Standardization of process parameters for microwave assisted convective dehydration of ginger

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Abstract Ginger (*Zingiber Officinale*, Cv. Suprava) slices (4 mm thick) were dehydrated at 25°, 40°, 50° and 60 °C with three different microwave power levels, viz. 120, 240, and 360 W in microwave assisted convective dryer up to 0.07 g moisture/g dry solid to observe the feasibility of microwave assisted convective drying for ginger. The samples were also dried without application of microwaves (0 W) at the above air temperatures. The final product quality was compared in terms of rehydration characteristics, oleoresin and volatile oil contents, hardness, color and organoleptic quality. The maximum rehydration ratio of 3.86 ± 0.06 was obtained at 50 °C without application of microwaves and was followed by 120 W-40 °C combination treatment (3.64 ± 0.15). The minimum rehydration ratio was 2.34 ± 0.20 for 360 W with 60 °C. The yield of oleoresin content was higher for 120 W as compared to other power levels, which ranged between $5.12 \pm 0.85\%$ and $6.34 \pm 0.89\%$. The maximum retention of oleoresin was observed in case of 120 W-40 °C. The samples dried with microwave power level of 120 W also gave better yields of volatile oil as compared to other power levels. The best color was observed at 120 W-50 °C and 120 W-60 °C conditions with Hunter 'a' (redness) values at 0.50 ± 0.03 and 0.35 ± 0.03 , respectively. The sensory analysis also

indicated that drying at 120 W-50 °C and 240 W-50 °C combinations gave the most acceptable quality product. Drying ginger with 120 W-50 °C combination helped in a saving of 53% and 44% in drying time as compared to hot air drying at 50° and 60 °C, respectively. Drying at 240 W-50 °C also gave a reasonably acceptable quality product with a net saving of 91% and 89% in drying time as compared to hot air drying at 50° and 60 °C, respectively. However, on the basis of rehydration characteristics, the acceptable process conditions were hot air drying at 50° or 60 °C, or with the 120 W-40 °C combination.

Keywords Ginger · Microwaves · Dehydration · Oleoresin · Volatile oil · Rehydration · Hardness · Color

Ginger (*Zingiber Officinale*) is one of the most important spices grown in India. It is widely used as a flavoring substance in food. In addition, it has many medicinal properties. The pungent taste of ginger is due to the principal constituent "oleoresin" which is a very viscous dark brown liquid. Ginger oleoresin, also commercially known as *Gingerin*, is a combination of both volatile and nonvolatile oils. Commercially dried ginger samples have been reported to provide oleoresin in the range of 3.5 to 10%, and that contains 15 to 30% of volatile oils (Lewis et al. 1972; Naves 1974). India is the largest producer and exporter of ginger in the world. Total production of ginger in India during 2008–09 was about 795028 MT from 138479 ha area (Spices Board 2011). However, the magnitude of post harvest losses of ginger is quite high, which is mainly due to the lack of suitable preservation methods. Dehydration has been considered as a suitable method for preservation of surplus ginger. However, due to long drying time in conventional dehydration processes, the

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final product is often not comparable with the fresh product because of its poor color and flavor, loss of volatile matters, poor rehydration characteristics, etc.. All of these lead to poor acceptance by consumers. Some other cost intensive methods as freeze drying, vacuum drying, etc. could overcome many of these problems, but the high capital and operating costs associated with these methods have limited their applications.

A comparatively recent development is microwave assisted convective heating for dehydration. The method comprises of subjecting the food pieces to electromagnetic waves. Two narrow bands of microwaves allocated for use in industrial food processing are 915 MHz and 2450 MHz. In India, the frequency used is mostly 2450 MHz as the lower frequency band creates interferences with mobile phones (900 MHz) and computers (Nijhuis et al. 1996, Sharma and Prasad 2006). This radiation penetrates the food material depending upon the thickness and changes the polarity of water molecules present in the food rapidly. It results in friction among the water molecules and between water and solid molecules leading to rise in temperature. In this way the heat of vaporisation is supplied directly to the water molecules and the moisture from within the food pieces are evaporated. The moisture content and water activity of the produce are thus reduced within a short period of time. Due to short exposure time and maintenance of low temperature, the final product is reported to have better quality (Ren and Chen 1998).

Microwaves remove the water throughout the product simultaneously, but the loss of water is restricted due to the limiting diffusion coefficient. Further, exposure to microwave field results in localization of heat inside the product leading to charring. Hence, coupling with some other methods like convective, osmotic or fluidized bed drying, etc. along with low power microwaves have been tried for dehydration. These combined methods are reported to have good potential for high speed and high quality drying. Microwave assisted convective dehydration has been found to be successful for some food products like corn (Gunasekaran 1990), grapes (Tulasidas et al. 1993), potato (Bouraoui et al. 1994), banana (Maskan 2000), carrot cubes (Prabhanjan et al. 1995), button mushroom (Kar et al. 2004), garlic (Sharma and Prasad 2001), various medicinal plants (Ren and Chen 1998), apple (Zhenfeng et al. 2010), pineapple (Botha et al. 2011), etc. It has been observed that the final product has a better color and rehydration ratio. The drying time has also been reported to be reduced by up to 90% as compared to convective drying at similar temperature conditions. In a recent study, Alibas (2007) used two different microwave power levels (160 and 350 W) and two different air temperatures (50 and 75 °C) at 1 m/s air velocity for drying of pumpkin slices and found that the drying periods were 125–195, 45–90 and 31–

51 min for microwave, air and combined microwave–air drying, respectively depending on the drying level. Drying temperature and microwave power are the two most important factors in microwave drying of agricultural products. These two factors significantly influence the drying parameters such as drying time, drying curve, drying speed, drying efficiency, and the final product quality (Zhenfeng et al. 2010).

Drying of ginger with hot air takes a long time of 12 to 24 h or even longer depending on the operating conditions. Therefore, it was planned to study the feasibility of microwave assisted convective dehydration for ginger with different microwave power levels and air temperature. The objective was to standardize the parameters for the microwave assisted convective dehydration of ginger.

Materials and methods

This experimental setup has been developed by coupling an air heating and blowing system with a 600 Watt (W), 2450 MHz microwave oven (Fig. 1). The back of the oven just above the turn table was cut open and was coupled with the heating system. The walls of the air heating chamber were made of two layers, i.e., the inner asbestos and the outer GI sheet. The gap between the two was filled with glass wool to prevent heat loss. Three electrical heating elements (1.5 kW) were fitted inside the chamber. A blower with regulator was used to force air at the desired rate through the heating system and then through the drying chamber. The air velocity close to the samples being dried was monitored with a hot wire anemometer (Make: Extech, resolution 0.1 m/s) and accordingly the air flow rate was controlled with a variac fitted to the blower. Air temperature was controlled with the help of a thermostat and it was observed that the temperature of the air close to the samples being dried was maintained at ± 1 °C, which was continuously monitored with the help of a datalogger (Make: Datalogger, Model: DT 600 with Cu-constantan thermocouple). The microwave intensity was maintained using the control panel of the microwave oven. The microwave oven had the capability of maintaining the microwave power level from 0 to 600 W with a step value of 120 W. There was provision of continuous recording of the weight of the samples with an analytical balance (Make: Sartorius, Least count: 0.01 g) fixed with the setup.

Mature freshly harvested ginger (Cv. Suprava) was procured from the farmers and was graded on the basis of size and mechanical damage. Then it was washed thoroughly and surface water was removed. The cleaned ginger was stored/cured in ventilated condition till further use. The initial moisture content of samples was determined by oven method (Ranganna 1986). It was

Fig. 1 Schematic diagram of the microwave assisted convective dryer used for the study

observed that the samples took 72 h to come to the equilibrium condition in the oven maintained at 70 °C, and hence subsequently for determination of initial moisture content, 20 g of the sliced sample was kept in the oven at 70 °C for 72 h. The moisture content of sample was expressed as g of moisture per g of dry solid (Sharma and Prasad 2001). The weights were taken on an analytical balance (Sartorius) with a least count of 0.01 g.

To study the effect of microwave power level and air temperature on the product quality, 4 mm thick ginger slices were used for the study. The ginger samples were peeled by sharp bamboo sticks and sliced by sharp stainless steel knives just before the dehydration experiments. The different levels of air temperature and microwave power used in the study are as follows.

Air temperature: 25 °C (room temperature or RT), 40°, 50° and 60 °C

Microwave power : 0 (No microwave power), 120, 240 and 360 W

Higher microwave power levels were avoided as preliminary studies with 480 W microwave power caused dark colored products and burnt flavor at all air temperatures. The deteriorations were immediately noticed at the completion of drying. The air velocity inside the microwave assisted convective dryer in the vicinity of the drying tray was kept at 2 m/s (Sharma and Prasad 2001).

The dryer was run without sample placed in it for about 15 min to set the drying condition before each drying experiment. Experiments were conducted using full factorial CRD with three factors in duplicate. The sample size was kept uniformly as 300 g.

The weight of the samples and thus the moisture loss were monitored at 2 min intervals during the first 50 min, at 5 min intervals subsequently for the next hour and then at 30 min intervals till the completion of drying. The final moisture content of the ginger samples were kept approximately at 0.07 g of moisture per g of dry solid.

The product characteristics were studied in terms of rehydration characteristics, texture, color, oleoresin content, volatile oil content and organoleptic qualities.

Rehydration characteristics

The time and temperature of soaking was initially standardized by soaking 10 g of ginger slices in 250 ml distilled water at 70 °C. It was observed that the weight of the sample equilibrated after 6 h and hence, for determination of rehydration characteristics, this time and temperature combination was followed. The rehydration ratio and the coefficient of restoration for the products were determined as follows (Dash and Bhatnagar 1991).

$$\text{Rehydration ratio (R.R.)} = \frac{C}{D} \quad (1)$$

$$\text{Coefficient of restoration of weight (C.R.)} = \frac{C(100 - A)}{(D - BD) \times 100} \quad (2)$$

Here, A and B are the percentage of water in original and dehydrated samples. C is the drained weight of rehydrated sample and D is weight of dry sample.

Texture

The hardness of the dried products was determined with the help of a texture analyzer (Make: Stable Microsystems, Model: TA XT Plus) The HDP/90 with Warner Bratzler blade probe was used. The test configurations were pre-test speed: 2 mm/s, test speed: 2 mm/s, post test speed: 10 mm/s. trigger type: auto - 5 g, and data acquisition: 200 pps. The maximum peak value of force obtained in the force-deformation curve in the texture analyzer was taken as the hardness.

Color

The ginger slices were powdered before measuring the color. The chromaticity of the ginger powder was measured

in terms of L (the degree of lightness), a (degree of redness) and b (degree of yellowness) values, using a Hunter lab colorimeter. The colorimeter was calibrated against a standard calibration plate of a white surface with L, a, b values of 91.10, −0.64 and −0.43, respectively. The measurements of color were replicated five times after shaking the samples and average of L, a and b values were reported along with the standard deviations values (Sharma and Prasad 2001).

Ginger oleoresin

Ginger oleoresin is normally obtained by extraction of dried ginger powder with suitable solvents like hexane, petroleum ether, dichloromethane and ethanol (Alfaro et al. 2003). In the present study, the oleoresin content of ginger was found out by extraction with hexane. An amount of 50 g ginger powder was extracted for 2 h in a Soxhlet apparatus using 200 ml hexane. The amount of oleoresin was presented as percent w/w basis of the dehydrated sample.

Volatile oil content

The volatile oil content of ginger was measured by distillation method using a modified Clevenger apparatus. Two hundred g of ground sample was taken in the flask and was heated for 5 h at boiling temperature, till a constant reading of the volatile oil was obtained (Ranganna 1986). The amount of volatile oil was expressed in percent w/w of the dehydrated sample.

Organoleptic evaluation

Dehydrated ginger powder was subjected to sensory evaluation by a 12 members consumer test panel on the basis of a 9-point Hedonic scale (IS: 6273, 1971). The sensory attributes included taste, color, flavor and overall acceptability.

Statistical analysis

Results obtained were subjected to analysis of variance with full CRD by MSTATC software. The standard deviations for each set of experiments and the critical difference (CD) for the individual effects and the interaction effects were calculated at 5% probability level ($p \leq 0.05$) and were analyzed.

Results and discussion

The initial moisture content of the ginger used for the studies was found to remain within 3.77–3.35 g per g dry solids. The final moisture content to which the samples were dried was

0.07 g per g dry solids (approx.). The different results obtained from the experiments are discussed below.

Rehydration characteristics

The observations on the rehydration ratio and the coefficient of restoration of the ginger samples dehydrated with different combinations of microwave power and air temperature are presented in Fig. 2. It was observed that the maximum rehydration ratio of 3.86 ± 0.06 was obtained at 50 °C without application of microwaves and was followed by 120 W–40 °C combination treatment (3.64 ± 0.15). The minimum rehydration ratio was 2.34 ± 0.20 for 360 W with 60 °C. From the statistical analysis it was found that both the convective air temperature and the microwave power level affected significantly the rehydration quality and the coefficient of restoration of the final product. Considering the individual effects, the 40 °C air temperature yielded better rehydration ratio as compared to other air temperatures. However, the difference was not significant from 50 °C temperature. Similarly, drying without microwave power resulted in more acceptable rehydration quality as compared to other treatments involving the use of microwaves. The combined effects of microwave power and air temperature were significant in terms of rehydration characteristics of the final product.

Considering the interaction critical difference for rehydration ratio at 5% probability level to be 0.45, the acceptable process conditions in terms of rehydration characteristics were at 0 W–50 °C, 0 W–60 °C and 120 W–40 °C.

It indicated that drying at higher microwave power levels than 120 W resulted in less acceptable rehydration quality. It could be due to the very fast drying rate at higher microwave power levels, causing shrinkage of the cell structure. Similarly, drying at 50–60 °C resulted in more acceptable rehydrated product than drying at room temperature and 40 °C, which was attributed to the longer drying time at lower air temperatures.

Texture

The ginger slices were tested for their hardness with the texture analyzer, so as to have an idea about the acceptability of the dehydrated samples in sliced form and the power requirement in subsequent milling operations. A sample observation is given in Fig. 3. The hardness of the dehydrated samples as obtained from the texture analyzer have been plotted in Fig. 2. It was observed that there was considerable variation within the replications. The statistical analysis concluded that there was no significant variation in hardness with the change of air temperature between 40 and 60 °C, even though drying at 50 °C temperature yielded products with minimum hardness. Drying at room temper-

Fig. 2 Effect of drying air temperature and microwave power level on quality of ginger slices ($n=3$)

ature gave products with maximum hardness, which could be due to the extended exposure to the drying air. However, the effect of microwave power level was insignificant. Even though the 120 W microwave power level yielded products with minimum hardness, still the differences in effects of different power levels were not significant. But the interaction significantly affected the hardness of the samples and it was observed that the product obtained

Fig. 3 Texture profile of dehydrated ginger slices as obtained from the texture analyzer (240 W-60 °C)

from drying at 240 W-50 °C had the minimum hardness of 4.66 kg. However, considering the interaction CD (microwave power level $\times$ convective air temperature) value at 5% probability level as 4.988 kg, the samples dried without application of microwaves at 50° and 60 °C, those dried at 120 W at all temperatures, at 240 W for the temperatures between 40 and 50 °C and at 360 W for 40 °C were also acceptable in terms of hardness.

However, the maximum hardness of the samples was limited to less than 12 kgf only, indicating that the hardness might be ignored as a parameter for deciding the optimum process conditions for drying 4 mm thick slices. Thicker slices would have required higher force for breakage.

Color

A significant difference in color of samples dried with different combinations of microwave power and air temperature was noticed (Table 1). The CD values ($p \leq 0.05$) for L, a and b were 3.83, 0.21 and 6.67, respectively. It was observed that in general, the use of 120 W microwave power level gave products with less redness and yellowness. At room temperature (25 °C), there was no significant difference between color values obtained at different microwave power levels between 120 and 360 W. However, at higher drying air temperatures the variation was remarkable. The samples dried at 360 W were darker as compared to lower power levels as indicated from their L, a and b values.

In view of the above, the samples dried at low microwave power level or 120 W microwave power level were acceptable. At 120 W power level, drying at temperatures of 40–60 °C yielded lighter colored samples than those dried at room temperature. The best color was obtained at 120 W-50 °C and 120 W-60 °C conditions with the Hunter a (redness) values at 0.5 ± 0.03 and 0.4 ± 0.03 , respectively.

Oleoresin

The oleoresin content as obtained from the ginger samples dehydrated with different microwave power levels and

Table 1 Hunter color characteristics of dehydrated ginger samples

Process parameters	L	a	b
0 W-25 °C	79.0±2.89 ^a	0.6±0.04 ^e	29.3±3.59 ^{a b}
0 W-40 °C	75.4±2.45 ^{a b c}	1.0±0.05 ^d	28.5±3.65 ^{a b}
0 W-50 °C	75.4±1.85 ^{a b c}	1.1±0.05 ^d	28.7±4.57 ^{a b}
0 W-60 °C	74.6±1.98 ^{b c}	1.6±0.08 ^c	30.1±4.77 ^{a b}
120 W-25 °C	75.4±2.65 ^{a b c}	1.8±0.10 ^{b c}	32.0±3.70 ^{a b}
120 W-40 °C	77.4±3.12 ^{a b}	0.6±0.04 ^e	28.2±3.69 ^{a b}
120 W-50 °C	77.1±1.69 ^{a b}	0.5±0.03 ^{e f}	29.1±4.89 ^{a b}
120 W-60 °C	76.5±1.55 ^{a b}	0.4±0.03 ^f	25.8±3.80 ^b
240 W-25 °C	73.7±2.25 ^{b c d}	1.7±0.10 ^c	30.2±3.60 ^{a b}
240 W-40 °C	69.3±1.93 ^c	1.9±0.09 ^b	31.1±3.69 ^{a b}
240 W-50 °C	68.5±1.50 ^e	3.0±0.12	32.8±3.31 ^a
240 W-60 °C	70.6±2.81 ^{d e}	4.6±0.27	30.2±4.53 ^{a b}
360 W-25 °C	72.1±2.11 ^{c d e}	1.9±0.11 ^b	31.8±3.80 ^{a b}
360 W-40 °C	71.2±2.28 ^{d e}	4.0±0.14 ^a	32.4±3.48 ^{a b}
360 W-50 °C	68.3±2.14 ^e	4.2±0.20 ^a	32.1±3.69 ^{a b}
360 W-60 °C	69.3±2.84 ^e	5.1±0.21	32.6±4.91 ^a

^{a–f} means within the same column by different letters are significantly different ($p \leq 0.05$). Each observation indicates the average value of 5 replications ($n=5$)

temperatures, are given in Fig. 2. The analysis revealed that the individual effects of drying air temperature and microwave power levels used in the study were significant on the retention of oleoresin content during drying. Drying at 60 °C caused a significant reduction in oleoresin content as compared to other air temperatures. Drying at a microwave power level of 120 W gave higher yields of oleoresin as compared to drying with no microwave power or with higher power levels at all air temperatures. The reduction was more pronounced in case of higher power levels than without the use of microwave power. The yield of oleoresin content at 120 W microwave power ranged between $5.12 \pm 0.85\%$ and $6.34 \pm 0.89\%$, and the maximum value was observed in case of 120 W-40 °C. Considering the critical difference of interaction effects at 5% probability level as 1.286%, all the samples dried at no power level and 120 W microwave power level were acceptable in terms of oleoresin content in the final product. It indicates that oleoresin was better retained at no or low microwave power level of 120 W and use of higher microwave power levels caused the reduction of oleoresin in the dried samples.

Considering the individual effects, the maximum oleoresin content was obtained in case of samples dried at room temperature, but there was no significant difference between the samples dried up to 50 °C temperature. Similarly the microwave power level of 120 W yielded maximum oleoresin content, though the difference in effects of no microwave power and 120 W microwave power was insignificant.

Volatile oil

The observations on the volatile oil content of the dehydrated ginger samples also showed that the individual effects of both

microwave power level and air temperature, and the combined effects, were all significant. The observations are given in Fig. 2. Drying at a microwave power level of 120 W yielded more volatile oil as compared to other power levels. The yield of volatile oil at 120 W power ranged between 1.59 and 1.89%. The air temperature of 50 °C was also suitable for getting higher yield of volatile oil.

The maximum volatile oil retention was for the 120 W-40 °C combination, which was 1.89%. However, considering the CD at 5% probability level as 0.15%, the samples dried at 120 W-25 °C, 120 W-50 °C and 240 W-50 °C were also acceptable.

The use of 360 W microwave power levels significantly reduced the volatile oil content. Similarly, with the increase in air temperature from 50 to 60 °C, the volatile oil content of the dehydrated samples reduced.

The percent loss in volatile oil content was lower than that of oleoresin content, when the microwave power level was increased from 120 to 240 W, indicating that some other components than volatile oil were also lost from the oleoresin at higher microwave power levels. At 60 °C air temperature, there was almost no difference between the yields of volatile oil content at 0–240 W power levels. With further increase in convective air temperatures, it is naturally expected that the volatile oil content would further reduce.

Organoleptic quality

The mean scores obtained for the different sensory parameters obtained from the consumer test panel have been given in Table 2, along with the critical difference at 5% probability level. The maximum scores for color, flavor,

Table 2 Sensory quality characteristics of dehydrated ginger sample

	Process parameters	Color	Flavor	Taste	Overall acceptability
	0 W-25 °C	7.7±0.78 ^{c d}	6.8±0.75 ^{c d}	7.0±1.76 ^{b c}	6.6±0.90 ^e
	0 W-40 °C	8.2 [#] ±0.71 ^{a b c}	7.7 ±1.07 ^{a b c}	7.8 ±0.96 ^{a b}	8.1 ±0.79 ^{a b}
	0 W-50 °C	8.1 ±0.79 ^{a b c}	6.8±1.21 ^{c d}	7.0±1.21 ^{b c}	7.3±0.88 ^b
	0 W-60 °C	8.1 ±0.79 ^{a b c}	7.4 ±1.08 ^{a b c}	7.9 ±0.90 ^a	8.0 ±0.74 ^{a b c}
	120 W-25 °C	7.8±1.14 ^{b c d}	7.9 ±0.99 ^{a b}	7.8 ±0.94 ^a	7.9 ±0.99 ^{a b c d}
	120 W-40 °C	7.9 ±0.67 ^{a b c d}	7.3 ±1.06 ^{a b c}	7.5 ±1.24 ^{a b}	7.8±1.05 ^{b c d}
	120 W-50 °C	8.7 ±0.49 ^a	8.2 ±0.71 ^a	8.2 ±1.02 ^a	8.5 ±0.52 ^a
	120 W-60 °C	7.7±1.16 ^{c d}	7.5 ±0.79 ^{a b c}	7.5 ±0.90 ^{a b}	8.0 ±0.85 ^{a b c}
	240 W-25 °C	7.9 ±0.79 ^{a b c d}	7.1±0.99 ^{b c}	7.8 ±0.57 ^a	7.6±0.99 ^{b c d}
	240 W-40 °C	6.7±0.77 ^e	5.9±0.99 ^d	6.6±1.24 ^c	6.6±1.51 ^c
	240 W-50 °C	8.5 ±0.52 ^{a b}	7.8 ±0.96 ^{a b}	8.3 ±0.62 ^a	8.4 ±0.51 ^a
	240 W-60 °C	7.3±1.05 ^{d e}	7.1±1.16 ^{b c}	7.0±0.95 ^{b c}	7.4±0.90 ^{c d}
	CD (p≤0.05)	0.77	0.97	0.78	0.64

^{a–f} means within the same column by different letters are significantly different ($p \leq 0.05$); #The figures marked bold are acceptable in terms that quality parameter at 5% probability level

Each observation indicates the average value of 12 replications ($n=12$)

taste and overall acceptability were obtained at 120 W microwave at 50 °C, and the maximum score for taste was obtained at 240 W microwave with 50 °C.

In view of the sensory tests, it was observed that the sample dried at 120 W-50 °C and 240 W-50 °C were most accepted by the consumer panel. The scores received by the 120 W-50 °C sample for color, flavor, taste and overall acceptability were 8.7±0.49, 8.2±0.71, 8.2±1.02 and 8.5±0.52, respectively. The corresponding values for 240 W-50 °C sample for color, flavor, taste and overall acceptability were 8.5±0.52, 7.8±0.96, 8.3±0.62 and 8.4±0.51, respectively. The scores of color, flavor, taste and overall acceptability for sample dried at 60 °C without any microwave power were found to be 8.1±0.79, 7.4±1.08, 7.9±0.90 and 8.0±0.74, respectively, which were within the critical limit and hence acceptable.

Drying time

The time required for drying of 4 mm thick ginger slices from the initial moisture content of 3.77–3.35 g per g dry solids up to 0.07 g moisture/g dry matter (approx.) has been given in Table 3. It was observed that drying with application of 120 W or 240 W microwave power level gave considerable saving in drying time as compared to drying without application of microwave power. Alibas

(2007) also mentioned that the use of microwave assisted convective drying reduced the drying time substantially as compared to only convective or hot air drying. If we used normal hot air drying (without use of microwaves), the drying times for 50 °C and 60 °C were 960±16 and 810±5 min, respectively. However, with the 120 W-50 °C condition, the drying time was reduced to 450±16 min, i.e. drying with 120 W-50 °C air temperature combination caused a net saving of 53% and 44% in drying time as compared to hot air drying at 50° and 60 °C, respectively. Similarly drying at 240 W-50 °C combination caused a net saving of 91% and 89% drying time as compared to only hot air drying at 50° and 60 °C, respectively. Thus, by increasing the microwave power level from 120 W to 240 W, there was an additional reduction in drying time, i.e. drying at 240 W-50 °C caused a reduction of 80% in the drying time as compared to drying at 120 W-50 °C.

Selection of process conditions

As discussed in the previous sections, in view of the organoleptic characteristics, the samples dried at 120 W-50 °C and 240 W-50 °C were the most acceptable. In addition, the samples dried with only convective drying at 60 °C were also good. However, considering the advantage obtained in drying time, the microwave

Table 3 Drying time (in minutes) for 4 mm thick ginger slices to dry up to 0.07 g/g dry matter level (approx.)

Drying air temperature Microwave power level	25 °C	40 °C	50 °C	60 °C
0 W	8570±17	5370±18	960±16	810±5
120 W	810±12	480±10	450±16	440±8
240 W	120±7	95±3	90±3	90±3
360 W	80±3	80±6	70±3	70±3

The mean values have been rounded to nearest 5 min, $n=3$

assisted drying could be preferred to no-microwave application methods.

The samples dried at the microwave power level of 120 W gave better yields of oleoresin and volatile oil as compared to drying with no or higher microwave power levels at all convective air temperatures. However, as observed in the sensory analysis from response to flavor, the consumer test panel could not differentiate these variations in volatile oils between 120 W-50 °C and 240 W-50 °C. The samples dried with 120 W up to 50 °C retained more volatile oil content as compared to the drying at 60 °C.

Similarly, the samples dried at 120 W gave better color in the colorimeter as compared to higher microwave powers, at any particular temperature. At 120 W power level, drying at temperatures of 40–60 °C yielded less red colored samples than those dried at 25 °C. But as obtained from the sensory test, the samples dried with 240 W-50 °C got the second highest color score, indicating that the consumers preferred the color.

The hardness of the samples also did not vary in any systematic manner for the different process conditions and the maximum hardness was limited to 12 kg. Hence, the hardness might be ignored as a parameter for deciding the optimum process conditions.

On the basis of rehydration characteristics, the acceptable process conditions were at 0 W-50 °C, 0 W-60 °C and 120 W-40 °C.

Thus, in view of the saving in drying time and better quality parameters, the dehydration may be conducted with 120 W microwave power level at 50 °C air temperature. Drying at 240 W-50 °C combination may also be employed, as there was no remarkable difference in between the acceptability of the ginger slices dried at 120 W-50 °C or 240 W-50 °C combinations. As the 240 W-50 °C combination also causes a saving of 80% in the drying time as compared to 120 W-50 °C combination, the former can be employed, if the recovery of the volatile oil is not the prime objective.

However, if rehydration is more important, the drying should be conducted without microwave power at 50–60 °C or with 120 W microwave power level at 40 °C air temperature. It was also observed that the samples dried under both convective drying and microwave assisted convective drying conditions stored well without any significant degradation in the organoleptic quality parameters for up to 6 months in air tight PET jars under dark condition.

Conclusion

Microwave assisted convective dehydration of ginger was studied by taking 4 mm thick ginger slices with four

microwave power levels, viz. 0 (no microwave power), 120, 240 and 360 W, four air temperatures, viz. 25 °C (room temperature), 40°, 50° and 60 °C. The final product quality was compared in terms of rehydration characteristics, retention of oleoresin and volatile oil, hardness, color and organoleptic quality. It was observed that on the basis of rehydration characteristics, the acceptable process conditions were at 0 W-50 °C, 0 W-60 °C and 120 W-40 °C. However, the samples dried at the microwave power level of 120 W gave better yields of volatile oil and oleoresin as compared to drying at 0 or 240 W microwave power levels at all convective air temperatures. Drying with 120 W microwave power up to 50 °C also retained more oil as compared to the drying at 60 °C. The best color was obtained for 120 W and 40–60 °C conditions. Thus, in view of the saving in drying time and most acceptable quality parameters, the dehydration of ginger slices may be conducted with 120 W microwave power level at 50 °C air temperature. Dehydration with 120 W-50 °C air temperature combination would help in a net saving of 53% and 44% in drying time as compared to only hot air drying at 50° and 60 °C, respectively. If the recovery of the ginger oil is not the prime objective, then drying at 240 W-50 °C combination may also be employed. The 240 W-50 °C combination would cause an additional saving of 80% in drying time as compared to 120 W-50 °C combination.

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