Study of Changes in Shrinkage and Density as a Function of Moisture Content during Microwave Vacuum Drying under Various Operating Conditions

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Abstract

The objective of this paper is to study the changes in shrinkage and density as a function of moisture ratio during microwave vacuum drying (MVD) under various operating conditions. Fresh grapes (Thompson seedless) procured from local market were used for the present study. Two types of sample were taken for study, first one was untreated and second one was pretreated with solution of sodium hydroxide (0.5%) and ethyl oleate (2%) at 80°C for 30 seconds. Grapes with the initial moisture content of 80% (wb) were dried up to final moisture content of 20 % (wb). The effects of process variables, namely microwave power (100, 110, 120, and 130 W) and pressure (200, 400 and 600mm of Hg) were studied on the physical characteristics viz., shrinkage ratio and apparent density of grapes. Microwave vacuum drying resulted in 70 to 90% reduction in the drying time. Shrinkage ratio and apparent density of grapes (Thompson seedless) were determined during microwave vacuum drying at various moisture contents ranging from 80 to 20% (wb), the shrinkage ratio of grapes however, reduced linearly with the moisture content. Experimental data showed that system pressure had more significant effect on shrinkage and density changes than the power level during microwave-vacuum drying. Simple mathematical models were used to correlate the shrinkage ratio and apparent density with moisture content of grapes.

Keywords: Shrinkage; Apparent density; Grapes; Microwave-vacuum drying; Modeling

Introduction

The utilization of grapes and raisins goes back to ancient times. Around 95% of raisins today are dried "Thompson Seedless" grapes, *Vitis vinifera* L. followed by the "Fiesta" (3%) and "Zante currant" (1.5%). Beside many health benefits raisin are the rich source of flvonols, quercetin and kaempferol, and the phenolic acids, caftaric and coutaric acid and also on a wet weight basis protocatechuic and oxidized cinnamic acids are present at a higher level in raisins compared to grapes [1-28]. Conversion of grapes into good quality raisins is not easy because some problems are associated with grape drying, for example one problem is associated with grape skin structure. The skin of grapes, play a critical role in controlling the drying process. The skin of grapes consists of an epidermis and six to ten layers of small thick walled cells [14]. Skin is covered by waxes which are hydrophobic in nature and hinder the water evaporation rate from inner to outer part of grapes during drying. Another problem is that thermal conductivity of raisin varies from 0.126 to 0.392 W/(mK) with an increase in moisture content from 14 to 80% (wb) [6], due to this heat transfer in inner section in the falling rate period is slow during conventional method of drying. Drying is one of the most important processes applied in the food industries which have the profound effect on all the relative operations. The ultimate objective of any drying process is to produce a dried product near to fresh product in terms of quality at a minimal cost while keeping the high throughput. During drying various desirable as well as undesirable changes takes place. These changes are governed by drying method adopted, drying conditions and physiochemical properties of targeted

food. Generally three drying methods are employed to convert grapes into raisin: sun drying, shade drying and mechanical drying. These drying process vary with variety of grapes and geographical locality [19]. There are various losses associated with sun drying such as: environmental contamination due to dust and insect infections, physical microbial deterioration caused by rain, and color deterioration due to intense solar radiation [29]. Many drying techniques have been applied to grapes, such as sun drying [3,5,8] convective drying [1], combined convective and microwave drying [25,26], and microwave drying. Zhang et al. [30] proposed that many conventional drying methods are associated with some disadvantages such as low drying rates and high temperature in falling rate period which ultimately results in poor quality of dried food product. Microwave Vacuum Drying (MVD) provides a better drying option because it combines the advantages of Microwave (MW) and Vacuum drying as the vacuum lowers the process temperature and facilitates water evaporation, resulting in short drying time and good quality product.

Microwave vacuum drying is a novel option for drying of food product that permits to acquire adequate quality of dried product. It allows shorter drying time and substantial improvement in quality of dried product [4]. MVD resulted in 70-90% decrease in the drying time of mushrooms compared to convective air drying along with better quality of dried product [10,11]. The quality of dried food product can be improved by controlling the multiple changes that takes place in food product during drying including the physical and chemical modification. One of the physical properties that have a pronounced effect on transport phenomena property of dried food product is shrinkage; which can be defined as the ratio of volumes of initial to dried food product. To fulfill the requirement of high quality product, good knowledge of shrinkage mechanism and process variables which influence the shrinkage are needed. Several authors have successively reviewed the process variables which influence the extent of shrinkage. Some representative examples of such efforts are the work [10-13,15,17,20,27]; Shrinkage is often considered negligible during modeling of the drying processes. There is little published data available on shrinkage and density changes of food materials as a function of moisture content during microwave vacuum drying. The objective of this study was to determine the shrinkage and density changes in grapes during microwave vacuum drying under various operating conditions and to correlate them with mathematical model. This paper has also the objective to study the shrinkage of pretreated and control grapes as a function of moisture ratio.

Theoretical Consideration

Volume changes have been incorporated into the diffusion coefficient to control transport properties affected by shrinkage during drying [18]. Diffusion coefficient multiplied by a power of the volume changing factor, which can be defined as the ratio between the actual volume and a reference volume which can be either the basic initial volume [2] or final volume of the totally dried samples [7]. The power exponent used by Crank [2] was 2 and by Fish, 2/3. Gekas and Lamberg [9] proposed the equation

for diffusion coefficient as follows:

$$\frac{D}{D_{ref}} = \left\{ \frac{V_f}{V_i} \right\}^{2/n} \tag{1}$$

Where, exponent n takes value of one in the case of one-dimensional and the value of three for isotropic three-dimensional shrinkage [24]. This parameter, n, may be viewed as a measure of the degree of isotropicity of the deformation and is related to linear and volume shrinkage by

$$S_{vol} = (S_{dia})^n \tag{2}$$

Where S_{vol} and S_{dia} are defined as:

$$S_{dia} = \frac{\varnothing_f}{\varnothing_i} \text{ or } \frac{l_f}{l_i} \tag{3}$$

$$S_{dia} = \frac{\varnothing_f}{\varnothing_i} \text{ or } \frac{l_f}{l_i} \tag{4}$$

Experimental shrinkage determination during drying allows the prediction of other physical properties as bulk density, taking in account the following relationship:

$$\frac{V_f}{V_i} = \frac{d_i (M_s + M_w)}{d_f (M_s + M_{wi})} \tag{5}$$

The product moisture content on a dry basis is defined as:

$$A = \frac{M_w}{M_s} \tag{6}$$

Combining the above equations (3, 5 and 6) give the relationship between volume shrinkage ratio and apparent density as:

$$S_{vol} = \frac{d_i (1 + A_f)}{d_f (1 + A_i)} \tag{7}$$

$$d_f = \frac{d_i (1 + A_f)}{S_{vol} (1 + A_i)} \tag{8}$$

The shrinkage ratio can be related to product moisture ratio by linear model [16]

$$S_{vol} = X + Y \left[\frac{A_f}{A_i} \right] \tag{9}$$

Putting the value of S_{vol} in equation (8) the apparent density can be correlated to moisture content by following equation

$$d_f = \frac{d_i (1 + A_f)}{\left(X + Y \left[\frac{A_f}{A_i} \right] \right) (1 + A_i)} \tag{10}$$

This equation can be used to predict the apparent density at any moisture content during drying of shrinking food materials.

Materials and Methods

Raw material and sample preparation

The fresh grapes of Thompson seedless variety was procured from the local market of Kharagpur, India and stored in the refrigerator at 4 to 5°C. All grapes sample were chosen with similar size, shape and colour. Prior to the experiments the sample were taken out from the refrigerator and kept at ambient atmospheric

condition for two hours to attain room temperature. The grapes were washed in the clean water. Uniform grapes were selected and the stems were hand removed prior to pretreatment. The pretreatment comprised of dipping the grapes in an alkaline solution of 2% ethyl oleate and 0.5% sodium hydroxide at 80°C for a period of 30s and these procedures are in accordance with the earlier studies reported [22,25], and immediately washed with tap water for 5 minutes.

Microwave vacuum drying

Pretreated and control grapes were dried in the developed laboratory microwave vacuum drying system as depicted in **Figure 1**. The dryer consists of a microwave oven (Samsung model M1739N) having a rated capacity of 800W at 2.45 GHz. The oven was modified to give variable power output (from 0 to 800 W) by incorporating a 230V AC variance in the circuit [23]. A vacuum pump with a pressure regulating valve was connected to the container for maintaining vacuum conditions inside it. The extent of vacuum in the container was monitored with a vacuum gauge. An airtight condenser was also used in the vacuum line for condensing the water vapour released from the drying samples during drying. The variables chosen for microwave vacuum drying experiments were microwave power (100, 110, 120 and 130W) and system pressure (200, 400 and 600 mm of Hg).

Shrinkage measurement

For measuring the shrinkage ratio in grapes during drying samples were selected and their exact initial weights were recorded. The initial dimension of individual sample were measured with a vernier caliper with least count of 0.01 cm, the initial apparent volumes of grapes were determined by toluene displacement method with an accuracy of 0.1 ml. the fresh samples were dried to six different desired moisture contents of 70, 60, 50, 40, 30 and 20% (wb) in separate experiments. The samples were removed from the dryer when they attained a pre calculated weight corresponding to the desired level of moisture content. The dried sample were then cooled in desiccators for sometimes and stored in sealed plastic bags for at least 30 minutes to allow the internal moisture to equalize. The final weight, dimension and volume were measured. These partially dried samples were coated with a thin layer of paraffin wax film (melting point: 58 to 62°C) to prevent penetration of toluene during volume measurements. The volume of wax film was considered negligible. Each experiment was replicated twice. The shrinkage ratios were calculated as the ratio of volume and length or diameter at any moisture content level to their corresponding initial values. The initial and final apparent densities were calculated for different moisture levels as the ratio between the total weight of the sample and its apparent volume [29,30].

Results and Discussions

The changes (reduction) in volume of the samples with moisture content are shown in **Figures 2 and 3** for both pretreated and control sample**.** These figures show the mechanism of shrinkage during drying. When water is extracted from the material, a pressure imbalance; that is variation in pressure between the

inner of the material and the external pressure, is produced generating contracting stresses that lead to material shrinkage or breakdown, changes in shape and sometimes cracking of the product. It was observed that reduction in volume was higher in the initial stage of drying than the later stage. After the moisture content has reached to approx. 30% (wb), volume changes was negligible for both type of sample (pretreated and control). From the results obtained as shown in **Table 1**. It was observed that there was about 67.5% reduction in volume at 20% moisture
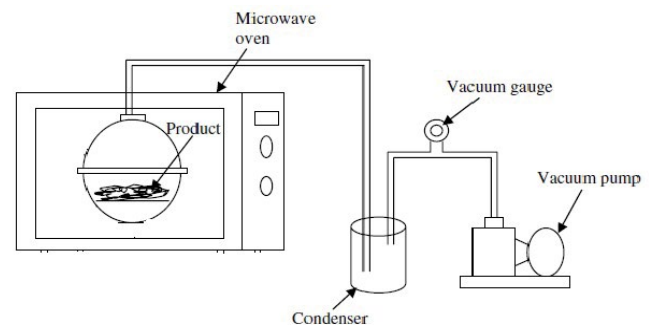

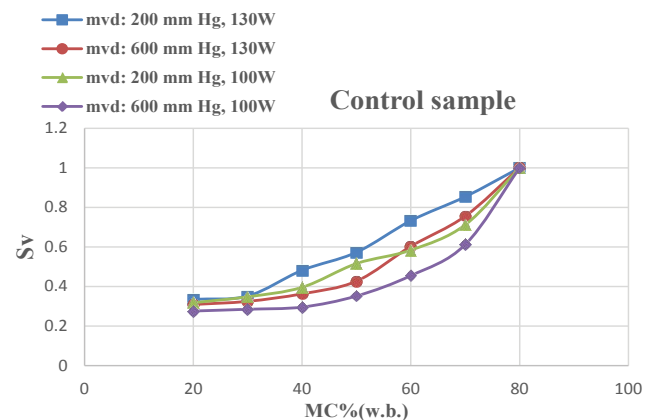**Figure 1**   Experimental microwave-vacuum drying apparatus.

Figure 2   Volumetric shrinkage ratio vs. moisture content (wet basis) at different drying condition (control sample).
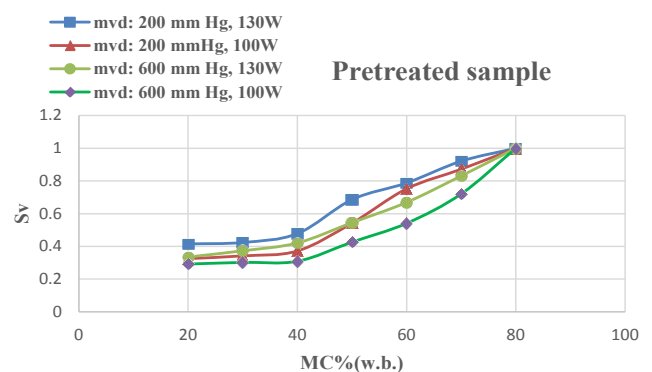

Figure 3   Volumetric shrinkage ratio vs. moisture content (wet basis) at different drying conditions (pretreated sample).

Table 1: Shrinkage ratio and apparent densities of grapes at different moisture content.

Drying method	Operating condition	Moisture content% (wb)	Shrinkage ratio		Apparent density g/cm³	
			Pre-treated Sample	Control sample	Pre-treated sample	Control sample
MVD	200 mm Hg 130 W	70	0.921	0.854	0.565	0.623
		60	0.788	0.733	0.444	0.517
		50	0.686	0.573	0.398	0.478
		40	0.478	0.482	0.338	0.429
		30	0.424	0.352	0.313	0.382
		20	0.415	0.335	0.301	0.346
MVD	600 mm Hg 130 W	70	0.831	0.756	0.622	0.681
		60	0.669	0.603	0.521	0.533
		50	0.545	0.427	0.416	0.427
		40	0.421	0.363	0.398	0.386
		30	0.373	0.325	0.366	0.325
		20	0.335	0.309	0.347	0.317
MVD	200 mm Hg 100 W	70	0.872	0.712	0.551	0.678
		60	0.752	0.584	0.42	0.568
		50	0.542	0.516	0.367	0.485
		40	0.372	0.396	0.333	0.473
		30	0.342	0.348	0.304	0.421
		20	0.325	0.318	0.288	0.310
MVD	600 mm Hg 100 W	70	0.872	0.612	0.682	0.695
		60	0.752	0.455	0.572	0.583
		50	0.542	0.352	0.461	0.510
		40	0.372	0.296	0.409	0.436
		30	0.342	0.285	0.399	0.366
		20	0.325	0.276	0.275	0.281

content (wet basis) took place. **Figures 4 and 5** show the effect of system parameters on shrinkage ratio; **Figure 4** shows the effect of system pressure on shrinkage ratio while **Figure 5** shows the effect of microwave system power level. It is clear by observing **Figures 4 and 5** that system pressure has more pronounced effect on shrinkage ratio than power level. **Figures 6 and 7** exhibits the correlation between shrinkage ratio and moisture ratio for both type of sample pretreated and control. A good linear regression was obtained by fitting the experimental data to model equation (9) for all the cases. **Figures 6 and 7** exhibit the correlation between shrinkage ratio and moisture ratio for both type of sample pretreated and control respectively. A good linear regression was obtained by fitting the experimental data to the model eqn. (9) for all the cases. **Table 2** shows the constants of the above regression equations. Linear relation may propose that volume of food product that is lost in drying is equivalent to volume of water removed. Using the shrinkage data, the apparent densities at different moisture content was calculated according to model eqn. (10). **Figures 8 and 9** represent the experimental apparent density at different moisture contents. It is observed that apparent density decreases as the water is removed from the grapes, this is because MVD results in porous nature of the sample.
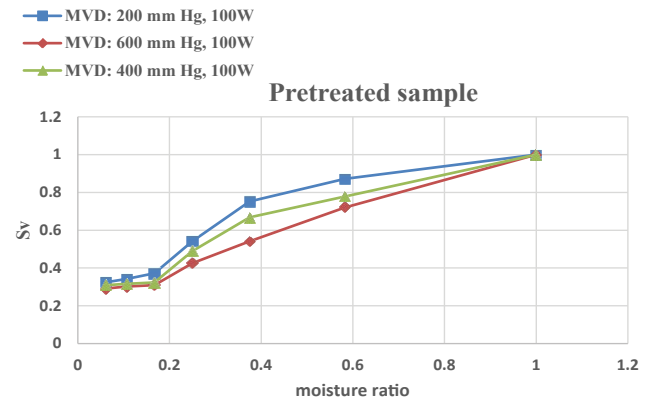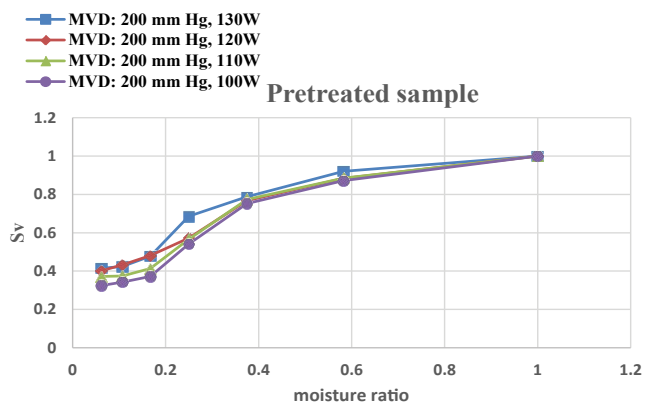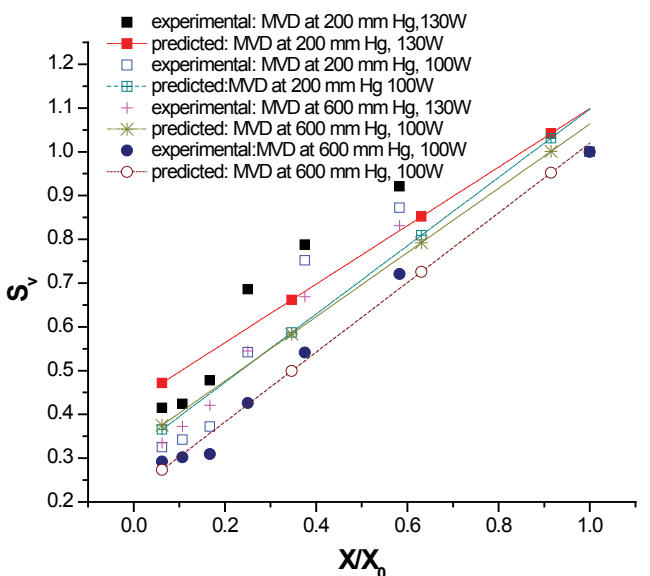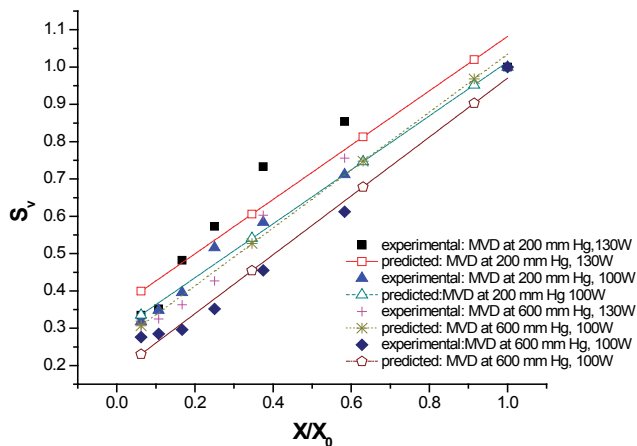

Figure 4 Shrinkage ratio vs. moisture ratio: effect of microwave system pressure.

Figure 5 Shrinkage ratio vs. moisture ratio: effect of microwave system power level.

Figure 6 Experimental and predicted volumetric shrinkage ratio of grapes as a function of moisture ratio (pretreated).

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Table 2: Correlation constants of the linear model representing the shrinkage of raisin at various drying.

Drying condition	Pretreated sample			Control sample		
	Constant X	Coefficient Y	R^2	Constant X	Coefficient Y	R^2
MVD:200 mmHg, 130 W	0.2301	0.7686	0.9818	0.3538	0.7279	0.9894
MVD:600 mmHg, 130 W	0.2295	0.7339	0.9711	0.2584	0.7758	0.9774
MVD:200 mmHg, 100 W	0.1769	0.7806	0.9864	0.2907	0.7228	0.9875
MVD:600 mmHg, 100 W	0.2237	0.7960	0.9871	0.1813	0.7887	0.9836

Figure 7 Experimental and predicted volumetric shrinkage ratio of grapes as a function of moisture ratio (control).
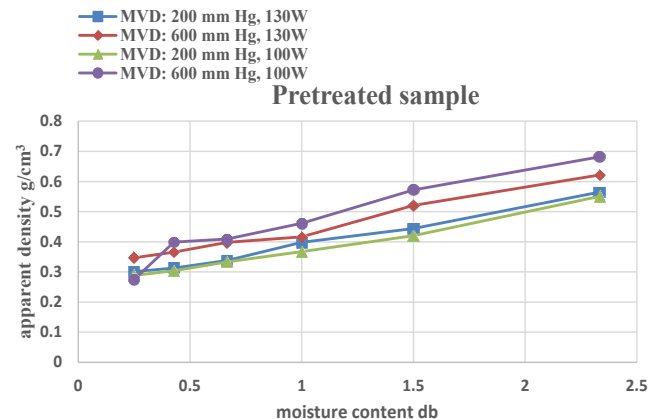
Figure 9 Experimental values of apparent density as a function of moisture content.
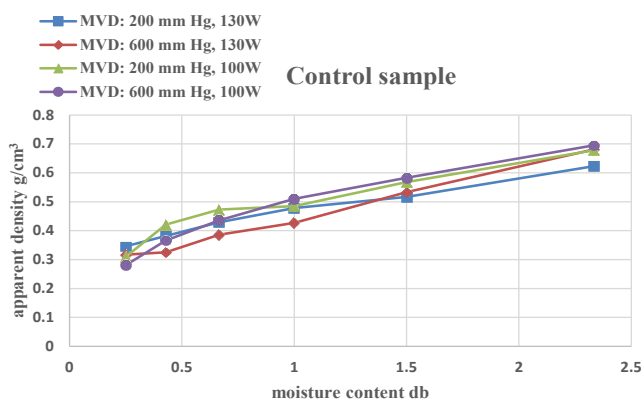
Figure 8 Experimental values of apparent density as a function of moisture content.

Conclusion

It is clear by observing the results that shrinkage of pretreated sample was lesser than the untreated sample, possible reason may be the depletion of waxy layer while pretreatment leading to porous nature of the sample. The porous sample leads to easy removal of moisture from within the sample to the surface without destructing the fibrous structure of grapes sample, since there was no destruction of fibrous structure of grape and there was easy removal of moisture hence comparatively lesser shrinkage. Shrinkage ratio of grapes reduced linearly with the moisture content. Experimental data showed that system pressure had more significant effect on shrinkage and density than the power level during microwave-vacuum drying. Simple mathematical models were used to correlate the shrinkage ratio and apparent density with moisture content of grapes.

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