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DRYING CHARACTERISTICS OF SWEET ORANGE PEEL

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ABSTRACT
The aim of this work is to investigate the drying characteristics of sweet orange peel in three different drying methods *i.e*., solar tunnel drying, hot air drying and dehumidified air drying. The drying study showed that the times taken for drying of sweet orange peel in three different drying method. The drying data were fitted to 5 thin-layer drying models, *viz.*,Newton, Page, Henderson-Pabis, Logarithmic and Midilli-Kucuk models The performances of these models were compared using the determination of coefficient (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) between the observed and predicted moisture ratios. Among the five tested model Midilli-Kucuk model described the best fit to the experimental data.

KEYWORDS: Dehumidified air Drying, Hot air drying, Drying characteristics, Drying models and Sweet orange peel.

INTRODUCTION
Sweet orange (*Citrus sinensis* Osbeck) belongs to sub family Aurantoideae which is categorised under family Rutaceae (Milind and Dev, 2012). In sweet orange 16-20% is composed of peel and it is main by-product obtained from sweet orange fruit juice processing industries. It is the highly perishable and if not processed the peel become waste and in turn may become a possible source of environmental pollution. By-product recovery from fruit wastes can improve the overall economics of the processing units and the problem of environmental pollution also can be reduced considerably (Kumar *et al*., 2011). Around the world, 31200 tonnes of orange and other citrus fruits are annually processed out of which the estimated annual waste is 15.6 million MT (Djilas, 2009). These are mainly used for animal feeds, due to their high fibre content; they could represent an interesting source of dietary fibre (Larrauri *et al*., 1997). Since the fruit by-product has high moisture content it need efficient drying method to convert wet sweet orange peel into dry form. Solar tunnel drying is an improved method over the open yard sun drying since the farmer results in shorter drying time and safer product. Nowadays hot air drying is quite common in many industries due to easing of operation, low investment and operation cost compare to other advanced technique. Dehumidified air drying is one of the improved drying methods which dry the sample at relatively less temperature and humidity.

Garau *et al*. (2006) conducted experiments on drying kinetics, modelling and functional properties of orange skin, Silva *et al*. (2011) proposed combined approach to optimize the drying process of flavonoid-rich leaves using thin layer modelling, Ponkham *et al.* (2012) conducted experiment on thin layer modelling of combined far-infrared radiation and air drying of a ring shaped pineapple, Galvez *et al*. (2010) determined the effective moisture diffusivity and mathematical modelling of the drying curves for the olive-waste cake. In all the stated studies they considered thin layer drying models *viz*., Newton, Page, Henderson and Pabis, logarithmic and Midilli–Kucuk models. There are no studies showing drying characteristics of sweet orange peel. So in present study efforts were undertaken to describe the drying characteristics of sweet orange peel with respect to three drying (solar tunnel drying, hot air drying and dehumidified air drying) by considering the above said models.

MATERIAL AND METHODS
Sample preparation
Fresh sweet orange (cv. Sathgudi) were selected uniformly according to maturity, colour, size and freshness. The fruits were washed, weighed and peeled by using knife. Then peels were cut into small pieces (20mm×10mm), after that it was washed using hot water at 90°C for 5 min. After that peel surface moisture was removed by using muslin cloth then it was followed by three drying methods with bed thickens of 5mm.

Drying process and mathematical modeling
Sweet orange peel was dried using three drying methods till constant weight is obtained. In hot air drying, hot air drying at 60 ±1°C was selected according to results of Garau *et al*. (2007) in case of dehumidified air drying 45 ±1°C at 15 ±1% RH was selected which is less than hot air drying temperature. In solar tunnel drying, the average temperature recorded was 52°C when average ambient temperature was 37 °C. The mathematical models namely, Newton, Page, Henderson-Pabis, Logarithmic and Midilli-Kucuk models were selected on their ability to best fit the experimental data. The models are;

Newton model: $MR = \exp(-K\theta)$ ....(1)

Page model: $MR = \exp(-K\theta^{n})$ ....(2)

Henderson- Pabis model: $MR = a*\exp(-K\theta)$ ....(3)

Logarithmic model: $MR = a*\exp(-K\theta) + c$ ....(4)

Midilli-Kucuk model: $MR = b\theta + a*\exp(-K\theta^{n})$ ....(5)

Where,

MR= Moisture ratio

The moisture ratio (MR) is denoted by $\left[\dfrac{M-M_e}{M_o-M_e}\right]$ ....(6)

Where,

M_e = equilibrium moisture content, (% d.b.)
M = moisture content at any time, θ (% d.b.)
M_o = initial moisture content (% d.b.)
K, n, a, b and c = drying rate constants
θ = drying time (min)

Drying rate was calculated according to methodology explained by Chakraverty 1981.

$$\text{Drying Rate} = \frac{\text{Amount of moisture removed}}{\text{Time taken} \times \left(\dfrac{\text{Total bone dry weight of sample in gm}}{100}\right)} \quad ....(7)$$

The drying parameters of all the models were estimated by using 'Matlab' version 7.0 software. The fit quality of the proposed models on the experimental data was evaluated using linear regression analysis using curve fitting tool in MATLAB. The statistical parameters standard square error (SSE) and root mean square error (RMSE) were calculated employing the following equations.

$$P = \frac{100}{N}\sum_{i=0}^{N}\frac{MR_o - MR_P}{MR_o} \quad ....(8)$$

$$RMSE = \sqrt{\frac{\sum_{i=0}^{N}\left(MR_o - MR_p\right)^2}{df}} \quad ....(9)$$

$$SSE = \frac{1}{N}\sum_{i=1}^{N}(MR_o - MR_p)^2 \quad ....(10)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_o - MR_p)^2}{N - z} \quad ....(11)$$

Where,

MR_o = observed moisture ratio
MR_P = predicted moisture ratio
df = degrees of freedom
N = No. of data points
z = No. of constants

RESULTS & DISCUSSION

Drying behaviour of sweet orange peel

Irrespective of drying method, an increasing trend was observed in the reduction of moisture content in beginning of the drying. As the drying proceeded, the loss of moisture in sweet orange peel decreased with drying time. The reduction in moisture content, drying rate and moisture ratio with respect to drying time is given in Table 1.

TABLE 1: Final Moisture content, average drying rate and drying time for drying of sweet orange peel in three drying methods

Sl. No.		Dehumidified air drying	Hot air drying	solar tunnel drying
1	Drying time, h	3.5	5	12
2	Final Moisture content, % d.b.	6.52	8.09	8.73
3	Average drying rate, g of water/min. per 100 gm of bone dry materials	0.19	0.14	0.06

Fig. 1 shows the influence of drying air temperature on drying rate with respect to drying time. It can be seen that, the drying process mainly consisted of three drying periods i.e., heating up, constant rate and falling rate period. Hot air drying at temperature of 60±1 °C showed only the falling rate period, which was due to moderate temperature of drying. In hot air drying, the drying rate started from 0.33 to 0.01 g of water/min. Per 100 g of bone dry materials at 60 ±1°C. Constant rate of drying was not observed in the drying period, this might be due to thin layer arrangement and too rapid heating of peel, similar observation was observed by Giri and Prasad (2007) during microwave and hot air drying of mushroom.

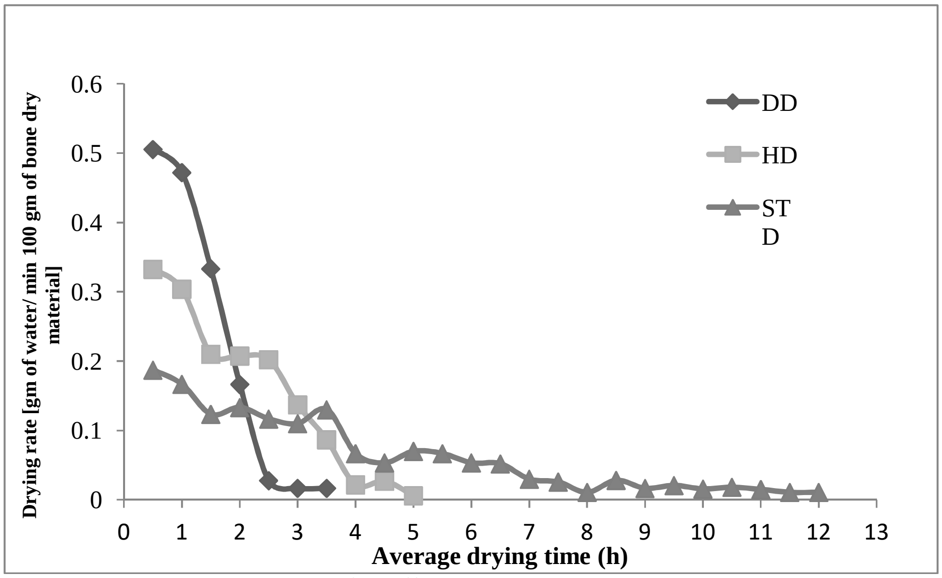

FIGURE 1: Drying rate curve for different drying methods with respect to drying time
Abbreviation: STD, solar tunnel drying; HD, hot air drying; DD and dehumidified drying

In dehumidified air drying process at temperature of 45 ±1°C and 15 ±1% RH, only falling rate period was detected and the drying rate was observed from 0.51 to 0.02 g of water/min. per 100g of bone dry materials, due to lower RH of drying air. Drying rate curves showed a fast increase at the beginning of the process (*i.e*., 0.51 g of water/min. per 100 gm of bone dry materials) due to rapid sample heating and a subsequent decrease of the drying rate (*i.e*., 0.02 g of water/min. per 100 gm of bone dry materials). The results of present research are in agreement with previous studies dealing with drying of orange peel in microwave drying (Ghanem *et al*., 2012) and similar result was also observed for drying of onion in dehumidified air dryer (Gouda *et al*., 2014).

TABLE 2: Constants of drying models

Sl. No.	Model	Constants	Drying method		
			STD	TD	DD
1	Newton	k	0.273	0.6084	1.071
2	Page	k	0.2375	0.499	1.017
		n	1.094	1.295	1.406
3	Henderson-Pabis	a	1.025	1.18	1.038
		k	0.2797	0.634	1.104
4	Logarithmic	a	1.045	1.18	1.09
		c	-0.0338	0.1661	-0.0638
		k	0.2548	0.4501	0.9427
5	Midilli- Kucuk	a	0.993	0.9902	0.9982
		b	-0.00062	-0.0051	0.0019
		k	0.2344	0.485	1.023
		n	1.089	1.258	1.428

The drying rate of sweet orange peel varied from 0.19 g of water/min. per 100 g of bone dry materials in the initial stage of drying to 0.01 g of water/min. per 100 gm of bone dry materials in final stage of drying in solar tunnel drying. In this drying, the drying rate was mainly dependent on varying drying temperature. Here, the temperature varied according to the climatic condition.

From the data obtained during investigation, it was observed that, the constant rate period of drying was absent during the entire period of drying and the drying took place under the falling rate period in all drying methods. Similar type of results were observed in the case of orange peel dried in hot air dryer (Garau *et al*., 2007), microwave drying of three citrus peel (Ghanem *et al*., 2012), cabinet drying of pomegranate peel (Nogueira *et* *al*., 2012) and for thin layer drying for apple slices (Mabrouk *et al*., 2012).

Mathematical modelling of drying of sweet orange peel in different drying methods

The drying data obtained during thin layer drying was fitted into five different drying models *viz*., Newton, Page, Henderson-Pabis, logarithmic and Midilli-Kucuk models. The values of moisture ratio were determined for all drying methods. Drying constants and estimated values of statistical parameters of all five models were given in Tables 2 and 3, respectively.

TABLE 3: Estimated values of statistical parameters of Newton, Page, Henderson-Pabis, Logarithmic and Midilli-Kucuk models used for four drying methods

Sl. No.	Parameter	Method	Model				
			Newton	Page	Henderson- Pabis	Logarithmic	Midilli- Kucuk
1	R^2	STD	0.9968	0.9993	0.9976	0.9990	0.9940
		HD	0.9803	0.9962	0.9831	0.9960	0.9972
		DD	0.9823	0.9992	0.9841	0.9898	0.9993
2	SSE	STD	0.0064	0.0015	0.0049	0.0021	0.0012
		HD	0.0200	0.0041	0.0179	0.0042	0.0032
		DD	0.0168	0.0008	0.0152	0.0097	0.0007
3	Adjusted-R^2	STD	0.9968	0.9993	0.9975	0.9989	0.9930
		HD	0.9803	0.9957	0.9810	0.9949	0.9960
		DD	0.9823	0.9991	0.9814	0.9858	0.9987
4	RMSE	STD	0.0164	0.0080	0.0147	0.0097	0.0077
		HD	0.0481	0.0225	0.0473	0.0245	0.0215
		DD	0.0490	0.0113	0.0503	0.0440	0.0131
5	P (%)	STD	-14.2553	-3.4384	-12.0647	1.8173	-0.8350
		HD	-48.3636	-12.9302	-62.7916	9.3542	-4.3520
		DD	-44.0927	18.3424	-39.9801	30.8935	9.8384
6	χ2	STD	2.679E-004	261E-005	2.145E-004	9.47E-005	5.88E-005
		HD	2.3301E-003	5.143E-005	7.0799E-003	6.090E-004	4.720E-004
		DD	2.3466E-003	1.496E-004	2.4664E-003	2.0908E-003	1.654E-004

The Midilli-Kucuk model successfully described the relationship between moisture ratio and drying time with the highest R^2 value and lower χ^2, P, SSE and RMSE values. The experimental and predicted drying curves of dried sweet orange peel are given in Fig. 2. Similar result was found for drying of onion (Gouda *et al*. 2014). Present result is also similar to the value (R^2=0.99) of Garavand *et al*. (2011) for thin layer drying of tomato and they also reported Midilli-Kucuk model as a good estimation model for drying process. The results obtained are also in line with the value of Mirzaee *et al*. (2011), for thin layer drying of apricot and they reported Midilli-Kucuk is the best model with highest R^2 value of 0.999.

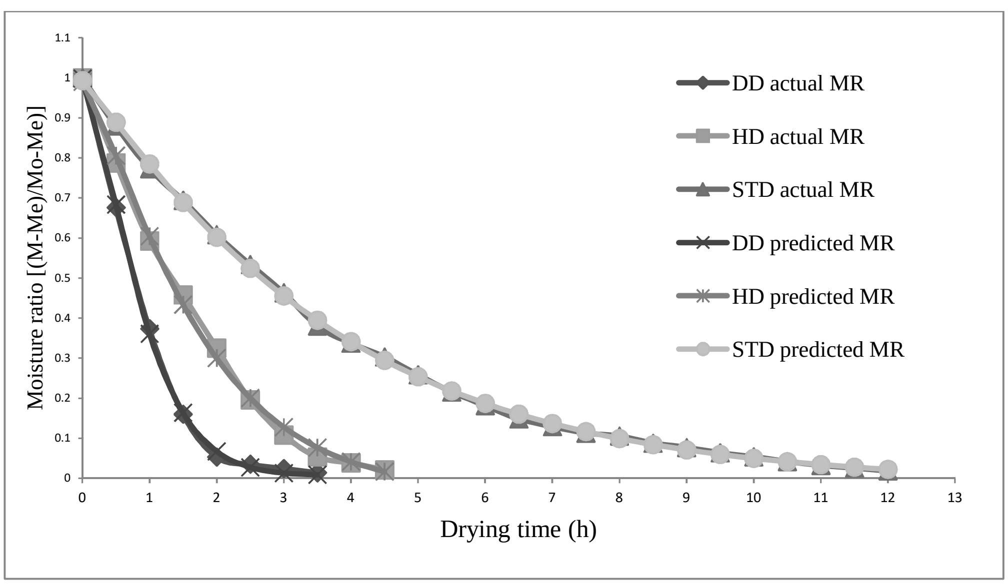

FIGURE 2: Experimental and midilli-kucuk model predicted moisture ratio for different drying methods (Abbreviation: STD, solar tunnel drying; HD, hot air drying; and DD dehumidified drying)

CONCLUSION

Among three drying techniques dehumidified air drying required less drying time (3.5 h) with lowest moisture content (6.52 % d.b.). Experimental results show that dehumidified drying is the best method to dry the fresh sweet orange peel. Among the five drying models tested namely, Newton, Page, Henderson-Pabis, Logarithmic and Midilli-Kucuk, the Midilli-Kucuk model described the best fit of the experimental data with higher R^2 value and lowest SSE, χ^2, RMSE and P values.

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