smell and sharpness, what's more, it is likewise natural. Be that as it may, because of ill-advised post-harvest handling the greater part of the ginger is to be burned-through as a new vegetable and a portion of the great characteristics, for example, visual offer, surface, smell, flavor, design, and shade of the material get influenced. A few investigations have been accounted for an assortment of sunlight-based dryers for drying grains, vegetables, and various natural products[9]. Reenactment models are extremely useful in planning a new dryer or in improving a current dryer for the drying of horticultural items. Numerous specialists have conveyed out the examinations on the numerical displaying and trial concentrates on slight layer drying marvel of different items, as shown in Table 1.

2 Materials and Method

2.1 Sample preparation

From the open market of Bikaner, Rajasthan, India fresh ginger was bought and cleaned toremove excess debris and other stuff under tapwater. The washed ginger was peeled and sliced intothin slices of thickness 4 ± .5 mm. The gingerslices werekept in an open atmosphere for an hour to eliminate surfacemoisture.

2.2 Experimental setup

The experimental setup consistsof opaque and glass to glass photovoltaic thermal (PVT) modules by connecting 7 modules in series. At the outlet, hot air of the duct was used for the crop drying which is transferred in the dryer box using an insulation pipe. Drying operation was performed on two types of hot air dryer's namely hot air dryer of glass-to-glass module and opaque module shown in Figs 1 and 2 respectively.

The dryer consists of a solar collector and drying chamber. Two different types of solar collectors were used for drying ginger samples namely, glass to glass and opaque. At the inlet of the duct ambient air having a temperature range of 26 to 32 °C was passed through the solar collectors. The maximum air temperature inside the duct of glass to glass and the opaque module was observed 68°C and 62°C respectively. Hot air collected by the thermal energy transfer of solar collectors was fed into the dryer/box using insulated pipes.The dimensions of the chamber were 2.9 feet in length, 2 feet wide, and 2.6 feethigh.

Table 1 — Literature study of thin-layer drying of crops

Author	Year	Crop	Method	Best model	Reference
Fudholi A, & Hidayati S,	2020	Seaweed	Indirect type forced convection	Modified page model	[10]
Nukulwar M R, &Tungikar V B	2020	Turmeric	Indirect natural convection solar dryer (INCSD) and OSD	Page model	[11]
Nimnuan P, & Nabnean S,	2020	cassumunar ginger (Plai)	greenhouse solar dryer	partial differential equations	[12]
Karthikeyan A K, & Murugavelh S	2018	Turmeric (Curcuma longa)	Mixed-mode solar tunnel dryer	Varma model	[13]
Sahdev R K *et al.*	2018	Groundnut	Natural and forced convection mode	Henderson and Pabismodel,Lewis model	[14]
Dhanushkodi S *et al.*	2017	Cashew	Solar biomass hybrid dryer	Page model	[15]
Taghipour M *et al.*	2016	Lime slices	Laboratory dryer	Peleg model	[16]
Mutuli G P, & Mbuge D	2015	Cowpea leaves and jute mallow	Convective laboratory dryer	Page model	[17]
Mitrevski V *et al.*	2014	Banana slices	Convective dryer	Modified Henderson-Pabis model	[18]
Gharehbeglou P *et al.*	2014	Turnip	laboratory dryer	Modified Henderson and Pabis and Hii, Law and Cloke models	[19]
Bagheri H *et al.*	2013	Tomato slices	laboratory dryer	Page model	[20]
Mihindukulasuriya S D, & Jayasuriya H P	2013	Chilli	hot air oven and fluidized bed dryer	Midilli model	[21]
Kaleta A *et al.*	2013	Apple	Fluidized bed dryer	Page model	[22]
Akpinar, & E K	2006	Parsley, mint, and basil	Open sun drying	Modified Page model and Verma model	[23]

Inside the chamber, the maximum temperature observed in glass to glass and opaque hot air dryer was 59°C, and 54°C respectively.

2.3 Procedure

The experiments were performed during the month of November 2020 in the climaticconditions of Bikaner (28.0229° N, 73.3119° E), India.150 g weight of Ginger weighted on the electronic weighing machine having capacity 6 kg and least count 0.1g, and placed under OSD, hot air dryerof glass to glass and opaque module. Observations wererecorded for all modes. The observation timeinterval for all modes was an hour. The two consecutive values ofthe weighing machine directly gave the moisture evaporated during that time interval and were used in the calculations.The ginger samples were dried up to the safe storagemoisture level of 13% to 14% (w.b.). Fresh ginger and dried ginger samples under OSD, hot air dryer glass to glass, and opaque module are shown in Fig. 3.

Fig. 1 — Hot Air dryer of glass-to-glass module.

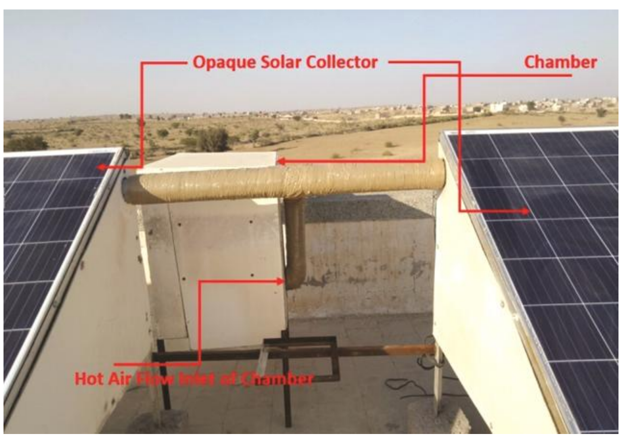

Fig. 2 — Hot Air dryer of opaque module.

2.4 Mathematical modeling

In terms of moisture removal rate, the experimental data obtained for the ginger was used for the drying kinetics of ginger. The moisture content data for both experimental modes were converted into moisture ratios and were used for various drying models. The moisture content data were converted into moisture ratios for both experimental modes and were used for different drying models as defined in Table 2.

2.5 Calculation

The moisture removal rate was based on**:**

Moisture content on wet basis (% w.b.)

$$M_{initial} = \frac{(W_w - W_d)}{W_w} \times 100 \quad \ldots(1)$$

where, $M_{initial}$ is the initial moisture content of ginger on d.b.%,W_w is the wet weight, and W_d is the dry weight of ginger in gm.

The moisture ratio of ginger during drying was estimated by:

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad \ldots(2)$$

Table 2 — Mathematical models for thin layer drying

Model name	Model	Reference
Lewis Model	$MR = exp(-kt)$	[24]
Page Model	$MR = exp(-kt^n)$	[25]
Henderson And Pabis	$MR = aexp(-kt)$	[26]

Note: k = drying constant (1/h); t = time (hrs); a = coefficient in the drying models, and n = no. of constants in drying models

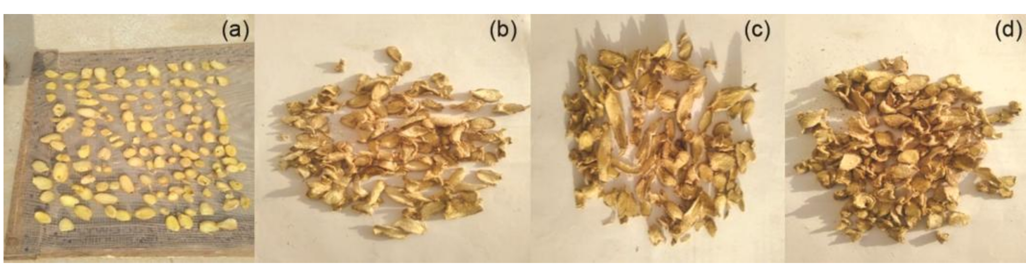

Fig. 3 — Sample of (a) Fresh ginger, (b) dried ginger under OSD, (c) dried ginger under glass-to-glass module, and (d) dried ginger under an opaque module.

where, M_t = moisture content at 't' drying time (%, dry basis); M_e= equilibrium moisture content, and M_i= initial moisture content (%, dry basis).

Statistical criteria, namely, coefficient of determination (R^2), reduced chi-square (χ^2), root mean square error (RMSE), and percent relative error for suitability of the best model described as

$$R^2 = \frac{\left(\sum M_{exp}\, M_{pre}\right)^2}{\sum M_{exp}^2\, \sum M_{pre}^2} \quad \ldots (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{(N-n)} \quad \ldots (4)$$

$$MBE = \frac{\sum_{i=1}^{n}\left(MR_{exp,i} - MR_{pre,i}\right)}{N} \quad \ldots (5)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N}} \quad \ldots (6)$$

3 Results and Discussion

The experimental data obtained for ginger drying under hot air drying in both glass to glass and opaque module and, open sun drying given in Tables (3–5).

The ginger samples were dried from the initial moisture content of 86% (w.b.) to the safe storage moisture content of 13% to 14% (w.b.). Drying data of ginger samples were fitted to three thin layer drying models and the statistical parameters along with their constants were calculated by regression analysis using the SOLVER computer program. The parameters are summarized in Tables (6-8).

The variation in terms of moisture ratio for both modules with respect to drying time for the drying of ginger samples is shown in Figs (4-6).

From Tables (6-8) it was observed that Page model with the highest value of R^2(0.996,0.997, and 0.994) and lowest values of $\chi 2$ (0.00698,0.0011 and 0.00248), *RMSE* (0.02573, 0.0296 and 0.0461), and *MBE* (0.00523, 0.00742 and 0.0097) was found to be most suitable for ginger drying under hot air oven

Table 3 — Experimental data for ginger in glass-to-glass module

Time, t (hrs)	0	1	2	3	4	5	6	7	8
Moisture Content	0.868	0.752	0.594	0.4513	0.2153	0.1267	0.0693	0.0173	0
Moisture Ratio	1	0.8664	0.6843	0.52	0.2481	0.1459	0.0799	0.02	0

Table 4 — Experimental data for ginger in opaque module

Time, t (hrs)	0	1	2	3	4	5	6	7	8	9	10
Moisture Content	0.865	0.8227	0.6813	0.5713	0.4853	0.366	0.2787	0.176	0.0973	0.036	0
Moisture Ratio	1	0.9514	0.788	0.6608	0.5613	0.4233	0.3223	0.2035	0.1126	0.0416	0

Table 5 — Experimental data for ginger in OSD

Time, t (hrs)	0	1	2	3	4	5	6	7	8
Moisture Content	0.8607	0.8527	0.7613	0.6793	0.5867	0.5433	0.4907	0.4427	0.3633
Moisture Ratio	1	0.9907	0.8846	0.7893	0.6816	0.6313	0.5701	0.5143	0.4222
Time, t (hrs)	9	10	11	12	13	14	NA	NA	NA
Moisture Content	0.2947	0.232	0.1433	0.0813	0.022	0	NA	NA	NA
Moisture Ratio	0.3424	0.2696	0.1665	0.0945	0.0256	0	NA	NA	NA

Table 6 — Modeling of *MR* for thin layer drying of Ginger under Glass-to-Glass module

Model name	k	N	a	R^2	RMSE	χ^2	MBE
Lewis	0.3009	-	-	0.970	0.10111	0.01168	0.00343
Page	0.1054	1.7962	-	0.996	0.02573	0.00698	0.00523
Henderson And Pabis	0.3276	-	1.1003	0.972	0.09158	0.01118	0.02095

Table 7 — Modeling of *MR* for thin layer drying of Ginger under Opaque module

Model name	k	N	a	R^2	RMSE	χ^2	MBE
Lewis	0.1929	-	-	0.976	0.1009	0.01133	0.00475
Page	0.0553	1.7415	-	0.997	0.0296	0.0011	0.00742
Henderson And Pabis	0.2162	-	1.1196	0.978	0.0873	0.00953	0.01603

Table 8 — Modeling of *MR* for thin layer drying of Ginger under OSD

Model name	k	N	a	R^2	RMSE	χ^2	MBE
Lewis	0.1232	-	-	0.974	0.1049	0.01185	0.0081
Page	0.0261	1.7474	-	0.994	0.0461	0.00248	0.0097
Henderson And Pabis	0.1407	-	1.1302	0.978	0.0923	0.0095	0.0132

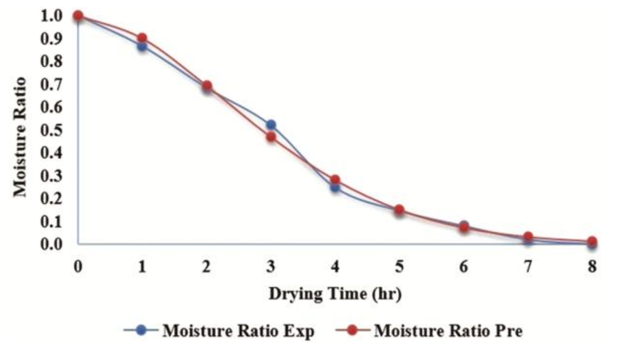

Fig. 4 — Moisture ratio v/s drying timeunder glass-to-glass module.

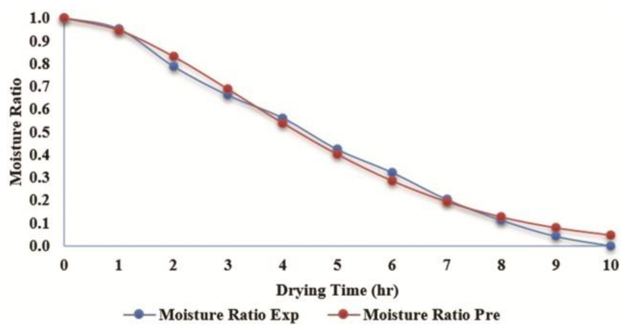

Fig. 5 — Moisture ratio v/s drying time under an opaque module.

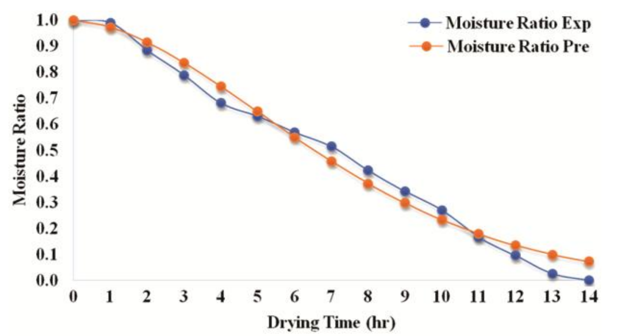

Fig. 6 — Moisture ratio v/s drying time under OSD.

in glass to glass, opaque and open sun drying respectively among all the models investigated. Deshmukh *et al.*[9] also suggested the Page model for drying ginger inside mixed-mode solar cabinet drying.

4 Conclusion

Experimental analysis and mathematical modeling of the drying behavior of ginger slices are analyzed using the three different solar drying systems based on the wet basis and presented in the study. Following are some important conclusions of this experimental investigation.

- Fresh ginger slices have dried from initial moisture content of 86 % (w.b.) to final moisture content of 13 to 14 % (w.b.).
- Hot air dryer of glass-to-glass module gave the best result as the time taken by hot air dryer of glass-to-glass module (8 hrs.) was less compared to opaque module (10 hrs.) and OSD (14 hrs.).
- The experimental data has validated to the predicted value and it has observed that the moisture removing rate have been quite similar.
- The drying behavior of ginger slices have been analyzed using various mathematical models and found that the result obtained by the Page model explains the drying behavior of ginger precisely with maximum values of coefficient of determination (R^2) i.e.,0.996, 0.997, and 0.994 for hot air dryer of glass-to-glass module, opaque module, and OSD respectively.
- Page model has minimum reduced chi-square, mean bias error, and root mean square error.

Acknowledgment

The authors greatly acknowledge the financial support from the collaborative research scheme (CRS) Project ID 1-5763884671 from NPIU under the TEQIP-III phase.

References

1 Thorat I D, Mohapatra D, Sutar R F, Kapdi S S, & Jagtap D D, *Int J Food Bioproc Tech*, *5*(4) (2012) 1379.

2 Deshmukh A W, Varma M N, Yoo C K, & Wasewar K L, *Chinese J Engg*, (2014) 1.

3 Muneer T, Asif M, & Munawwar S, *Renew Sust Energ Rev*, 9(5) (2005) 444.

4 ChavdaT V, & Kumar N, *Solar dryers for high value agro products*, Proceedings of the International Solar Food Processing Conferenceat SPRERI, (2009) 205.

5 Whitfield D E, *Solar dryer systems and the internet: Important resources to improve food preparation*, Proceedings of International Conference on Solar Cooking, Kimberly, South Africa, (2000)

6 Amoah R E, Kalakandan S, WirekoManu F D, Oduro I, Saalia F K, & Owusu, E, *J Food Sci Nutr*, *8*(11) (2020) 6112.

7 Rahman H, Karuppaiyan R, Kishorem K, & Denzongpa R, *Indian J Tradit Knowl*, 8(2009) 23

8 Singh K K, Tiroutchelvame D, & Patel S, *Drying characteristics of ginger flakes*, Proceedings of the 16th International Drying Symposium (IDS '08), Hyderabad, India, (2008) 1383.

9 Deshmukh A W, Wasewar K L, & Verma, M N, *Int J Chem Sci*, 9(3) (2011) 1175.

10 Fudholi A, & Hidayati S, *Int J Adv Sci Technol*, 29(5) (2020) 7407.

11 Nukulwar M R, & Tungikar V B, *Int J Appl Sol Energy*, 56(4) (2020) 233.

12 Nimnuan P, & Nabnean S, *Case Stud Therm Eng*, *22* (2020) 100745

13 Karthikeyan A K, & Murugavelh S, *Int J Renew Energy*, 128 (2018) 305.
14 Sahdev R K, Kumar M, & Dhingra A K, *Int J Agric Eng*, 19 (4) (2018) 152.
15 Dhanushkodi S, Wilson V H, & Sudhakar K, *Int J Resource-Efficient Technologies*, 3(4) (2017), 359.
16 Taghipour M, Kakolaki M B, Zomorodian A, & Nassiri S M, *Int J Agric Eng*,18(1) (2016) 284.
17 Mutuli G P, & Mbuge D, Int J Agric Eng, 17(4)(2015) 265.
18 Mitrevski V, Lutovska M, Mijakovski V, & Mijakovski N, *J Hyg Eng Des*,8 (2014) 145.
19 Gharehbeglou P, Askari B, Rad A H, Hoseini S S, Pour H T, & Rad A H E, *Int J Agric Eng*,16(3)(2014) 194.
20 Bagheri H, Arabhosseini A, Kianmehr M H, & Chegini, G R, *Int J Agric Eng*, 15(1) (2013)146.
21 Mihindukulasuriya S D, & Jayasuriya, H P, *J Food Sci Technol Int* ,52(8)(2015), 4895.
22 Kalet A, Górnicki K, Winiczenko R, & Chojnacka, A, *Int J Energy Convers*, 67 (2013)179.
23 Akpinar E K, *J Food Eng*, 77(4) *(*2006) 864.
24 Lewis W K, *J IndEngChem*,13(5) (1921) 427.
25 Page, G E (1949), *Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin layers*, M.Sc. Thesis, Purdue University, United States, 1949.
26 Hendorson S M, *J Agric Eng Res*, 6(3) (1961)169.