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Effect of Microwave Pre-treatment on Drying Kinetics and Quality Characteristics of Elephant Foot Yam

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Abstract

Drying characteristics and quality of the elephant foot yam slices processed with microwave pretreatment and convective drying were investigated. Elephant foot yam slices was blanched at 80°C for 4 min in hot water and exposed to microwave treatment under different microwave power ranging from 300 W to 900 W and exposure time (1, 1.5 and 2 min) and then dried in convective dryer at 60°C to study their effect on drying characteristics and quality. Drying time, average drying rate, and rehydration ratios were studied. Increase in microwave power and exposure time increased the drying rate and decreased the drying time. The whole drying took place in falling rate period only. Midilli et al. model was found to describe the drying behaviour of elephant foot yam most precisely (highest R^2 = 0.9996; least RMSE = 0.0051). From storage study and sensory evaluation with quality in terms of protein, total sugar and oxalate content dried samples were acceptable from all drying treatments. Based on oxalate content and drying characteristics, exposure to 900 W microwave power for 2 min followed by hot air drying at 60°C was the most acceptable to obtain the best quality dehydrated elephant foot yam slices.

Key words: Blanching, drying kinetics, elephant foot yam, microwave power, organoleptic evaluation, oxalate content

Introduction

Elephant foot yam, *Amorphophallus paeoniifolius* (Densst.) Nicolson, is a highly potential tropical underground stem tuber rich in nutrients. It is a very good source of starch as well as protein and very popular as a vegetable in various Indian cuisines. Elephant foot yam belonging to family *Araceae*, is widely grown and consumed in the south-east Asian countries like India, Philippines, Malaysia, and Indonesia and has great export potential since it is not commercially cultivated in many countries. The tubers are used for preparing ayurvedic medicines as they are anti-inflammatory, anti-haemorrhoidal, astringent, haemostatic, digestive, appetizer, rejuvenating and tonic (Misra et al., 2001). The plant starch is easily extractable and has good viscosity, stability and suitability for many applications in food industry (Moorthy, 1994). Because of its high yield potential, culinary, medicinal and therapeutic values, it is referred to as "King of Tuber Crops" (Sengupta et al., 2008).

Drying is one of the earliest methods of increasing the storage life of perishable agricultural produce by decreasing its moisture content thus preventing the growth of undesirable microorganism by reducing the water activity and extends its shelf life. It is a complex unit operation involving simultaneous heat and mass transfer, particularly under transient condition (Barbosa- Canovas et al., 1996). One of the most commonly used drying techniques is the convective hot air drying. During drying food materials are exposed to elevated temperatures, which lead to an increase in shrinkage and toughness, reduction of rehydration capacity of the dried product, and it also causes serious damage to flavour, colour, and nutrient content (Maskan, 2000). In common industrial dryers with hot air since the heat conduction is low the energy efficiency will decrease and more time is necessary for drying. In order to overcome these problems and reduce drying time to achieve efficient and rapid heat transfer processes with preservation of quality, the use of microwave for drying was considered. In microwave processing the energy is transferred directly to the sample producing a volumetric heating (Oliveira and Franca, 2002). This rapid internal energy generation causes pressure build up and results in rapid evaporation of water (Feng et al., 2012). Microwave drying has the advantage of high drying rates, reduced drying time, better product quality and efficient space utilization (Harish et al., 2014). The rapid and volumetric heat generation of microwaves has been utilized to improve conventional drying processes. But strictly speaking, a stand- alone microwave drying does not exist. Microwaves are used to assist or enhance another drying operation.

Enzymatic browning is the second largest cause of quality loss in fruits and vegetables. Since enzymatic browning causes deterioration of sensory and nutritional quality and affects appearance and organoleptic properties, inactivation of polyphenol oxidase (PPO) is desirable for preservation of foods (Samanta et al., 2010). Conventional hot water blanching of vegetables, widely used in industry, involves the immersion of the fresh product for a prescribed time in hot water kept at a constant temperature ranging from 70 to 100°C (Fellow, 1988). Tubers are quite acrid due to high content of calcium oxalates, causing throat irritation followed by burning sensation on eating (Sen and Choudhary, 2003). The acridity can be eliminated by boiling fairly for a long time.

Keeping the above points, the present investigation was carried out to use microwave heating as a pre-treatment in the beginning of drying to enhance the drying rate during convective drying of elephant foot yam, which could significantly contribute to time and energy saving with quality product for food processing industry. The objectives of the study were to investigate the effect of microwave power on drying kinetics of elephant foot yam and quality characteristics of dried product and to evaluate a best fit thin layer drying model.

Materials and Methods

Sample preparation and blanching

Fresh elephant foot yam tubers were collected from Navsari Agricultural University farm, Navsari, Gujarat, India. Prior to treatment, tubers were washed properly with clean tap water, peeled and cut in to 10 mm thick slices of square shape of 30 mm × 30 mm size using a stainless steel knife. The samples (approximately 500g each) were then submitted to a blanching process in which the slices were placed in a metal basket in water bath containing 1.5 L of water previously heated to 80°C. Then, blanching was carried out at three level of time duration viz., t_1 (2 min), t_2 (4 min), and t_3 (6 min). After blanching, the samples were cooled and the effects of blanching time on the activity of polyphenol oxidase (PPO) were evaluated. The activity of polyphenol oxidase (PPO) in elephant foot yam was determined by the spectrophotometric method (UV-VIS Spectrophotometer, Beckman) (Esterbaner et al., 1977).

Microwave - assisted drying

Blanched slices of elephant foot yam were heated in a microwave oven (Make: SAMSUNG, Model-CE1041DFB ; MW output at 2450 MHz) at different power levels of 300, 600 and 900 W with different exposure time of 1, 1.5 and 2 minutes. Microwave heated elephant foot yam slices were then immediately transferred to hot air tray dryer for further drying at a constant temperature condition of 60°C up to a final moisture content of 10% (db). There were total ten treatments including the control (P_0T_0) where microwave exposure was not given. The detail of treatment combinations of MW power and exposure time were presented in Table 1. Furthermore, the abbreviation db denotes dry weight basis and wb denotes wet weight basis in all representation through this literature.

Table 1. Treatment combinations of MW power (W) and exposure time (min)

Treatment	Drying conditions		
	Microwave Power (W)	Exposure Time(min)	Hot air Drying (°C)
P_1T_1	300	1.0	60
P_1T_2	300	1.5	60
P_1T_3	300	2.0	60
P_2T_1	600	1.0	60
P_2T_2	600	1.5	60
P_2T_3	600	2.0	60
P_3T_1	900	1.0	60
P_3T_2	900	1.5	60
P_3T_3	900	2.0	60
P_0T_0	0	0	60

Moisture content

Moisture content of fresh elephant foot yam was determined using the method as described in AOAC (1990).

Drying rate

The drying rate during the experiments was calculated using the following formula.

$$\text{Rate of drying} = \frac{dM}{dt} = \frac{M_{t+dt} - M_t}{dt} \quad \text{.... 1}$$

Where, M_t = moisture content at instant of time t; M_{t+dt} = moisture content at time after an interval of dt

The overall drying rate was calculated as the ratio of difference of initial and final moisture content (M_0–M_f) and total drying time (t_T). The overall drying rate was calculated as follows

$$\text{Overall drying rate} = \left(\frac{\partial M}{\partial t}\right) = \frac{M_o - M_f}{t_T} \quad \text{..... 2}$$

Mathematical modeling of drying kinetics

Experimental moisture content data of elephant foot yam during microwave assisted convective drying were converted to dimensionless moisture ratio using eq. (3):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad \text{..... 3}$$

Where, MR = moisture ratio (dimensionless); M_0 = initial moisture content; M_t = moisture content at time t; M_e = equilibrium moisture content (Dadali, 2007; Ertekin and Yaldiz, 2004). The eq. 3 can further simplified to $MR = \frac{M_t}{M_0}$ as the values of M_e is relatively small compared to M_0 and M_t for long drying time, hence the error involved in the simplification by assuming thatM_e is equal to zero is negligible (Wang et al., 2004; Diamante and Munro, 1993). All moisture contents are denoted on dry basis (kg water/ kg dry matter).

The moisture ratio curve can better explain the drying behavior than that of the moisture content curve, as the initial was one in each experimental data irrespective of the initial moisture content if varies because of sample collected at different time. The experimental data of these moisture ratios versus drying time were fitted to drying models to describe the drying behavior of elephant foot yam. The following three semi-empirical models were tested to describe the drying behavior of elephant foot yam.

(1) Generalized exponential model

$$MR = \frac{M_t}{M_0} = ae^{(-kt)} \quad \text{..... 4}$$

(2) Page's Model

$$MR = \frac{M_t}{M_0} = ae^{(-kt)^n} \quad \text{.....5}$$

(3) Midilli et al., Model

$$MR = \frac{M_t}{M_0} = ae^{(-kt)^n} + bt \quad \text{..... 6}$$

Where k and b are the drying constant (1/min); and a and n are dimensionless model parameters.

Statistical analysis of drying kinetics

Curve expert (version 1.4) software (Microsoft Corporation, Mississippi, USA) was used to fit the mathematical models to experimental data. Two comparative indices were used as goodness and to select the best model such as:

(1) coefficient of determination (R^2) and

(2) the root mean square error (RMSE)

These indices are as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)}{\sum_{k=1}^{N}\left(MR_{pre,i} - \frac{\sum_{k=1}^{N} MR_{pre,i}}{N}\right)} \quad \text{..... 7}$$

and

$$RMSE = \left[\frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N}\right]^{\frac{1}{2}} \quad \text{..... 8}$$

Where, $MR_{exp,i}$ = experimental moisture ratio of i^th^ data; $MR_{pre,i}$ = predicted moisture ratio of i^th^ data; N = number of observations

The model is said to be good if R^2 value is high and RMSE value is low.

Rehydration ratio

Dried elephant foot yam slices were rehydrated by immersing in warm water (at 60°C) and allowed to cool down to room temperature (30°C). 5g of dried samples were placed in glass beakers containing water in ratio 1:25 (w/w) for 8 hr. Samples were drained, blotted with tissue paper and weighed. The rehydration capacity was calculated as follows.

$$\text{Rehydration ratio } \frac{W_r}{W_d} \quad \ldots.. 9$$

Where, W_r is the rehydrated weight (g) and W_d is the dehydrated weight (g)

Quality analysis

For quality analysis after drying and storage studies following methods were adopted. Protein content by Lowry's method (1951); Total sugar content and sensory evaluation by Ranganna (1990); oxalate content by Abaza et al., (1968).

Results and Discussion

Influence of blanching time on the enzyme activity

In the experiment blanching treatments using water bath (80°C) was conducted on elephant foot yam slices and the variation of PPO activities with blanching time (t_1 = 2, t_2 = 4 and t_3 = 6 minutes) during the blanching process was measured in replication of seven and the average values were presented in Fig. 1. From the Fig. 1, it can be concluded that the PPO activity was decreased as the blanching time increased in all three treatments. The maximum and minimum values for PPO activity were observed in t_1 (2 min) and t_2 (4 min) as 0.0010 U/g and 0.0008U/g respectively. A unit of enzyme activity (1U/g wet basis) was defined as the change of 0.001 in the absorbance (420 nm) value under the conditions of assay. Treatments t_2 and t_3 are at par with each other.

Effect on moisture content

The average initial moisture content of elephant foot yam was found to be 395.05 % db (3.9505 kg H_2O/ kg dry

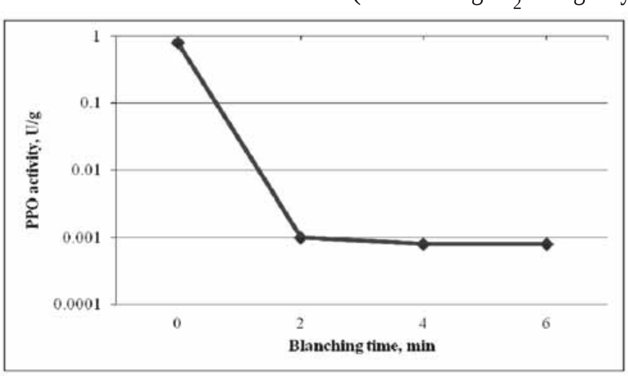

Fig.1. Influence of blanching time on the enzyme activity

matter) and the final moisture content of elephant foot yam after drying in different treatments were found to be 9.9 % db (0.099 kg H_2O/ kg dry matter). The moisture content (kg H_2O/ kg dry matter) vs. drying time (min) were plotted and shown in Fig. 2. From the figure it can be concluded that the decrease in moisture content was faster during initial period of drying and the reduction in moisture content was found to be slower during the latter part of drying. Reduction in moisture content was very less in last few hours of drying.

Effect on drying time

From Fig. 2., it can also be seen that the minimum value for drying time was noted to be 720 minutes for the treatment P_3T_3 and maximum value was 1440 minutes for the treatment P_0T_0 (without microwave heating, only hot air drying at 60°C). This result indicated that mass transfer within the sample was more rapid during higher

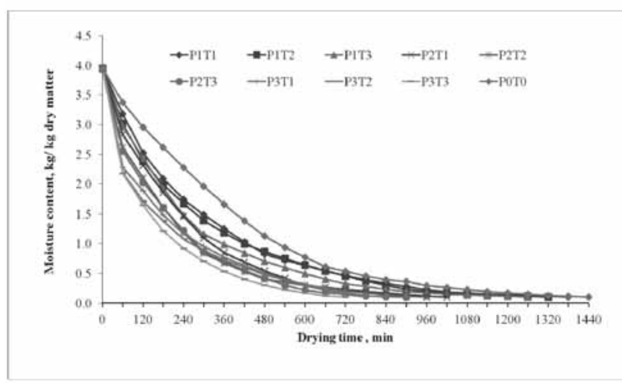

Fig. 2. Variation of moisture content with drying time for different drying treatments

microwave power heating because more heat was generated within the sample creating a large vapour pressure difference between the center and the surface of the product due to characteristics microwave volumetric heating. It can be seen that the decrease in moisture content with drying time was remarkable during the period of microwave heating and then slowly decreasing with time.

Effect on drying rate

The variation of drying rate (kg H_2O/kg dry matter*min) vs. drying time (min) of elephant foot yam were shown in Fig. 3 to 5. From the Fig. 3 to 5 it can be seen that maximum overall drying rate was observed in treatment P_3T_3 which was noted to be 0.0535 kg H_2O/kg dry

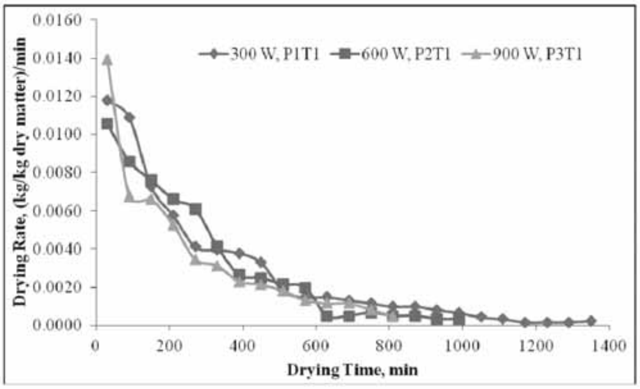

Fig. 3. Variation of drying rate with drying time at different MW power levels for 1 min exposure time

matter*min and the lowest value of drying rate among the treatments was noted to be 0.00267 kg H_2O/kg dry matter*min for the treatment P_0T_0 (convective tray drying @ 60°C). There was no constant rate drying period in the present investigation. Whole drying took place in falling rate period of drying process for all treatments.

Initially there was sudden increase in drying rate and later on the drying rate decreased with decreasing moisture content and increasing drying time. The result of microwave assisted drying showed that increasing microwave power level increased the drying rate.

Validation of semi-empirical mathematical models for drying kinetics

Drying curves of moisture ratio vs. drying time reflecting the effect of microwave power and sample thickness were shown in Fig. 6. From the figure it can be seen that drying time was inversely proportional to microwave power and exposure time. The moisture ratio vs. drying time curve can better explain a drying behaviour than moisture content vs. drying time curve as the initial value was one

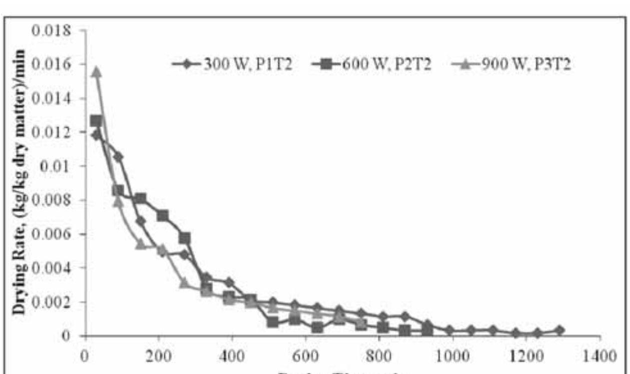

Fig. 4. Variation of drying rate with drying time at different MW power levels for 1.5 min exposure time

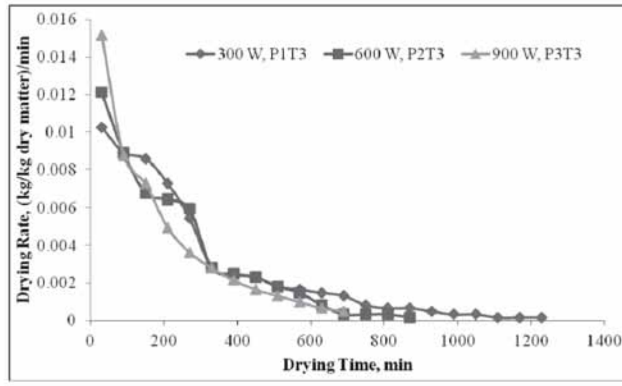

Fig. 5. Variation of drying rate with drying time at different MW power levels for 2 min exposure time

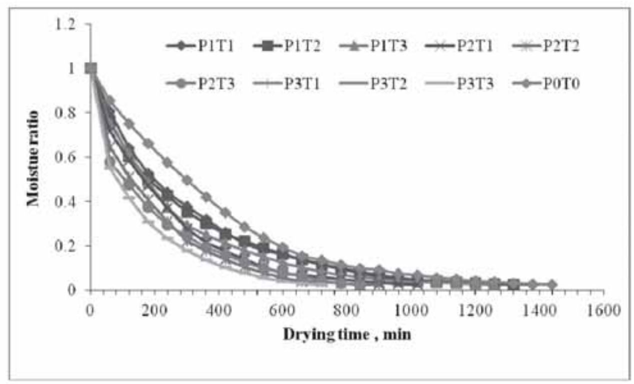

Fig. 6. Variation of moisture ratio with drying time for different drying treatments

in each experimental data irrespective of the initial moisture content. To describe the effect of microwave power and exposure time on drying kinetics of elephant foot yam, three semi-empirical thin layer drying models such as Generalize Exponential model, Page's model and Midilli et al. model were used. The moisture ratio and drying time data were fitted to these three drying models.

All three models were adequate to describe the microwave assisted drying characteristics of elephant foot yam since lowest R^2 value and highest RMSE were found to be 0.9618 and 0.0545 respectively, (treatment P_3T_2, Generalize exponential model) that is adequacy of R^2 > 90 % is fulfilled by all models. The experimental moisture ratio and predicted moisture ratio vs. drying time curve fitting for treatment P_3T_3 in different models were shown in Fig. 7 to 9. Curve fitting of experimental data was performed using nonlinear regression analysis of Curve Expert (version 1.4).

Comparative indices for statistical model parameters and coefficient of models for MW assisted drying of elephant

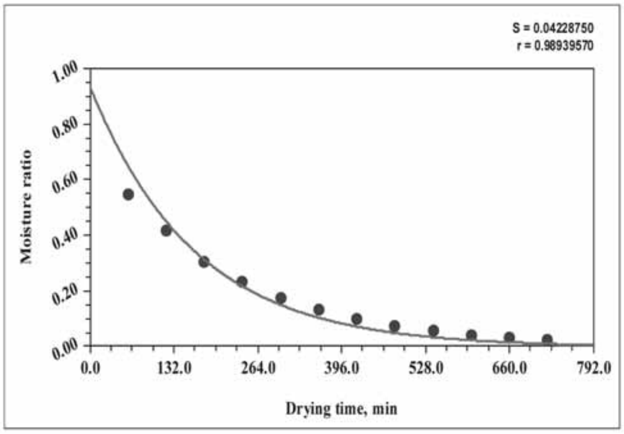

Fig. 7. Comparison of experimental and predicted moisture ratio vs. drying time of elephant foot yam by Generalized exponential model for treatment P_3T_3

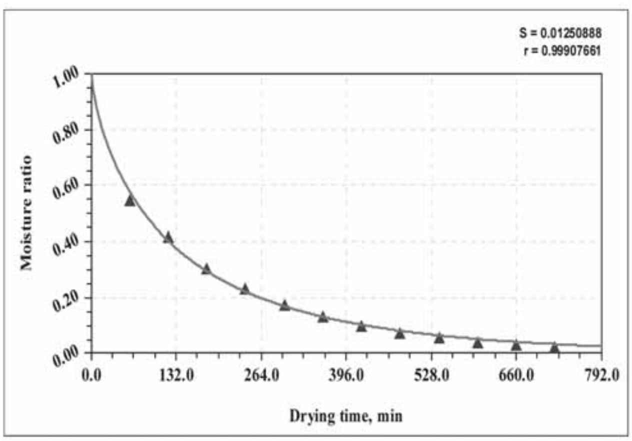

Fig. 8. Comparison of experimental and predicted moisture ratio vs. drying time of elephant foot yam by Page's model for treatment P_3T_3

foot yam were represented in Table 2 and Table 3, respectively. The highest value of R^2 (0.9996) and lowest value of RMSE (0.0051) observed for treatment P_3T_2 with Midilli et al. (2002) model.

Effect of MW power (P) and exposure time (T) on protein content % (wb)

The data recorded on protein content as influenced by MW assisted drying was graphically illustrated in Fig.10. The data pertaining to protein content % (wb or wet basis) levels of dried elephant foot yam showed decreasing trend with increasing microwave power level and microwave exposure time. The decreasing trend also found during storage period of 6 months. Initially (0 day) the maximum protein content (1.51 % wb) was recorded in P_1T_1 treatment and was at par with P_1T_2 (1.47 % wb). However, the protein content (1.06 % wb) was recorded in treatment P_3T_3, which is minimum, when the dried elephant foot yam slices were subjected to storage for a period of 6 months. Similar decreasing trend was also observed at all the levels of storage durations**.**

Effect of MW power (P) and exposure time (T) on total sugar content % (wb)

The data recorded on total sugar content as influenced by MW assisted drying treatments was graphically illustrated in Fig. 11. The data pertaining to total sugar content % (wb) levels of dried elephant foot yam showed decreasing trend as microwave power level and microwave exposure time increasing. The decreasing trend also found during

Table 2. Comparative indices of statistical models parameter for microwave assisted drying of elephant foot yam.

Treatments	Drying conditions		Generalized Exponential Model		Page's model $MR = a^{-(kt^n)}$		Midilli et al., model			
	MW power, W	MW exposure time, min	a	k	k	n	k	n	a	b
P_1T_1	300	1.0	0.9670	0.0031	0.0060	0.8950	0.0058	0.9010	1.0020	0.000003
P_1T_2	300	1.5	0.9420	0.0031	0.0086	0.8410	0.0098	0.8170	1.0000	-0.000010
P_1T_3	300	2.0	0.9630	0.0036	0.0079	0.8730	0.0070	0.8980	1.0000	0.000010
P_2T_1	600	1.0	0.9710	0.0041	0.0069	0.9150	0.0063	0.9290	0.9910	0.000003
P_2T_2	600	1.5	0.9560	0.0048	0.0012	0.8420	0.0106	0.8660	0.9950	0.000010
P_2T_3	600	2.0	0.9510	0.0048	0.0120	0.8440	0.0136	0.8170	0.9940	-0.000019
P_3T_1	900	1.0	0.9060	0.0046	0.0259	0.7090	0.0434	0.5980	0.9980	-0.000087
P_3T_2	900	1.5	0.8980	0.0049	0.0350	0.6640	0.0623	0.5390	0.9990	-0.000109
P_3T_3	900	2.0	0.9330	0.0061	0.0281	0.7260	0.0379	0.6590	0.9990	-0.000052
P_0T_0	No MW, only HAD		1.0210	0.0026	0.0015	1.0880	0.0010	1.1490	0.9830	0.000011

Table 3. Coefficients of drying model for MW assisted drying of elephant foot yam

Treat-ments	Drying conditions		Generalized exponential model		Page's model		Midilli *et al.*, model	
	MW power, W	MW exposure time, min	R^2	RMSE	R^2	RMSE	R^2	RMSE
P_1T_1	300	1.0	0.9970	0.0147	0.9996	0.0055	0.9996	0.0054
P_1T_2	300	1.5	0.9936	0.0212	0.9993	0.0070	0.9995	0.0060
P_1T_3	300	2.0	0.9953	0.0186	0.9989	0.0087	0.9992	0.0078
P_2T_1	600	1.0	0.9972	0.0150	0.9984	0.0117	0.9984	0.0123
P_2T_2	600	1.5	0.9928	0.0240	0.9978	0.0128	0.9980	0.0134
P_2T_3	600	2.0	0.9928	0.0244	0.9974	0.0148	0.9978	0.0146
P_3T_1	900	1.0	0.9726	0.0458	0.9952	0.0188	0.9988	0.0104
P_3T_2	900	1.5	0.9618	0.0545	0.9958	0.0180	0.9996	0.0051
P_3T_3	900	2.0	0.9789	0.0420	0.9982	0.0125	0.9994	0.0084
P_0T_0	No MW, only HAD		0.9970	0.0162	0.9984	0.0012	0.9988	0.0105

$MR = ae^{-(kt)}$

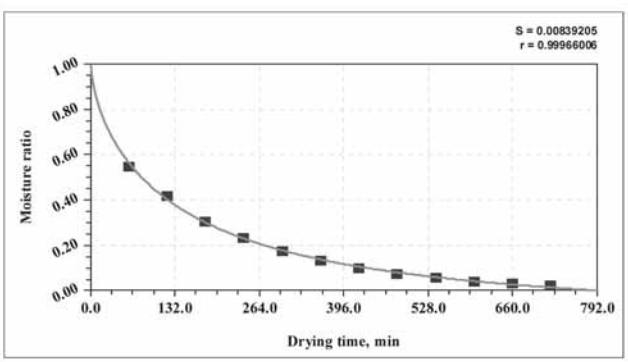

Fig. 9. Comparison of experimental and predicted moisture ratio vs. drying time of elephant foot yam by Midilli et al. model for treatment P_3T_3

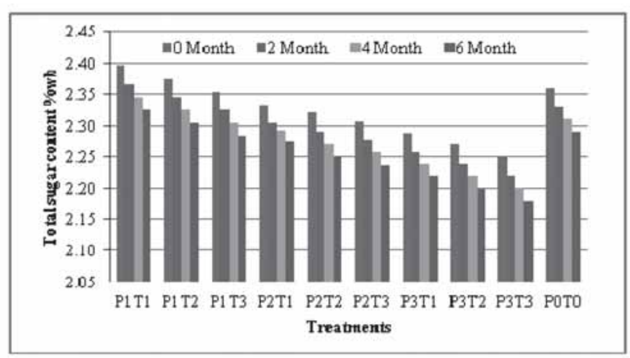

Fig. 11. Effect of microwave power and exposure time on total sugar content % (wb) of dehydrated elephant foot yam during storage

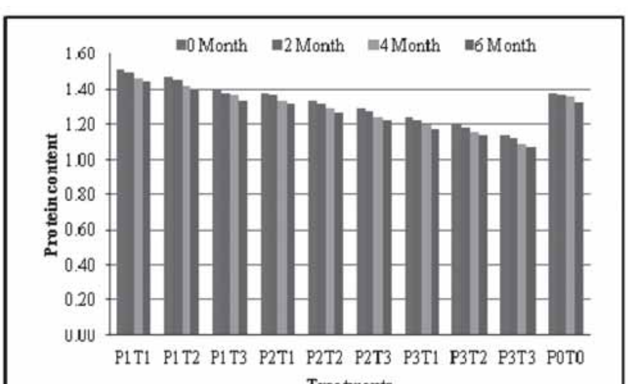

Fig. 10. Effect of microwave power and exposure time on protein content % (wb) of dehydrated elephant foot yam during storages

storage period. Initially the maximum total sugar content (2.40% wb) was recorded in P_1T_1 treatment which was at par with P_1T_2 (2.37 % wb), P_1T_3 (2.35% wb) and P_2T_1 (2.33% wb). In 2nd month of storage, treatment P_1T_1 (2.37 % wb) was at par with P_1T_2 (2.34 % wb). However, the least total sugar content (2.18 % wb) was recorded in treatment P_3T_3 when the dried elephant foot yam slices were subjected to storage for a period of 6 months. Similar decreasing trend was also observed at all the levels of storage duration. The variation in sugar content may be due to the partial break down of starch in presence of microwave energy. Slight reduction in sugar content during 6 months storage is attributed to increase in moisture content during that period.

Effect of MW power (P) and exposure time (T) on oxalate content

The data recorded on oxalate content as influenced by MW assisted drying treatments was graphically illustrated in Fig.12. The data pertaining to oxalate content % (db) levels of dried elephant foot yam showed decreasing trend during storage period. Initially the maximum oxalate content 0.212 % (db) was recorded in P_1T_1 treatment which was followed by P_1T_2 0.200 % (db). However, the least oxalate content (0.111 % db) was recorded in treatment P_3T_3 when the dried elephant foot yam slices were subjected to store. All treatments were at par with each other. Similar trend was also observed at all the levels of storage intervals. Microwave causes an acute heat stress which completely destroys the total oxalate (Randhir and Shetty, 2004).

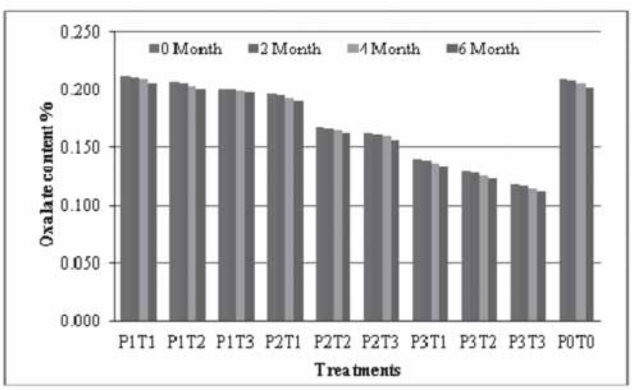

Fig.12. Effect of microwave power and exposure time on oxalate content % (db) of dehydrated elephant foot yam during storage

Effect of MW power (P) and exposure time (T) on rehydration ratio

The data recorded on rehydration ratio as influenced by MW assisted drying treatments was graphically illustrated in Fig.13. The data pertaining to rehydration ratio of dried elephant foot yam chips showed an increasing trend with increasing microwave power level and microwave exposure time. But it showed a decreasing trend during storage period. Initially (0 day) maximum rehydration ratio was recorded in P_3T_3 (2.94) treatment which was followed by P_3T_2 (2.93). However, the least rehydration ratio was recorded in treatment P_0T_0 (2.11) when the dried elephant foot yam slices were subjected to storage period of 6 months. All treatments were at par with each other. Similar decreasing trend was observed at all the levels of storage intervals. Change in rehydration ratio

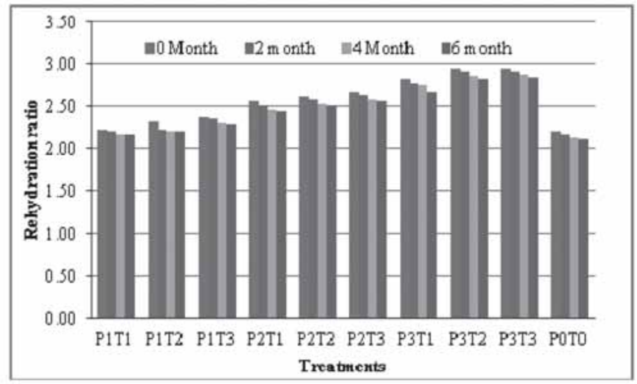

Fig.13. Effect of microwave power and exposure time on rehydration ratio of dehydrated elephant foot yam during storage

was attributed to the puffing of chips at high MW power and consequent high porosity might have led to high absorption of water during rehydration.

Organoleptic quality attributes

Organoleptic quality attributes like colour, texture and overall acceptability of dehydrated as well as rehydrated elephant foot yam, was evaluated by panel of judges at 0 to 6 months of storage at 2 months interval during the experimentation and results of sensory evaluation are presented in Fig. 14. The overall acceptability score (out of 9 points) of rehydrated elephant foot yam based on colour and texture by various treatments during the storage period are depicted in Fig.14. Panels of judges preferred the overall acceptability score (7.28) of rehydrated elephant foot yam in treatment P_3T_3. Due to higher MW power level, puffing was developed in elephant foot yams which provided more porous structure. Therefore rehydration characteristic of MW assisted elephant foot yam were improved.

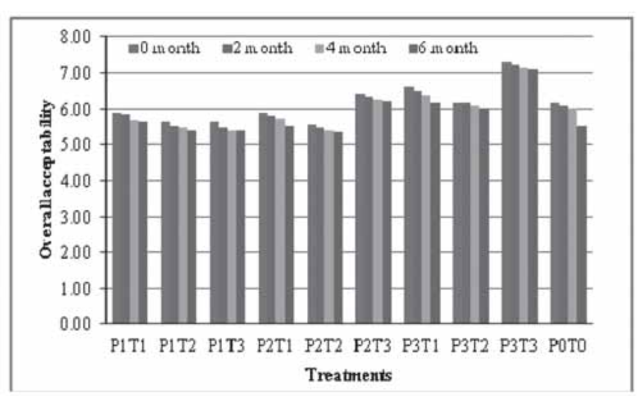

Fig.14. Effect of microwave power and exposure time on overall acceptability of rehydrated elephant foot yam during storage.

Conclusion

On the basis of experimental results and data analysis following conclusion can be drawn. Hot water blanching at 80°C for 4 min significantly decreased the PPO activity and stopped initiation of browning. Increased in MW power and exposure time, increased the drying rate and decreased the drying time. The whole drying process took place in falling rate period only and the average drying rate increased with increased MW power and exposure time. Midilli et al. model was found to describe the drying behaviour of elephant foot yam most precisely as R^2 was highest (0.9996) as well as least RMSE (0.0051) as compared to other models. Rehydration ratio increased with MW power and exposure time and MW power has significant effect on it. Product quality in terms of protein, total sugar and oxalate content was found to be acceptable in all microwave assisted drying treatments. Based on oxalate content and drying characteristics, treatments with microwave power of 900 W and exposure time of 2 min followed by hot air drying at 60°C was found to be the most acceptable. The experiment concluded that elephant foot yam slices should be blanched at 80°C for 4 min in hot water and pre-treated with microwave power of 900 W for 2 min exposure time followed by hot air drying at 60°C to produce best quality dehydrated elephant foot yam.

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