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Drying characteristics of onion shreds under different drying methods

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Onion (*Allium cepa* L.) is one of the most popular vegetables in the world due to its flavoring and health-promoting properties (Sharma *et al.* 2005). Dried onion is available in several forms: flaked, minced, chopped and powdered. It is also used as flavor additives in a wide variety of food formulations (Abbasi *et al.* 2011). Onion is a heat sensitive crop requiring favorable dehydration process to preserve its organoleptic characteristics. There are some reports on drying of onion shreds using conventional drying methods, viz. osmotic and air convection (Alabi *et al.* 2016), hybrid electric-gas dryer (Nwakuba *et al.* 2017), pulsed electric field pre-treated convective drying (Ostermeier *et al.* 2018), acoustic drying using sound waves (Da-Motaand Palau 2007), microwave drying (Kalse *et al.* 2012), catalytic infrared drying (Gabel *et al.* 2006) etc. to get the good quality products, but novel dehydration techniques may be used for onion drying to obtain a product with minimal change in physical, biochemical, nutritional and sensory attributes of high consumer acceptance. Review of literature reveals that systematic studies on drying of onion shreds haven't been done so far considering the quality of dried onion shreds. Keeping this in view, the present study was planned to explore the feasibility of drying of onion shreds with some new methods i.e. microwave assisted convective drying, heat pump drying and to compare the drying characteristics with the conventional hot air drying methods.

The experiment was conducted at CAET, OUAT, Bhubaneswar, during 2011. Onion (Nasik red variety) purchased from local market of Bhubaneswar and similar size onions (bulb diameter 50±5 mm) without visible damage were chosen for the experiments. The onion samples were cleaned, hand peeled, and trimmed and then sliced to 2 mm thickness with a slicer and the slices were shredded to single pieces (length: 15–20 mm).

Three laboratory scale dryers, viz. hot air dryer, heat pump dryer and microwave assisted convective air dryer were used for thin layer drying of onion shreds (Sahoo *et al.* 2015). Thin layer drying behavior of onion shreds was determined experimentally in hot air dryer, heat pump dryer and microwave assisted convective dryer at different drying conditions (Table 1). The samples were placed on the drying trays in single layer over the tray surface (4.2 kg/m^2 loading) and weighed using an electronic balance (Mettler-Toledo, Mumbai, India) with a precision of 0.01 g. All experiments were done at a constant air velocity of 2 m/s. The velocity of air flow was measured using a hot-wire anemometer (Model: AM 4201, Lutron Electronics Co., Inc, Coopersburg, United States) with a precision of 0.01 m/s. The drying air temperature and relative humidity were recorded at recommended pre-specified time intervals

Table 1 Drying conditions for different drying methods used for onion shred drying

Drying method	Drying conditions
Convective hot air drying (HAD)	50ºC (46±4% R.H.)
	55ºC (35±4% R.H.)
	60°C (28±4% R.H.)
	65ºC (20±4%.R.H.)
Heat pump drying (HPD)	35ºC (32±2% R.H.)
	40ºC (26±2% R.H.)
	45ºC (19±2% R.H.)
	50ºC (15±2% R.H.)
Microwave assisted convective drying	Microwave power level 120 W and air temperature 50ºC
	Microwave power level 240 W and air temperature 50ºC
	Microwave power level 360 W and air temperature 50ºC
	Microwave power level 480 W and air temperature 50ºC

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defined for the drying method. The weight of samples was measured accordingly until a constant value was attained by the sample, which was the indication of attaining equilibrium with the exposed environment. The power consumption was recorded by a watt meter (Make: Alstom, Single Phase, LW/RL no. 9190175, with 240 watt, 5–20 Amp and 50 Hz capacity). The initial and the final moisture content of the samples, after attaining equilibrium were determined gravimetrically by hot air oven method (AOAC 1984). All the experiments were carried out in triplicate.

The drying rates and moisture ratios were computed from the experimental data and drying characteristics curves i.e. moisture content (d.b.) vs. drying time and drying rates vs. moisture content (d.b.). The single exponential Lewis equation (Lewis 1921) and Page's power equation (Page 1949) were fitted to the experimental data:

$$\text{Lewis model} \quad \frac{M - M_{eq}}{M_{\theta i} - M_{eq}} = A \exp(-K\theta)$$

$$\text{Page model} \quad \frac{M - M_{eq}}{M_{\theta i} - M_{eq}} = \exp(-K\theta^n)$$

Where

$$\frac{M - M_{eq}}{M_{\theta i} - M_{eq}} = \text{Moisture ratio (MR)}$$

Where A, n, Empirical coefficients; K, drying constant/min; M, Moisture content at time θ, % (d.b.); M_{eq}, Equilibrium moisture content, % (d.b.); $M_{\theta i}$, Initial moisture content, % (d.b.); θ, Drying time, min.

Linear regressions of these equations were carried out using least square method and coefficients were determined using MS Excel. The fitting of the equations were evaluated on the basis of co-efficient of determination (R^2) and root mean square error (RMSE). The lower RMSE values and the higher R^2 values were determined as the basis for goodness of fit.

Hot air drying: It was observed from drying curves (Fig 1) that increase in hot air temperature reduced the drying time which took 480, 390, 300 and 240 min to reduce the moisture content of onion shreds from the initial value of 675.8% (d.b.) to the final value of 5–6% (d.b.) at 50, 55, 60 and 65ºC, respectively.

Heat pump drying: drying time decreased with increase in drying air temperature from 35–50ºC (Fig 2). The moisture content of onion shreds were observed to reduce exponentially with drying time. These curves followed the general trend of convective drying curves as reported for many food materials (Ahmed and Shivhare 2001). At higher temperatures, the drying curve exhibited a steeper slope, thus exhibiting higher drying rate. The drying times were observed to be 840, 660, 480 and 360 min for drying of onion shreds from 675.8 to 7±1.5% moisture content (d.b.) at 35, 40, 45 and 50°C, respectively. Drying time was lower at higher temperature and lower relative humidities of drying air. Viswanathan *et al.* (2003) also observed the similar results that decrease in drying air temperature for onion caused substantial increase in drying time.

Microwave-assisted convective drying: The drying time reduced significantly with increase in microwave power level from 120–480 W (Fig 3). The drying time required for drying of onion shreds from 675.8% to 4±1% moisture content (d.b.) were observed to be 140, 75, 55 and 35 min for 120, 240, 360 and 480 W power levels, respectively at 50ºC convective air temperature (Table 1). The drying curves became steeper with increase in microwave power indicating faster drying of the product. This was because drying at higher power led to higher temperature and implied a larger driving force for heat transfer (Arslan and Ozcan 2010).

Comparison of HAD, HPD and MW Assisted Convective Drying: The drying methods had a significant effect on drying rate and total drying time. It was observed that an increase in air temperature decreased the drying time regardless of the type of dryer used (Fig 4).

The Lewis and Page equations were fitted to experimental drying data for onion shreds by direct least square procedure. It was observed that the mean values of R^2 of Page equation were higher and the RMSE were lower than Lewis equation for all the experimental runs (Table 2).

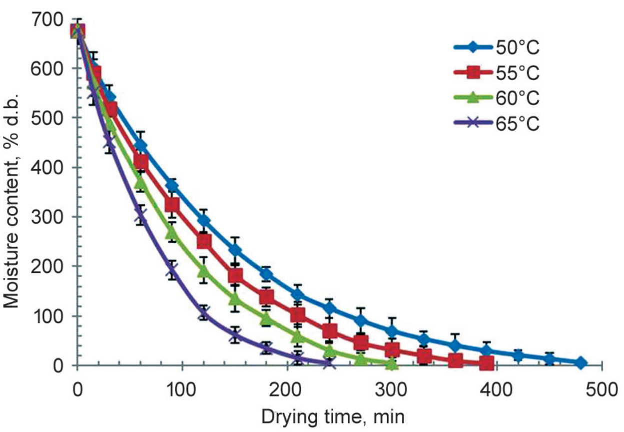

Fig 1 Variation of moisture content with drying time of onion shreds during hot air drying

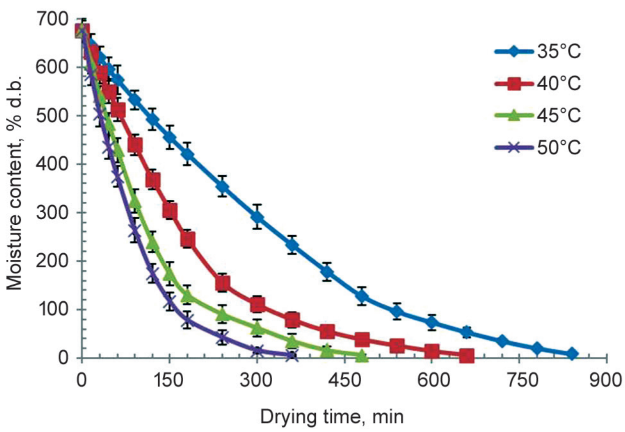

Fig 2 Variation of moisture content with drying time of onion shreds during heat pump drying

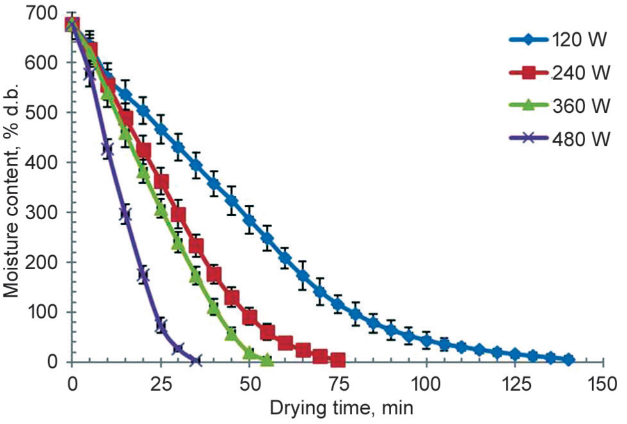

Fig 3 Variation of moisture content with drying time of onion shreds at different microwave power levels and drying air temperature of 50°C

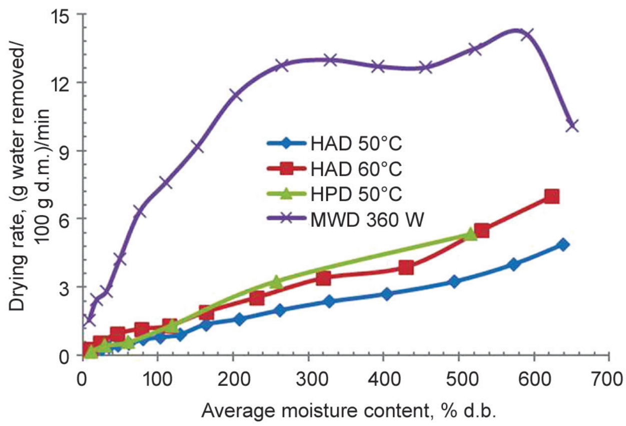

Fig 4 Comparison of drying rates of hot air, heat pump and microwave assisted convective drying

Table 2 Drying parameters of Lewis and Page model for onion shreds dried under different drying conditions

	Lewis Model				Page Model			
	A	K	R2	RMSE	K	n	R2	RMSE
Hot air drying								
50°C	1.215	0.0092	0.978	28.7	0.0058	1.057	0.994	5.30
55°C	1.33	0.0122	0.954	46.8	0.0061	1.094	0.988	15.1
60°C	1.253	0.0143	0.953	40.6	0.0083	1.073	0.986	15.2
65°C	1.218	0.0188	0.978	38.6	0.0090	1.121	0.994	11.6
Heat pump drying								
35°C	1.255	0.0045	0.954	54.4	0.0018	1.108	0.986	19.6
40°C	1.155	0.0069	0.990	27.6	0.0030	1.125	0.998	7.1
45°C	1.076	0.0094	0.987	14.5	0.0058	1.079	0.997	8.7
50°C	1.166	0.0135	0.988	29.5	0.0067	1.114	0.997	7.1
Microwave assisted convective drying								
120 W	1.807	0.036	0.949	108.6	0.0060	1.329	0.981	23.3
240 W	1.762	0.058	0.914	123.8	0.0057	1.507	0.988	16.7
360 W	1.622	0.065	0.858	122.7	0.0063	1.548	0.981	21.6
480 W	1.519	0.108	0.914	127.1	0.0102	1.667	0.993	15.0

Hence Page model was found to be better than Lewis model to describe the thin-layer drying of onion shreds. In all cases, the values of R^2 for Page models were greater than an acceptable threshold of 0.90, indicating goodness of fit. The rate constant, K, which is a measure of the drying rate, increased with the drying air temperature, also indicating substantial reduction in total drying time.

Drying rate was found to increase with increase in drying air temperature and microwave power levels for onion shred drying. In general microwave assisted convective drying resulted in shorter drying times than normal convective and heat pump drying at equivalent temperatures. The drying rates were observed to be higher in heat pump dryer as compared to hot air dryer at same drying air temperature of 50ºC due to the lower relative humidity of the drying air. Page model fitted well to the experimental drying data for describing the thin layer drying behavior of onion shreds for all drying methods. However, in-depth study of these processes considering the product quality is required before commercialization of onion-based food processing industry.

SUMMARY

Experiments were conducted to study drying characteristics of onion shreds in heat pump drying at 35, 40, 45 and 50ºC, microwave assisted convective drying at 50ºC convective air temperature at four microwave power levels, i.e. 120, 240, 360 and 480 W and convective hot air drying at 50ºC (46±4% R.H.), 55ºC (35±4% R.H.), 60ºC (28±4% R.H.) and 65ºC (20±4% R.H.). Drying rate was found to increase with increase in drying air temperature in all drying methods and microwave power level in microwave assisted convective drying. The drying times observed for bringing down the moisture content of onion shreds from 675.8 to 6±2.5 % (d.b.) were 480 min (maximum) for hot air drying (50ºC, 46±4% R.H.), 360 min for heat pump drying (50ºC, 15±2% R.H.) and 75 min (minimum) for microwave assisted convective drying (240 W power and 50ºC). The Page model can be used to predict moisture content of onion shreds at any time during drying process under different conditions with an acceptable accuracy.

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