Effects of ethyl oleate and microwave blanching on drying kinetics of bitter gourd

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Abstract In the present study effects of pre-treatments such as blanching with hot water and microwave, ethyl oleate dipping, and combinations of these treatments on drying characteristics of the bitter gourd (*Momordica charantia* L.) at various temperature were studied. The overall drying time was reduced significantly in the ethyl oleate treated and microwave blanched samples. The minimum diffusivity ($2.65 \times 10^{-8} \text{ m}^2/\text{s}$) was observed in control samples whereas the maximum diffusivity ($3.86 \times 10^{-8} \text{ m}^2/\text{s}$) was observed in ethyl oleate treated and microwave blanched samples at 50 °C. Ethyl oleate treated and microwave blanched samples dried at lowest temperature (50 °C) showed the lowermost shrinkage ratio (46.04%). The rehydration ratio increased from 3.49 to 4.90 as the temperature increased from 50 to 70 °C for control samples. Combined pre-treatment of ethyl oleate and microwave blanching had resulted in most acceptable drying characteristics and quality of bitter gourd. Drying of the samples were mathematically modelled. The drying characteristics of bitter gourd could be explained suitably by Page drying model.

Keywords Bitter gourd · Pre-treatments · Drying · Modelling

Introduction

India has varied climatic and topographical condition which favours production of many fruits and vegetables. The total production of fruits and vegetables in India has been estimated approximately 81 and 162 Million tonnes, respectively (NHB 2014). Bitter gourd (*Momordica charantia* L.) is one of the traditional and widely consumed vegetables that belongs to *Cucurbitaceae* family. It is commonly known as bitter melon, balsam pear, ampalaya, karela etc. (Potawale et al. 2008). It is an antioxidant and nutrient rich vegetable and is famous for its medicinal and nutritional values. It is known for its role in treating diabetes, cancer, malaria, blood pressure and digestive disorders (Budrat and Shotipruk 2008). Momordicin and Charantin are the two principal components responsible for its bitterness (Kumar et al. 2010). The matured bitter gourd is rich in vitamin A and C, β -carotene, phosphorous and iron (Namdeo et al. 2013). The current production of bitter gourd in India has been estimated around 830 million tonnes (Ministry of Agriculture 2016). Though the production is high, 30–40% wastage is reported due to inappropriate post-harvest practices, lack of processing and storage facilities (Singh et al. 2014).

Naturally, fruits and vegetables are covered by a protective wax layer which interrupts the moisture removal during drying. Pre-treatments plays an important role in permeabilisation, enzyme inactivation, oxidation, and acceleration of drying rate in many fruits and vegetables. For this reason, Bitter gourds were pre-treated with different methods such as hot water blanching, steam blanching, microwave blanching and chemical dipping. These pre-treatments highly affect the other quality parameters such as vitamin C, 2,2-diphenyl picryl hydrazyl (DPPH) and ferric reducing antioxidant power (FRAP);

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Mitra et al. 2013). Water blanching involves uniform heating by exposing vegetables to a temperature range of 70–100 °C for 1 or 2 min (Arroqui et al. 2001). It has been used widely for various fruits and vegetables such as Bitter gourd (Choo et al. 2014), Pineapple (Agarry et al. 2013), Bell pepper (Akintunde et al. 2011), Carrot (Kidmose and Martens 1999), Potato (Arroqui et al. 2001) etc. However, it is reported that there is higher leaching of water soluble (thiamine) and heat sensitive vitamins (vitamin C) during hot water blanching (Arroqui et al. 2001). Microwave blanching is an alternative process as it reduces the energy consumption by 50% (Patricia et al. 2011). Microwave blanching of vegetables at 900 W for 3–5 min significantly retained the ascorbic acid and increased inactivation rate of peroxidase (Tuta et al. 2011). Broccoli (Patricia et al. 2011), Turnip greens (Osinboyejo et al. 2003), Peas (Chung et al. 1981) and Spinach (Quenzer and Burns 1981) were immersed in hot water and microwave blanched at 900–1200 W for few minutes. It reduced the leaching loss and retained nutrients. Even though hot water and microwave blanching enhanced the quality and drying characteristics, shrinkage of the raw materials is the major problem. Due to high temperature processing, the product shrinks more. Shrinkage and rehydration ratio are the two important drying characteristics (Abasi et al. 2009). These two parameters have significant role in quality, appearance and consumer acceptance of dried samples. Treating fresh cut foods with ethyl oleate solution (2% ethyl oleate and 4% potassium carbonate) reduces the drying time significantly as compared to other organic solvents (Ioannou 2013; Doymaz 2004a). Potassium carbonate (4%) is used as an emulsifier to form an alkaline emulsion of ethyl oleate. Dipping of Grapes (Pangavhane et al. 1999), Apricot (Doymaz 2004a), Ginger (Deshmukh et al. 2013), Red pepper (Doymaz and Pala 2002) and Tomato (Doymaz 2007) in ethyl oleate solution significantly accelerated the drying rate. Drying kinetics of many fruits and vegetables such as Apricot (Doymaz 2004a), Banana (Karim and Hawlader 2005), Carrot (Doymaz 2004b), Jujube (Motevali et al. 2012) and Bitter gourd (Chen et al. 2013) have already been studied. The primary objective of this work is to investigate the effect of conventional blanching and ethyl oleate treated microwave blanching on the drying characteristics of Bitter gourd and to fit the best possible drying model to the experimental data.

Materials and methods

Sample preparation

Bitter gourds (ver. Pusa hybrid) were procured from the local vegetable market and washed properly. Initial

moisture content (90% wb) of the sample was measured (AOAC 1990). Samples were sliced into 3.5 cm diameter and 0.5 cm thickness using a stainless steel knife.

Pre-treatments

Sliced samples, each of 50 g were blanched in hot water (WB). A domestic microwave oven (Make: Samsung India, Model: MS2021CW, Capacity: 700 W) was used for microwave assisted blanching (MB). The power absorption capacity in the cavity of the microwave was calculated using 2L IMPI method. The temperature was measured by thermocouple and was maintained throughout the process. Samples without any pre-treatment was taken as control. Another set of samples was taken and dipped in ethyl oleate solution (2% ethyl oleate and 4% potassium carbonate) (EO) and subsequently blanched in hot water (EOWB) and microwave (EOMB). The description for these combinations of treatments is given in Table 1. After blanching, the samples were cooled down and excess water was removed by muslin cloth.

Enzyme inactivation

Blanching is mainly done to inactivate the heat resistant enzymes i.e. peroxidase and polyphenol oxidase (Matsui et al. 2007). The adequacy of blanching was done by peroxidase test. Blanched sample (10 g) was taken and ground with 3–5 ml of water in a mortar and pestle unit. The mixture was filtered and taken in test tubes containing 20 ml of distilled water, 1 ml of 0.5% guaiacol and 1 ml of 0.08% of hydrogen peroxide (Ranganna 1986). Completion of blanching was assured if there was no colour development after 3.5 min.

Drying procedure

The pre-treated samples, each of 50 g, were dried at three different temperatures 50, 60 and 70 °C in a tray dryer (Make: SM Sciencetech, India). The direction of air flow was kept parallel to the sample. The air velocity was maintained at 0.8 m/s throughout the process. Sample weight was measured at 5 min interval using an electronic weighing balance (Make: Wensor, India) having 0.001 g precision and the moisture loss was calculated. The drying was continued till the samples reached constant weight. The dried bitter gourd samples were packed in low density polyethylene (LDPE) pouches and stored in the desiccator for further analysis.

Determination of drying characteristics

Moisture ratio

Moisture ratio was determined using Eq. 1 (Lopez et al. 2000). As the value of M_e (equilibrium moisture content) is

Table 1 Pre-treatments and its methodology

Pre-treatments	Methodology
NOP	Dried without any pretreatment
WB	80 °C for 3 min
MB	600 W for 135 s
EO	2% EO and 4% potassium carbonate (K ₂ CO ₃) for 1 min at room temperature
EOWB	Dipped in 2% EO and 4% K ₂ CO ₃ for 1 min at room temperature and water blanched
EOMB	Dipped in 2% EO and 4% K ₂ CO ₃ for 1 min at room temperature and microwave blanched

too small as compared to M_t (moisture content at time, t) and M_o (initial moisture content), it has been neglected. The simplified equation is given as follows.

$$MR = M_t/M_o \quad (1)$$

where MR = moisture ratio.

Moisture diffusivity and activation energy

The effective moisture diffusivity was determined using Fick's second law of diffusion (Crank 1975). The following slab boundary conditions (Eq. 2) were assumed for the samples.

$$MR = \frac{M_t}{M_o} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp \frac{-(2n-1)^2 \pi^2 D t}{4L^2} \quad (2)$$

where $n = 1, 2, 3$ no. of terms taken for considerations; t = drying time (s); D = effective moisture diffusivity (m^2/s); L = thickness of sample (m).

Shrinkage ratio

Shrinkage ratio of dried bitter gourd was determined using Eq. 3 by measuring the sample volume before (V_i) and after (V_f) drying. The sample dimensions were measured using a vernier caliper with an accuracy of 0.01 cm (Abasi et al. 2009).

$$\text{Shrinkage (\%)} = \frac{V_i - V_f}{V_i} \times 100 \quad (3)$$

Rehydration ratio

Rehydration ratio was determined using Eq. 4. The dried sample (5 g) was taken in 100 ml beaker with addition of 80 ml distilled water. The beaker was placed in the hot water bath maintained at 80 °C for 10 min. The sample was taken out, surface moisture was removed and weighed. The sample weight before (R_i) and after (R_f) rehydration were measured and the rehydration ratio was calculated (Abasi et al. 2009).

$$\text{Rehydration ratio (\%)} = \frac{R_f}{R_i} \times 100 \quad (4)$$

Theoretical considerations of thin layer mathematical modeling

Thin layer mathematical modelling of drying characteristics for the Bitter gourd was done by fitting experimental data to five semi-empirical models (Table 2). The best model fit was selected based on highest co-efficient of determination (R^2), lowest root mean square error (RMSE) and sum of square error (SSE).

Statistical analysis

All the results were statistically analysed using SPSS (Ver-21). Statistical difference was determined by Tukey's method and significant level used for all data was $P \leq 0.05$. The curve fitting was performed using MATLAB (Ver-2011b, Mathworks, USA).

Results and discussion

Effects of pre-treatments on moisture ratio

All the samples were dried to the final moisture content of 5–6% from an initial moisture of 90% (wb). The drying time for control, WB, MB, EO, EOWB and EOMB was 270, 260, 240, 230, 210 and 190 min respectively at 50 °C. There was a significant reduction in drying time with all of the pre-treatments. Hot water blanching and microwave blanching reduced the drying time due to blanching at high temperature and high power level (600 W) altering the cell wall structure and forming pores in the tissues and enabling increased water diffusion from interior to surface during drying (Agarry et al. 2013; Tang et al. 2002). The reduction in drying time for EO treated samples were found to be higher than water and microwave blanched samples. This may be due to the dipping of sliced bitter gourd in EO

Table 2 Selected mathematical models

Model	Equation	References
Newton	$MR = \exp(-kt)$	Henderson (1974)
Page	$MR = \exp(-kt^n)$	Sarimeseli (2011)
Henderson and pabis	$MR = a \exp(-kt)$	Zhang and Litchfield (1991)
Logarithmic	$MR = a \exp(-kt) + c$	Akpınar et al. (2006)
Wang and singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)

Table 3 Effect of pre-treatment and temperature on shrinkage and rehydration ratio

Pre-treatments	Drying temperature	Diffusivity ($\times 10^{-8}$ m ² /s)	Shrinkage ratio (%)	Rehydration ratio (%)
NOP	50 °C	2.65 ^{aA}	70.30 ^{fA}	3.49 ^{aA}
WB		3.03 ^{bA}	68.04 ^{eA}	3.51 ^{bA}
MB		3.11 ^{cA}	63.90 ^{dA}	3.68 ^{bA}
EO		3.14 ^{dA}	55.50 ^{cA}	3.72 ^{cA}
EOWB		3.72 ^{eA}	50.46 ^{bA}	3.81 ^{cA}
EOMB		3.86 ^{fA}	46.04 ^{aA}	4.21 ^{dA}
NOP	60 °C	3.70 ^{aB}	75.41 ^{fB}	3.59 ^{aB}
WB		3.83 ^{bB}	71.93 ^{eB}	3.83 ^{bB}
MB		4.42 ^{cB}	65.99 ^{dB}	4.16 ^{bB}
EO		4.5 ^{dB}	57.92 ^{cB}	4.34 ^{cB}
EOWB		4.96 ^{eB}	53.92 ^{bB}	4.29 ^{cB}
EOMB		6.03 ^{fB}	49.34 ^{aB}	4.85 ^{dB}
NOP	70 °C	4.85 ^{aC}	80.20 ^{fC}	4.90 ^{aC}
WB		4.93 ^{bC}	74.40 ^{eC}	4.76 ^{bC}
MB		5.52 ^{cC}	69.84 ^{dC}	4.23 ^{bC}
EO		6.06 ^{dC}	60.23 ^{cC}	4.98 ^{cC}
EOWB		6.43 ^{eC}	57.85 ^{bC}	4.85 ^{cC}
EOMB		7.48 ^{fC}	52.06 ^{aC}	5.16 ^{dC}

Different small letters in rows indicates significant ($P < 0.05$) difference due to pre-treatments

Different capital letters in columns indicates significant ($P < 0.05$) difference due to temperature

solution desolving the waxy layer around the sample and creating pores which improves moisture diffusion at a faster rate. The same results were reported in drying of apricots, red pepper (Doymaz and Pala 2002), ginger (Deshmukh et al. 2013) and grapes (Pangavhane et al. 1999). However, the combined pre-treatment of ethyl oleate and subsequent water and microwave blanching showed greater response in moisture ratio. The overall drying time was reduced significantly in the EOMB samples. It may be due to the combined effect of blanching and EO, accelerating the moisture diffusion more effectively during drying. The reduction in moisture ratio is dependent on both drying temperature and time. The increase in drying temperature from 50 to 70 °C decreased the drying time from 270 to 190 min for control samples. The same results were reported during bitter gourd drying at 50–80 °C (Chen et al. 2013). It may be due to faster evaporation rate of

water at higher temperature. All the pre-treatments and temperature significantly ($P < 0.05$) affected the moisture ratio of dried bitter gourd.

Effects of pre-treatments on moisture diffusivity

The moisture diffusivity data for all pre-treated and control samples are given in Table 3. The samples were dried at three different temperatures that followed a falling rate curve. Effective diffusivity of agricultural products falls in the range of 10^{-12} – 10^{-8} m²/s (Wang et al. 2007). The results for bitter gourd dried at 50–80 °C were verified with that reported by Chen et al. (2013). The moisture diffusivity was found higher in EOMB treated samples followed by EOWB, EO, MB, WB and control samples. The minimum diffusivity (2.65×10^{-8} m²/s) was observed in control samples whereas the maximum diffusivity

Table 4 The best model fit (Page model) and constant values

Samples	Drying temperature	R ²	SSE	RMSE	k	n
NOP	70 °C	0.9984	0.0026	0.0128	0.007143	1.198
WB		0.9971	0.0045	0.0167	0.012500	1.100
MB		0.9965	0.0059	0.0192	0.008616	1.202
EO		0.9962	0.0064	0.0200	0.00824	1.230
EOWB		0.9976	0.0042	0.0161	0.008124	1.238
EOMB		0.9981	0.0034	0.0150	0.005373	1.364
NOP	60 °C	0.9998	0.0003	0.0040	0.004886	1.190
WB		0.9977	0.0044	0.0148	0.005076	1.193
MB		0.9979	0.0046	0.0152	0.002967	1.350
EO		0.9979	0.0045	0.0150	0.003373	1.317
EOWB		0.9995	0.0130	0.0076	0.002962	1.415
EOMB		0.9987	0.0031	0.0124	0.002542	1.452
NOP	50 °C	0.9935	0.0010	0.0062	0.007535	1.124
WB		0.9989	0.0027	0.0101	0.009002	1.158
MB		0.9937	0.0160	0.0248	0.009404	1.282
EO		0.9943	0.0136	0.0229	0.009443	1.159
EOWB		0.9972	0.0064	0.0157	0.009666	1.124
EOMB		0.9922	0.0204	0.0280	0.003547	1.262

($3.86 \times 10^{-8} \text{ m}^2/\text{s}$) was observed in EOMB treated samples at 50 °C. The increase in temperature from 50 to 70 °C increased diffusivity from 2.65 to $4.85 \times 10^{-8} \text{ m}^2/\text{s}$ for control samples (Sivakumar et al. 2013). There was significant ($P < 0.05$) effect of pre-treatments and temperature on diffusivity.

Effects of pre-treatments on shrinkage ratio and rehydration ratio

Shrinkage and rehydration ratio are the two important drying characteristics used to specify quality of dried products. The shrinkage and rehydration ratio for all samples dried at 50, 60 and 70 °C are given in Table 3. Temperature had significant ($P < 0.05$) effect on shrinkage ratio. The increase in temperature from 50 to 70 °C increased the shrinkage ratio from 70.30 to 80.2%. This may attributed to the fact that drying at higher temperature increases the contractile stress in the cellular structure that cause shrinkage in the tissues (Abasi et al. 2009). All pre-treatments had significant ($P < 0.05$) effect on shrinkage ratio. The highest shrinkage ratio (80.2%) was observed in control samples and lowest shrinkage ratio (52.06%) was observed in EOMB treated samples dried at 70 °C. EOMB samples dried at lowest temperature (50 °C) showed the lower most shrinkage ratio (46.04%). This is due to dipping samples in ethyl oleate and subsequent microwave blanching reducing the contractile stress and maintaining the cell structure during drying.

The rehydration ratio for all pre-treated samples and control samples are given in Table 3. The rehydration ratio was maximum in EOMB treated samples following the order of EOWB > EO > MB > WB > control samples. Out of all treatments, EOMB treated samples showed a significant ($P < 0.05$) increase in rehydration ratio. It may be due to dipping of sliced bitter gourds in EO solution and immediate blanching releasing air from tissues and creating more porous structure thus absorbing maximum water. The rehydration ratio increased (3.49–4.90) as the temperature increased from 50 to 70 °C for control samples. The results were in line with findings reported by Abasi et al. (2009). They stated that cellular tissue becomes more porous at higher temperature for absorbing maximum water. There was significant ($P < 0.05$) effect of combined temperature and pre-treatments on rehydration ratio.

Mathematical modelling of thin layer drying kinetics of bitter gourd

The thin layer drying kinetics of bitter gourd were analysed with the selected five mathematical models. The experimental and predicted moisture ratio curve fitting for samples dried at 50, 60 and 70 °C are shown in Figs. 1, 2 and 3. The best fit model with all constant values are given in Table 4. Among all the models, Page model described the best drying characteristics of bitter gourd dried at 50, 60 and 70 °C.

Fig. 1 Experimental and predicted moisture ratio at 50 °C

Fig. 2 Experimental and predicted moisture ratio at 60 °C

Conclusion

Bitter gourd is rich in antioxidants and other nutrients which is famous in south Asian countries. The vegetable has numerous medicinal and health benefits. Despite of all these benefits, processing of Bitter gourd has not been standardized. Out of all the pre-treatments, the combination of ethyl oleate and microwave blanching significantly reduced the drying time. The drying time was the highest for control samples and was the lowest for the samples with combined ethyl oleate and microwave pre-treatments at all selected temperature. The rehydration ratio was maximum (5.16%) and shrinkage ratio was minimum (46%) for the samples with combined pre-treatments of ethyl oleate and microwave. From the selected five mathematical models, Page model described the best drying characteristics of bitter gourd dried at all the selected temperatures. The combined ethyl oleate and microwave pre-treatment can be explored for large scale processing of bitter gourd.

Fig. 3 Experimental and predicted moisture ratio at 70 °C

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