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Effect of ultrasound pre-treatment on microwave drying of okra

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Abstract

The experiment was conducted to study drying kinetics of ultrasound assisted, microwave drying of okra and its effect on colour change, texture and rehydration properties of okra. The samples were dried in a continuous microwave dryer at 540 W power level and at a belt speed of 5 mm s^{-1}. It was observed that ultrasound as pre-treatment led to significant reduction in drying time of okra. Page model was found to be the best to explain the drying behaviour of okra with high R^2, lowest RMSE and X^2. Ultrasound retained the colour properties of okra. The lowest total colour difference was recorded in ultrasound treated- 60 minutes sample (18.11) followed by the control dried sample (17.58). The textural properties of the treatments of ultrasound treated – 60 minutes and ultrasound treated-vacuum packed -30 minutes samples had the values of hardness, gumminess and chewiness closer to fresh okra values. The highest coefficient of rehydration was recorded in ultrasound treated- 60 minutes samples. The vacuum pack did not show any effect on the rehydration ratio. The rehydration ratio increased with increase in time from 30 to 60 minutes.

Key word: Ultrasound pre-treatment, microwave drying, okra, vacuum packing

Introduction

Okra is a vegetable crop that belongs to the genus *Abelmoschus*, family Malvaceae. It originated probably from East Africa and is widely distributed in the tropics, subtropics and warmer portions of the temperate region (ECHO, 2003). India contributes about 75% of okra production to the global production. Okra has a good potential for export and it accounts about 60% to the total export of fresh vegetables. It is cultivated in 0.349 M ha area with an annual production of 3.34 MT. Okra contains proteins, carbohydrates and vitamin C and plays a vital role in human diet. The okra can be boiled, fried or cooked. Freshly harvested okra is highly perishable because of its high moisture content (88-90%) and higher respiratory activities; thus, it is necessary to preserve the commodity.

Drying is the most convenient and beneficial method of preserving perishables by reducing the moisture content below the level that is susceptible to contamination. Many conventional methods, like sun drying, vacuum drying, freeze-drying and air flow drying result in lower drying rates, however, microwave drying is a time and energy efficient dehydration method and can retain product quality to certain extent. This method has been combined with hot air drying, vacuum drying, freeze drying, etc., and applied in numerous drying practices in recent decades. During microwave drying process, the volume, mass and moisture content of the product are constantly changing with time of treatment and power levels used. The microwave assisted drying presents the following set of advantages: shorter drying time, minimum product quality changes, and flexibility in producing a wide variety of dried products. The need to prevent product deterioration has led the investigators around the world to research new methods of combination of drying technologies.

In context to this, ultrasound technique is used as a pre treatment for drying. The ultrasound creates microscopic channels that ease moisture removal in solid medium by producing rapid alter compressions and expansions (Mulet *et al*., 2011). Drying assisted with ultrasound leads to a significant increase in drying rate due to the good acoustic impedance matching between the transducer and the food materials. Also significant reduction in drying time can be achieved when samples are treated with ultrasound. Bantle *et al*. (2014) showed that the drying process can be improved in two different ways by using ultrasound; maintaining the same drying temperature, the drying time can be reduced and by maintaining the same drying time, the temperature can be reduced by application of ultrasound. Ultrasound as a pre-treatment in drying has been applied by many researchers in recent times for fruits (Nowacka *et al*., 2012; Kek *et al*., 2013; Gamboa-Santos *et al*., 2013) and vegetables (Nowacka *et al*., 2012; Ghafoor *et al*., 2014) to increase the drying rate and drying efficiency. The drying models are developed and used for the agricultural products to predict the drying trend for the microwave drying (Minaei *et al*., 2012; Eze and Akubor, 2012; Lam Van Mana *et al*., 2012; Ismail and Ibn Idriss, 2013; Afolabi and Agarry, 2014; Swain *et al*., 2014; Sadi and Meziane, 2015).

This study investigated the application of ultrasound as a pre-treatment prior to microwave drying of okra. The influence of ultrasound on drying kinetics, rehydration ratio, changes in colour and textural properties were studied. The drying kinetics was studied by applying various mathematical models.

Materials and methods

Sample preparation: Fresh green okra pods were bought from the local market. Samples were thoroughly washed in distilled water and sliced to a uniform size of 3.5 cm length pieces. The initial moisture content of the okra was determined by drying the sample in conventional oven at 105± 2 °C for 24 hours. The initial moisture content of the okra was 90.14 ± 0.004 % (w.b). The samples for treatment were classified to three; control, ultrasound treated (UST) and vacuum packed- ultrasound treated (V*P*=UST). The vacuum packed (99 % vacuum) samples were packed in HDPE polythene packs. The experiments were conducted in three replicates. The treatments were: Control (T1), Ultrasound treated – 30 min (T2), Ultrasound treated – 60 min (T3), Vacuum packed-Ultrasound treated – 30 min (T4) and Vacuum packed-Ultrasound treated – 60 min (T5).

Ultrasound pretreatment: The samples were immersed in ultrasonic water bath (hi-frequency Mosfet based electronic ultrasonic generator and PZT type ceramics transducers) at the room temperature and the top was covered with a thin wire mesh to avoid floating of the samples. The frequency of ultrasonicator was set at 30 KHz at 600W power with voltage at 230 V. The ultrasound energy was applied for two different time periods of 30 and 60 min, respectively for individual samples. After the pretreatment they were dried in continuous microwave drier.

Microwave drying: The samples were dried in a continuous microwave dryer (Enerzi Microwave system, Model No- PTF-2515, Power Range- 300 W to 2900 W, 2 magnetrons-1.45 kW each, Microwave frequency of 2450MHz with WR 340 wave guide) at 540 W power level. The belt speed was set at 5 mm s^{-1}. The exhaust system was kept running during the experiment. The samples were dried until equilibrium moisture content (no weight change) was reached.

Mathematical modeling: The thin layer drying models widely used are Newton model, Page Model, Modified Page Model, Henderson and Pabis model, Logarithmic model, Two term model, Two term exponential model, diffusion approach model, Midilli-Kucuk model and Verma *et al*. model.

The drying rate is expressed as the amount of the moisture evaporated over a time. The drying rate was calculated for the okra using the equation as follows;

$DR= (M_{t+\Delta t}-M_t)/\Delta t$

Where, $M_{t+\Delta t}$ is moisture content at time t +Δt (kg water/kg dry matter, t is the time (min) and DR is the drying rate (kg water/ kg dry matter).

The dimensionless moisture ratio in these models is given by equation

$$MR = \frac{M - M_e}{M_o - M_e}$$

Where, M is the moisture content at any time, M_o is the initial moisture content and M_e is the equilibrium moisture content. The values of the M_e are relatively small (Waewsak *et al*., 2006) compared to M and M_o for long drying times (Akgun and Doymaz, 2005). The equilibrium moisture content is assumed as equal to zero. So, the MR is simplified as

$MR = M/M_o$.

To determine the most suitable thin layer drying model for the microwave drying of ultrasound treated samples, experimental data was fitted in five different and most commonly used thin layer drying models (Table 1). The drying experimental data was fitted using the software MATLAB 7.11.0 (R2010b). The goodness of the fit of the tested mathematical models to the experimental data was evaluated with the correlation coefficient (R^2), chi square (X^2) and the root mean square error (RMSE). The lower the values of the Chi square, and the higher the values of R^2 values indicate the high fit of the model. The most suitable model for describing drying characteristics of okra is a model with the highest R^2 and the lowest X^2 and RMSE values (Sharma *et al.*, 2015; Gunhan *et al*., 2005).

The values are calculated as below;

$$X^2 = \frac{\sum_{i=1}^{n}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - z}$$

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

$$R^2 = \frac{\sum_{i=1}^{n}\left(MR_{\exp,i} - MR_{pre,i}\right)\sum_{i=1}^{n}\left(MR_{pre,i} - MR_{\exp,i}\right)}{\sqrt{[\sum_{i=1}^{n}\left(MR_{\exp,i} - MR_{pre,i}\right)]^2[\sum_{i=1}^{n}\left(MR_{pre,i} - MR_{\exp,i}\right)^2]}}$$

Where, MR_{exp}, i is the i th experimental moisture ratio, MR_{pre}, i is the i th predicted moisture ratio, N is the number of observations and z is the number of constants.

Colour: Sample colour of fresh and dried okra was measured using a Hunter Lab Color Flex EZ spectrophotometer. The total color difference between fresh and dried okra ΔE was defined in equation as follows:

$$\Delta E = \sqrt{\left(L_o - L\right)^2 + \left(a_o - a\right)^2 + \left(b_o - b\right)^2}$$

The subscript "o" refers to the color reading of fresh okra and L, a, and b indicate the brightness, redness and yellowness of the dried sample, respectively. Fresh okra L, a, b values are used as reference and higher ΔE denotes greater change in colour after drying.

Texture: The texture profile analysis (TPA) was conducted using TA- HD plus texture analyser with a maximum force of ±30 kg and a speed range of 0.01 - 20 mm/sec up to 250 kg. TPA was carried out with 30 kg load cell and circular probe. The readings for hardness, chewiness and gumminess were noted.

Rehydration ratio: The rehydration ratio of dried okra was determined by boiling 10 g of dehydrated okra in 300 mL distilled water for 30 minutes (Al Sulaiman, 2011). The rehydration ratio was calculated using the equation as follows:

$$COR = \frac{m_{rh}\left(100 - M_{in}\right)}{m_{dh}\left(100 - M_{dh}\right)}$$

Where, COR - Coefficient of rehydration, m_{rh}- mass of rehydrated sample, m_{dh}- mass of dehydrated sample, M_{in}- initial moisture content % (wet basis) of the sample before drying and M_{dh}- moisture content % of the dry sample (wet basis).

Data analysis: The data obtained from the experiments were subjected to the statistical analysis of variance (ANOVA) at 95% confidence level (P<0.05) using SPSS statistics 20.

Table 1. Mathematical models applied to the drying curves of okra

Model Name	Equation	Reference
Newton	MR= exp (-kt)	Lewis, 1921
Page	MR= exp(-kt^n)	Page, 1949
Modified Page	MR= exp(-$(kt)^n$)	Wang *et al*., 2007
Henderson and Pabis	MR= a*exp(-kt)	Henderson and Phabis, 1961
Logarithmic	MR= a*exp(-kt)+c	Yagcioglu, 1999

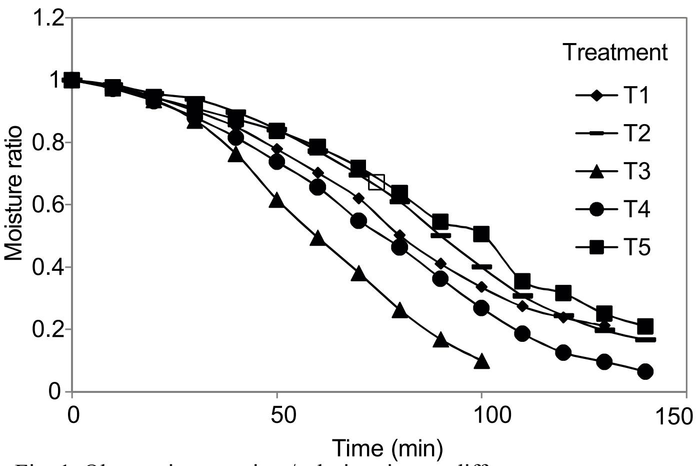

Fig. 1. Okra moisture ratio v/s drying time at different treatments

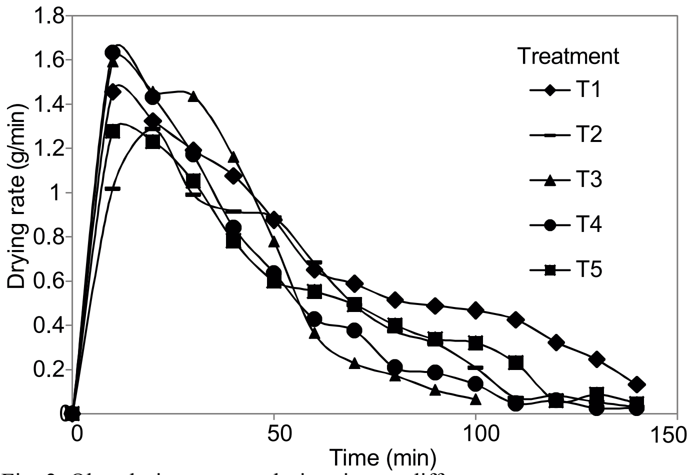

Fig. 2. Okra drying rate vs. drying time at different treatment

Results and discussion

Drying curves: The moisture ratio versus drying time curves, for the microwave drying (540 W) of ultrasound pre-treated okra (90.14 ± 0.004 % (w.b)) are shown in Fig. 1. The okra with vacuum packing and without packing was pre-treated with ultrasound for a period of 30 and 60 minutes. The moisture decreased gradually for the control, and faster decrease was observed in ultrasound treated (60 min) okra without packing. The maximum amount of moisture removed was in vacuum packed, 30 minutes ultrasound treated sample. As seen in the Fig. 1, reduction in drying time occurred in the ultrasound pre-treated (60 min) sample without packing with the increase in treatment time. The lowest drying time (100 min) was recorded in the ultrasound pre-treated (60 min) without packaging. In comparison to the control (130 min), there was a reduction of 30 minutes. The moisture ratio decreased with increase in ultrasound treatment time.

The relationship between drying rate and drying time are shown in Fig. 2. In all the treatments with the increase in drying time, the drying rate increased up to a certain level and then gradually decreased. This may be due to the presence of small amount of water and more time to remove from the sample resulting in decrease in drying rate. The maximum drying rate was observed in vacuum packed, 30 minutes ultrasound treated sample (T4). The

Table 2. Statistical results of different thin-layer drying models for okra

Model	Treatment	a	k	n	c	R^2	RMSE	X^2
Newton	T1	-	0.008640	-	-	0.8795	0.1017	0.01035
	T2	-	0.007840	-	-	0.8306	0.1269	0.01418
	T3	-	0.012570	-	-	0.8485	0.1304	0.01702
	T4	-	0.010660	-	-	0.8699	0.1230	0.01343
	T5	-	0.007070	-	-	0.8536	0.1060	0.00967
Page	T1	-	0.000119	1.970	-	0.9967	0.0174	0.00030
	T2	-	0.000017	2.357	-	0.9979	0.0146	0.00021
	T3	-	0.000064	2.272	-	**0.9994**	**0.0089**	**0.00008**
	T4	-	0.000073	2.127	-	0.9981	0.0156	0.00024
	T5	-	0.000039	2.148	-	0.9935	0.0232	0.00053
Modified Page	T1	-	0.010160	1.970	-	0.9967	0.0174	0.09287
	T2	-	0.009497	2.358	-	0.9976	0.0146	0.14136
	T3	-	0.014260	2.272	-	0.9994	0.0089	0.12685
	T4	-	0.011350	2.127	-	0.9981	0.0156	0.09231
	T5	-	0.008816	2.148	-	0.9935	0.0235	0.11906
Henderson and Pabis	T1	1.133	0.010330	-	-	0.9146	0.8564	0.00733
	T2	1.158	0.009648	-	-	0.8832	0.1093	0.01058
	T3	1.152	0.015050	-	-	0.892	0.1161	0.01348
	T4	1.158	0.012630	-	-	0.9085	0.1071	0.01020
	T5	1.125	0.008512	-	-	0.8959	0.0928	0.00747
Logarithmic	T1	1.133	0.010330	-	$4.196*10^{-011}$	0.9212	0.0856	0.08800
	T2	1.158	0.009648	-	$2.532*10^{-011}$	0.8832	0.1093	0.38770
	T3	1.152	0.015050	-	$1.404*10^{-011}$	0.8920	0.1161	0.58767
	T4	1.158	0.012630	-	$1.155*10^{-011}$	0.9085	0.1071	0.53496
	T5	1.125	0.008512	-	$6.897*10^{-009}$	0.8959	0.9278	0.30728

T1- Control, T2- Ultrasound-30 min-without packing, T3- Ultrasound-60 min-without packing, T4- Ultrasound-30 min-with vacuum packing and T5- Ultrasound-60 min-with vacuum packing ultrasound had a positive effect on the drying rate of okra during microwave drying. Similar results were reported by Kadam *et al*. (2015) who used ultrasound treatment for reducing the drying time, which thereby reduced the energy consumption in drying.

Mathematical modeling: Many models have been proposed to study the thin layer drying kinetics of agricultural produce. In this study the non-linear regression was used for 5 thin layer drying models (Table 1) as a function of drying time and moisture ratio. The correlation coefficient (R^2), chi square (X^2) and the root mean square error (RMSE) were calculated. The best fit was determined by the higher R^2 and the lowest X^2 and RMSE. The values of all the constants of the models, R^2, X^2 and RMSE are given in Table 2.

For the different treatments investigated, the Page model had the closest fit for all microwave drying experimental data with highest R^2 values ($\geq$ 0.99), RMSE values ($\leq$ 0.0232) and X^2 values ($\leq$ 0.00053). The closest fit was in the treatment of Ultrasound-60 min-without packing (T3) with the values of R^2 (0.9994), RMSE (0.0089) and X^2 (0.00008). The parameter k increased with the increase in the ultrasound treatment time in the treatment without packing, but reduced in vacuum packed samples. The drying constant n, increased with the increase in the ultrasound treatment time, which reflects the drying behaviour. The results obtained were similar to the results obtained by Vega *et al*. (2007) and Faroogh *et al*. (2012).

Colour: The colour values of the microwave dried okra with different pre-treatment was compared with the colour of the fresh okra. The mean measured colour values for fresh okra were found to be L* 33.042, a* -8.166 and b* 21.062. The total colour difference (ΔE) was calculated. The higher values of ΔE, shows greater change in colour. The colour of okra was affected by the ultrasound pre-treatment as shown in Table 3. The total colour difference of the ultrasound treated samples ranged from 18.11 to 18.82. The control sample (T1) recorded ΔE value of 17.58. The colour change was greater in ultrasound treated samples compared to control sample. In comparison with the fresh okra, all the treatments showed decrease in L values. The lowest reduction in L* value (25.27) was observed in ultrasound treated (60 min), without packing. The a value increased in all the treatments, whereas the b value decreased. The highest decrease in b value was observed in ultrasound treated (60 min), without packing and the value was 7.32. The ΔE of the ultrasound treated samples was lowest (18.11) in ultrasound treated (60 min), without packing. The ΔE values for all the five treatments ranged from 17.58 to 18.82. The colour of the okra turned darker during processing. This may be attributed for degradation of green chlorophyll to olive green or brown green pheophytin and pyropheophytin. Similar results were obtained by Mana *et al*. (2012) for microwave drying of okra, at 500W microwave power the total colour difference recorded was 16.5.

Table 3. Colour values of okra under different treatments

Sample	L	a	b	ΔE
Fresh Okra	33.04	-8.16	21.06	-
T1	22.40	0.74	10.25	17.58
T2	21.56	0.90	9.26	18.79
T3	25.27	0.73	7.32	18.11
T4	21.38	0.92	10.11	18.39
T5	21.40	0.54	9.11	18.82

Textural properties: The textural properties of the fresh okra, control dried and ultrasound treated dried okra were measured. The properties measured were; hardness, gumminess and chewiness. The lowest value of hardness was observed in ultrasound treated- 60 minutes (5166.07 g) and vacuum packed-ultrasound treated-30 minutes samples. The increase in hardness can be due to the reduction in moisture content to storage moisture during drying. In these two samples the values of hardness, gumminess and chewiness were closer to the values of fresh okra (hardness- 4132.95 g, gumminess- 2350.69 g and chewiness-3489.67). In the control dried sample the values recorded were hardness - 12890.62 g, gumminess - 7152.44 g and chewiness - 6093.87 g. The ultrasound treatment showed significant effect on hardness (0.000), gumminess (0.001) and chewiness (0.006) @ P < 0.05.

Table 4. Textural properties of okra under different treatments

Category	Hardness (g)	Gumminess (g)	Chewiness (g)
Fresh Okra	4132.95	2350.69	3489.67
T1	12890.62	7152.44	6093.87
T2	12458.12	6543.43	5134.24
T3	5166.07	2845.54	2314.38
T4	3277.73	1079.25	804.04
T5	15064.26	7682.11	5961.70

Rehydration ratio: Rehydration ratio was affected by ultrasound treatment to a considerable extent. Table 4 shows that the rehydration ratio of T1 and T4 treatments is equal to 0.98 which may be caused due to negation effect of ultrasound due to vacuum packing of the sample. Hence it is clear that vacuum packing did not contribute to the effect on rehydration ratio of the sample. The highest percentage of increase in weight (442.47 %) after rehydration was observed in Ultrasound treated - 60 minutes, without packing (T3). The treatments showed significant effect on the rehydration ratio (0.003 @ P<0.05).

Hence, it can be concluded that ultrasound as a pre-treatment has significant effect on drying time of okra. It also retains the color and the textural properties such as hardness, gumminess and

Table 4. Rehydration ratio of okra under different treatments

Treatment	Dried weight	Rehydrated weight	Initial weight	Initial MC	Dried product MC	COR	Increase in weight (%)
T1	9.2	44.4	81.78	88.65	9.97	0.98	382.61
T2	9.4	45.5	84.39	89.61	9.98	0.84	384.04
T3	7.3	39.6	81.33	89.77	8.06	1.10	442.47
T4	9.4	43.8	81.23	89.40	10.34	0.98	365.96
T5	10	46.5	83.2	87.92	10.57	0.87	365.00

chewiness of okra comparable to fresh. Higher rehydration ratio can be achieved following ultrasound as pre-treatment closer to the fresh sample. Page model can efficiently predict the drying behaviour of okra, with high R^2, lowest RMSE and X^2.

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