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Dehydration of Apple Slices using Microwaves in Combination with other Techniques

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Abstract: Application of microwave in combination with other dehydration techniques such as hot air and freeze-thaw drying was investigated for dehydration of apple slices using a customized batch type vacuum-assisted microwave dehydration system. Apple slices of uniform size and thickness (5 mm) were used in the dehydration experiments which were carried out at different microwave power levels (200, 400 and 600 W) with or without application of vacuum (150 m bar). Drying was accomplished till the moisture content of the apple slices reduced from initial moisture content of 1.80 kg water/kg solids to a safer level of 0.06 kg water/kg solids. The dehydration time reduced as the microwave power was increased from 200 W to 600 W at a constant vacuum level of 150 mm Hg. The quality attributes of the fresh and dehydrated apple slices were evaluated for color (L*, a*, b* values), texture, thermal and sensory characteristics. The rehydration characteristics were also evaluated for the dehydrated apple slices. The apple slices, dehydrated using microwave under vacuum at a power level of 200 W with vacuum (150 m bar) , was found to be superior to the rest of the samples in terms of different quality attributes.

Keywords: Microwave, Dehydration, Drying, Vacuum and Apple.

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1. Introduction

Apple (*Malus domestica*, family Rosaceae, sub-family Pomoideae) is one of the leading fruits produced and consumed around the world. Apple is a rich source of sugars, vitamins, minerals, phenolics and antioxidants in a major part.

Drying or dehydration is one of the oldest methods of food preservation. From the dawn of human civilization, people were preserving their food by different drying techniques. Drying comes as one of the easiest and cheapest

methods for preserving foods which are otherwise more or less perishable. The terms dried and dehydrated are not synonymous. The US Department of Agriculture lists dehydrated foods as those with no more than 2.5 % water (dry basis), while dried food applies to any food product with more than 2.5 % water (dry basis). While dehydration may be defined as the application of heat under controlled conditions for nearly complete removal of water from the food to a final moisture content of 1-5% with minimal changes in the food properties, the term drying is reserved for the process that accomplishes the removal of water by evaporation from a wet solid, not involving any specific parameter benchmarks. Dehydration involves both heat and mass transfer. Microorganisms need water for their growth cycles and dehydration reduces the water activity of food and extends the shelf life much longer than the fresh produce.

Dehydration using the application of microwaves, both in presence of air or vacuum is a latest fourth generation drying technique (Vega-Mercado, Gongora-Nieto, and Barbosa-Canovas, 2001). Microwave heating is a type of dielectric heating that takes place in non conductors due to polarization effects at frequencies 300MHz-300GHz (corresponding to wavelength 1mm-1m). Drying with a microwave reduces the drying time and improves the quality of the final dried products. The microwave may be applied either alone or in combination with other dehydration techniques that improves the efficiency of the process even further, thus giving the flexibility to produce a wide variety of dried products and at the same time maintaining the nutritive value of the food products.

Microwaves are the long frequency and short wavelength electromagnetic waves, that penetrate directly into the material, resulting in fast and uniform volumetric heating, as its energy is absorbed quickly by the water molecules, that comes in motion and kinetic energy is quickly transformed to thermal energy, thus heating up the product by the internal heat generation, inside the product itself and therefore, causing the minimum damage to the product and giving excellent product quality (Prabhanjan *et al*., 1995). A prerequisite for the absorption of microwave energy by the material is the existence of substances containing dipoles or dipolic regions (Grueneberg *et al*., 1992).

Present investigation is aimed at studying microwave dehydration behavior of apple slices at different power levels, with and without vacuum using different combination treatments.

2. Materials and Methods

Fresh apples (*Malus domestica*) of Himachal variety were purchased from the local market of Mysore in the state of Karnataka (India). The apples had

initial moisture content of 1.80 kg water/kg dry matter and were stored in a cold storage chamber maintained approximately at a temperature of 5^0 C and 75 % relative humidity. The apples were hand peeled, washed under water to prevent enzymatic browning and then cut into uniform slices with 5 mm thickness. Slices subjected to water blanching were immersed in hot water at 80 ^{0}C for 1 min and then cooled at room temperature. 1000 ppm Potassium metabisulphite (KMS) used during blanching to prevent browning.

2.1. Analytical Data

Moisture content was analyzed by atmospheric drying at 70°C until constant weight was achieved (AOAC, 1980). Soluble solid content (Brix) was measured in a refractometer (ABBE ATAGO 3 T) at 20°C. The pH of the samples was determined using a microprocessor based pH meter (Century, CP 931).

2.2. Dehydration

The dehydration experiments were performed in a specially designed vacuum assisted microwave dryer (Enerzi Microwave Systems Pvt. Ltd, Bangalore, India). The equipment allowed microwave power, dryer temperature, air velocity and vacuum pressure to be controlled. Temperature is measured by an infrared pyrometer (-20 to 480°C), using a temperature controller (Fuji PXR-4 PID programmed by Infrawin software). Both fresh and pre-treated samples were subjected to the dehydration process and the weight losses were registered. Microwave power levels of 200 W, 450 W and 650 W were applied in combination with 150 mm Hg vacuum pressure and in presence of air. Drying was performed according to a pre-set power and time schedule. A digitally monitored cabinet tray dryer was used to dry the apple slices at 60 °C using a flow of hot air.

2.3. Freeze drying

The apple samples were prepared following lyophilization protocol using Scanvac device, DK-3540, Lynge, Denmark. Samples were initially deep freezed to -35.5^{0}C and then subjected to sublimation.

2.4. High Pressure Processing

High pressure processing was used as a treatment for softening the tissues of the apple slices prior to microwave dehydration. A FPG 9400:922 High Pressure ISO-LAB System model High pressure processing equipment (Stansted Fluid Power Ltd, Stansted, Essex, UK), with a maximum pressure, voltage and current configured at 900 MPa, 400 V and 40 A, respectively. The frequency of the equipment was set at 50 Hz in 3 phases. Samples were packed

in polyethylene pouches and then subjected to a pressure of 500 MPa for a hold time of 2 min. The temperature was maintained at 30+/-1°. The samples were suspended in the liquid of monopropylene glycol.

2.5. Color

The chromaticity of the dehydrated apple slices was measured in terms of *L* (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 black and white surface with *L*, *a* and *b* values respectively. The measurements of color were replicated three times after shaking the dehydrated samples and the average values of *L*, *a* and *b* were reported. The shaking was primarily done to take into account the variation in the color at different points on the surface of the dehydrated apple slices.

2.6. Texture analysis

The firmness of apple samples was determined by a breaking test using a texture analyzer TAHDi, Stable Microsystems, UK. The breaking test was performed by breaking the fruit slices (3 cm x 1 cm x 0.5 cm) using a stainless steel knife edge with slotted insert (HDP/BS) using a 100 kg load cell heavy duty platform (HDP/90) with a speed of 2 mm/s and a distance of 12 mm.

2.7. Rehydration tests

Rehydration assays for the dehydrated apple slices were carried out by immersing the dehydrated samples in water. The apple slices obtained after 5 min of rehydration were evaluated for rehydration ratio. Approximately 5 g dehydrated apple sample was put in 100 ml boiling distilled water in a 250 ml beaker kept in a hot water bath at boiling. The water of the beaker was drained and the sample was removed. Surface moisture of the sample was removed gently by wiping it off with a tissue paper and the weight was taken. Dehydrated apple slices were evaluated for rehydration characteristics in respect of rehydration ratio, coefficient of rehydration, percent water in rehydrated material and weight-gain ratio, from the weight before and after the rehydration.

3. Statistical Analysis

Statistical analysis of variance (ANOVA) using completely randomized design (CRD) was performed by Statistica 7.1 software (Stat Soft, Tulsa, OK, USA), to

estimate the effect of different pre-treatments and dehydration methods on the quality parameters of apple slices.

4. Results and Discussions

4.1. Drying Kinetics

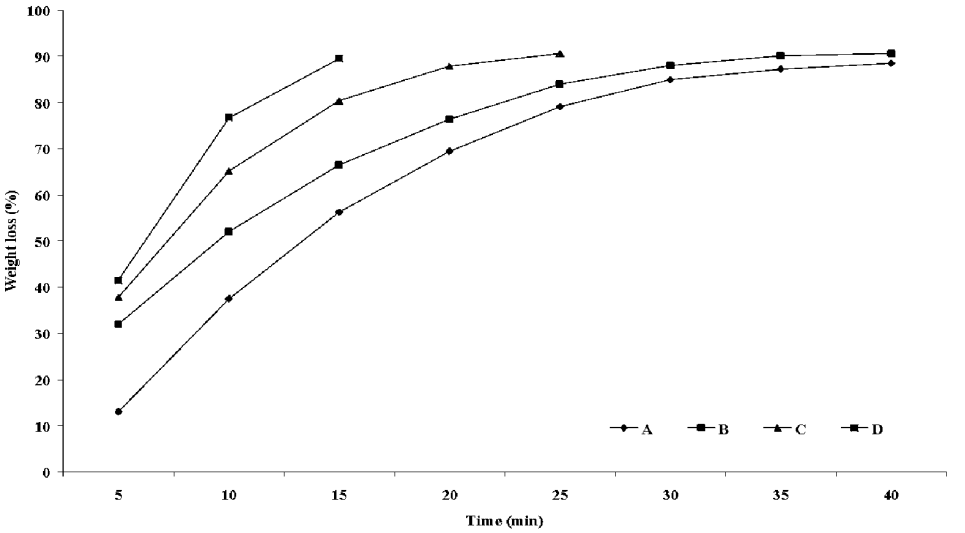

Figure 1: shows the direct influence of increasing microwave power level on the drying time and weight loss of the apple slices

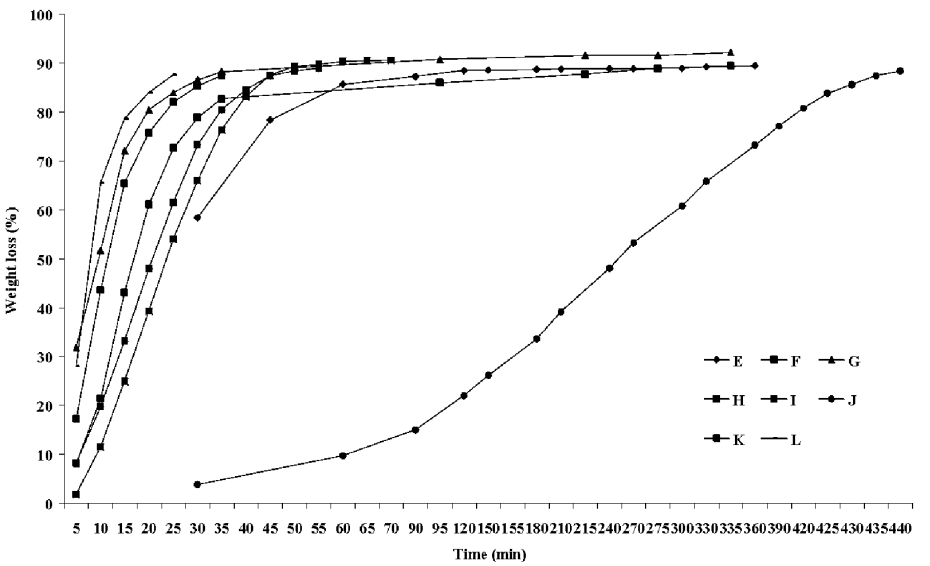

Figure 2: represents the effect of different microwave-related drying combinations on the drying time and the corresponding weight loss pattern

During the dehydration process, the sample loses water (or moisture), which is often expressed as the weight loss, because the dry matter content remains constant. Fig. 1 & 2 illustrates that the loss of water from the product i.e. weight loss (% in wb), increases with the increase in time as the dehydration process proceeds. Fig. 1 shows the direct influence of increasing microwave power level on the drying time and weight loss of the apple slices. It also explains the fact that the drying occurs at a relatively faster rate in the presence of vacuum than in the presence of air. Fig. 2 represents the effect of different microwave-related drying combinations on the drying time and the corresponding weight loss pattern.

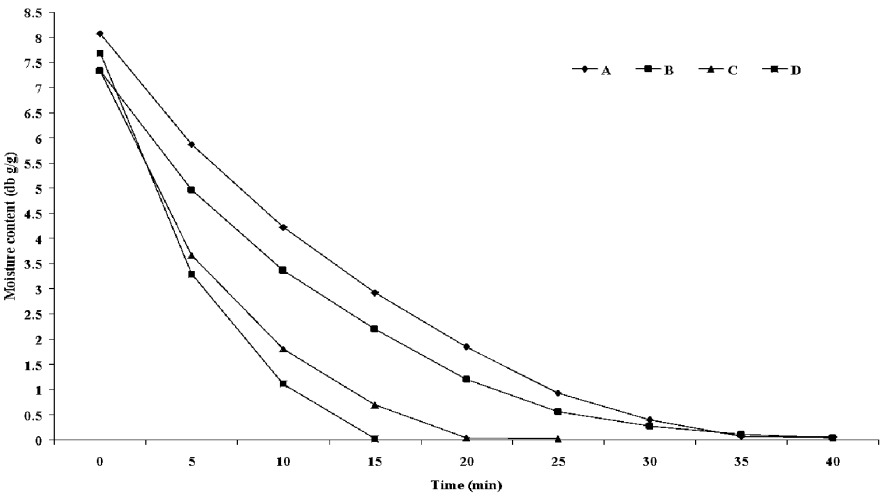

Figure 3: Illustrates the moisture-time diagram of microwave dehydrated apple slices

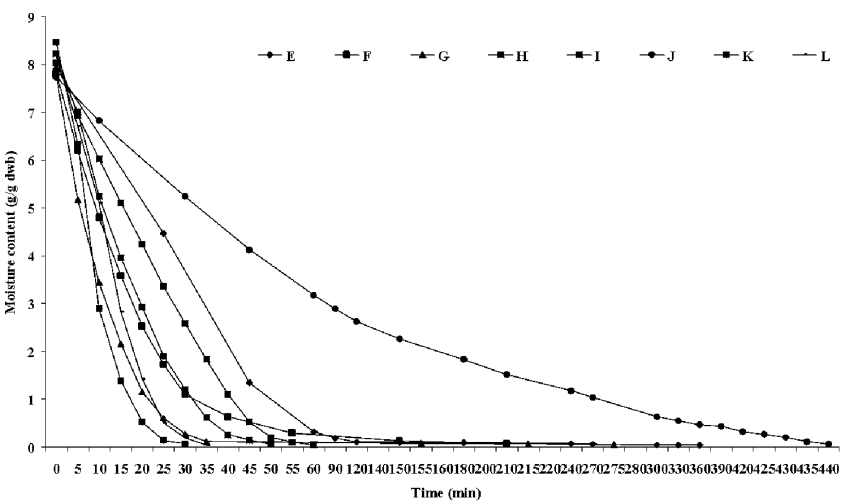

Figure 4: Illustrates the moisture-time diagram of microwave dehydrated apple slices

Fig. 3 & 4 illustrates the moisture-time diagram of microwave dehydrated apple slices. Unlike the weight loss pattern, the moisture content of the product decreases with the passage of the drying time. MW power levels and vacuum influence the drying time and moisture content. Apple slices were dried at three different power and vacuum levels, i.e. 600 W-150 mm Hg, 400 W-150 mm Hg and 200 W-150 mm Hg. It is clear from the Fig. that when a microwave power of 600 W was applied, drying took the shortest time, followed by 400 W and 200 W, respectively. When a power of 200 W was applied without vacuum, it took even longer to dry the samples to the same moisture content. When samples were dried using hot-air or freeze-dried along with microwaves, the samples lost moisture at relatively slower rates, resulting in extended drying periods.

Table 1: Values of drying ratio with for different dehydration methods

Dehydration method	*Drying ratio*
Microwave (200 W)	8.68
Microwave (200 W) + vacuum (150 mmHg)	9.171
Microwave (400 W) + vacuum (150 mmHg)	8.568
Microwave (600 W) + vacuum (150 mmHg)	9.5094
Hot air drying	9.50
Microwave (200 W) + hot air drying	9.45
Microwave (200 W) + vacuum (150 mmHg) + hot air drying	10.39
Freeze-thawing + microwave (200 W)	10.63
Freeze-thawing + microwave (200 W) + vacuum (150 mmHg)	9.02
Freeze-drying + microwave (200 W) + vacuum (150 mmHg)	9.23
CD ($p<0.05$)	0.043
CD ($p<0.01$)	0.058
SEM±	0.014
F value	**

Table 1 shows the values of the drying ratio for different dehydration methods. Drying ratio, which is the ratio of the weight entering and leaving the dryer shows a direct relation with the extent of drying. Higher values show enhanced dehydration. Although, it has no relation with the time taken in the dehydration process.

4.2. Quality Measurement

4.2.1. Physico-chemical Properties

Table 2 represents the color of dehydrated apple slices that were dried under different drying conditions using microwaves. The color values varied

Table 2: Values of color coordinates with for different dehydration methods

CIE co-ordinates	Dehydration methods										CD ($p<0.05$)	CD ($p<0.01$)	SEM±	F value
	A	B	C	D	E	F	G	H	I	J				
L*	68.175	70.420	73.974	60.518	70.912	71.427	61.795	69.435	68.082	76.662	0.099	0.134	0.034	**
A*	0.427	3.727	0.820	3.092	2.670	2.2475	2.177	2.068	1.775	-0.2300	0.035	0.048	0.012	**
B*	26.432	31.612	21.658	26.040	25.502	25.2825	23.832	26.273	26.922	22.507	0.054	0.073	0.018	**
C*	26.445	31.837	21.676	26.358	25.650	25.3825	23.932	26.356	26.980	22.507	0.115	0.156	0.039	**
H*	89.960	83.387	87.818	83.364	84.052	84.9275	84.657	85.518	86.242	90.610	0.126	0.171	0.043	**

significantly among themselves depending on the dehydration method used. All the dehydrated samples varied significantly ($p<0.01$) among themselves for L*, a*, b*, c* and h* values. The color values showed that the color of hot-air dried apple slices was almost as good as microwave-dried apple slices. Similar results were also reported by Funebo and Ohlsson (1998) for microwave assisted air dehydration of apple and mushroom. Browning and uneven heating is a problem in case of microwave dehydration. Among different dehydration methods used, freeze dried followed by microwave with vacuum sample showed the best results, comparable to the fresh sample in terms of color.

Table 3 represents the texture of dehydrated apple slices that were dried under different drying conditions using microwaves. The firmness of the samples obtained by different dehydration methods were measured in terms of their breakability along with the corresponding energies needed in the operation. The results varied significantly in terms of firmness and energy. The highest value for firmness was observed in the case of hot-air dried samples and that of energy for the samples that were hot-air dried followed by microwave without vacuum.

Table 3: Values of firmness with for different dehydration methods

Dehydration methods	*Firmness (N)*	*Energy (Ns)*
Microwave (200 W)	37.467	68.73
Microwave (200 W) + vacuum (150 mmHg)	51.427	83.5
Microwave (400 W) + vacuum (150 mmHg)	81.740	123.7
Microwave (600 W) + vacuum (150 mmHg)	13.689	8.688
Hot air drying	288.046	229.4
Microwave (200 W) + hot air drying	205.737	399.7
Microwave (200 W) + vacuum (150 mmHg) + hot air drying	156.970	154.1
Freeze-thawing + microwave (200 W)	63.250	88.43
Freeze-thawing + microwave (200 W) + vacuum (150 mmHg)	245.267	270.6
Freeze-drying + microwave (200 W) + vacuum (150 mmHg)	47.541	87.15
CD ($p<0.05$)	0.085	0.171
CD ($p<0.01$)	0.116	0.233
SEM±	0.029	0.058
F value	**	**

The overall acceptability of the dehydrated sample products were judged on the basis of combined results of all other sensory parameters namely color, texture, appearance, flavor and taste. All the samples were judged for their overall acceptability by the consumers on the sensory scale and the sample products were found to vary significantly ($p<0.01$). The freeze-dried with

Table 4: Values of sensory parameters for different dehydration methods

Sensory attributes	*Dehydration methods*										*CD (P<0.05)*	*CD (P<0.01)*	***SEM±***	***F value***
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*				
Color	7.35	8.20	7.20	7.00	7.90	7.80	8.25	7.80	8.30	8.40	0.050	0.068	0.017	**
Appearance	7.40	8.00	7.15	7.00	7.80	7.70	8.00	7.70	8.15	8.20	0.042	0.057	0.014	**
Texture	7.50	7.80	8.30	8.40	7.80	7.60	7.70	7.90	8.10	8.10	0.047	0.064	0.016	**
Aroma	7.40	7.80	7.10	7.00	7.10	7.35	7.55	7.80	8.00	8.05	0.047	0.064	0.016	**
Taste	7.30	7.75	7.20	7.00	7.25	7.35	7.50	7.75	8.00	8.10	0.053	0.072	0.018	**
Overall acceptability	7.35	7.75	7.20	7.00	7.30	7.40	7.55	7.80	8.00	8.10	0.047	0.063	0.016	**

vacuum assisted microwave finish dehydrated samples were judged the best product for their lighter color, uniform appearance, crisp texture, pleasant aroma characteristic sweeter taste. The overall acceptability of the dehydrated sample products were judged on the basis of combined results of all other sensory parameters. All the samples were judged for their overall acceptability by the consumers on the sensory scale and the sample products were found to vary significantly ($p<0.01$). The freeze-dried with vacuum assisted microwave finish dehydrated samples were judged the best product for their lighter color, uniform appearance, crisp texture, pleasant aroma characteristic sweeter taste. The microwave vacuum at high power (600 W) got the best texture as it was crisper and broken with a sound. The best aroma was sensed in case of freeze dried followed by microwave with vacuum sample. This is because freeze-drying is known to retain the flavor of volatiles and aroma components in the dried products. The samples were tested for taste on the basis of the characteristic mild sweetness of the apple fruit and absence of any sort of bitterness developed during dehydration treatment.

4.2.2. Rehydration Properties

Rehydration is an important test as far as quality of dried products is concerned and is widely used as a quality test. Rehydration is a complex process and indicates the physical and chemical changes caused by drying and treatments preceding dehydration (Lewicki, 1998; Feng and Tang, 1998). Rehydration also involves the reversal of some of the physiochemical changes that occur during drying, i.e., disruption of cellular integrity (Khraisheh *et al*., 2004).

It may be assumed that moisture movement during the rehydration process is occurring by liquid diffusion (Miller *et al*., 1968), with water transfer occurring from the rehydration liquid to the dry solid until equilibrium is reached. The rehydrability of apple samples subjected to different dehydration treatments was quantified on the basis of rehydration ratio, coefficient of rehydration, weight-gain ratio and percent water in rehydrated product. The values of the rehydration ratio, coefficient of rehydration, weight-gain ratio and percent water in rehydrated product for the dehydrated samples are given in Table 5.

The lowest rehydration ratio and highest coefficient of rehydration was observed in case of freeze dried followed by microwave with vacuum sample. The weight-gain ratio for different dehydration treatments gave the highest value for samples that were freeze dried followed by microwave with vacuum. The highest value for the percent water in rehydrated product was observed in case of freeze dried followed by microwave with vacuum sample.

Table 5: Values of rehydration characteristics with for different dehydration methods

Dehydration method	*Rehydration ratio*	*Coefficient of rehydration*	*Weight – gain ratio*	*% Water in rehydrated product*
Microwave (200 W)	0.250	4.072	3.000	75.00
Microwave (200 W) + vacuum (150 mmHg)	0.2105	4.788	3.75	78.94
Microwave (400 W) + vacuum (150 mmHg)	0.2197	4.556	3.55	78.02
Microwave (600 W) + vacuum (150 mmHg)	0.2156	4.639	3.63	78.43
Hot air drying	0.1960	5.15	4.10	80.39
Microwave (200 W) + hot air drying	0.2173	4.68	3.60	78.26
Microwave (200 W) + vacuum (150 mmHg) + hot air drying	0.1836	5.527	4.44	81.63
Freeze-thawing + microwave (200 W)	0.2020	5.013	3.95	79.79
Freeze-thawing + microwave (200 W) + vacuum (150 mmHg)	0.1916	5.264	4.22	80.83
Freeze-drying + microwave (200 W) + vacuum (150 mmHg)	0.1818	5.564	4.5	81.81
CD ($p<0.05$)	0.015	0.024	0.051	0.102
CD ($p<0.01$)	0.020	0.032	0.069	0.138
SEM±	0.005	0.008	0.017	0.035
F value	**	**	**	**

ANOVA results showed that the dehydration methods do influence the rehydration characteristics which varied significantly with the dehydration methods. Although, none of the dried samples regained the initial moisture, yet the best rehydration characteristics were observed in case of freeze dried followed by microwave with vacuum sample.

4.3. *Thermal Properties*

Water activity (a_w) is a very important thermodynamic drying parameter which plays a pivotal role in determining the shelf life of the dehydrated products. The concept of water activity has been used as a reliable assessment of the microbial growth, lipid oxidation, enzymatic and non-enzymatic activities, and texture/ mouthfeel of the food following manufacture (Rahman and Labuza, 1999). The water activity is a measure of the free water available in the system. This free water is utilized by the microorganisms for their growth and proliferation. No

microbial growth usually occurs below the a_w range of 0.4-0.5. The apple slices dehydrated using different dehydration methods, the water activity values varied over a narrow range of 0.30 to 0.35 which differ significantly ($p<0.01$).

Table 6: Values of water activity and glass transition temperature for different dehydration methods

Dehydration method	*Water activity (a_w)*	*Glass transition temperature (T_g °C)*
Microwave (200 W)	0.300	45.14
Microwave (200 W) + vacuum (150 mmHg)	0.309	24.55
Microwave (400 W) + vacuum (150 mmHg)	0.315	44.97
Microwave (600 W) + vacuum (150 mmHg)	0.323	28.87
Hot air drying	0.349	18.85
Microwave (200 W) + hot air drying	0.321	45.43
Microwave (200 W) + vacuum (150 mmHg) + hot air drying	0.314	13.11
Freeze-thawing + microwave (200 W)	0.310	23.88
Freeze-thawing + microwave (200 W) + vacuum (150 mmHg)	0.317	29.04
Freeze-drying + microwave (200 W) + vacuum (150 mmHg)	0.323	32.56
CD ($p<0.05$)	0.002	0.017
CD ($p<0.01$)	0.003	0.024
SEM±	0.0009	0.006
F value	**	**

Foods can be considered very stable at the glassy state, since below glass temperature compounds involved in deterioration reactions take many months or even years to diffuse over molecular distances and approach each other to react (Slade and Levine, 1991), due to the arrest of translational molecular motion (Rahman, 1999). The glass transition temperature is the temperature at which a second-order time-temperature-moisture dependent transition from amorphous to glassy (or crystalline) state occurs within the food. The glass transition temperature (T_g) determines the storage under maximum stability range. A DSC thermogram of sample containing no freezable water (plasticized sample is shown in the Fig. 5).

The glass transition temperature was determined from the DSC heat flow curve as shown in Table 6. ANOVA results showed a significant ($p<0.01$) variation in the T_g values. Highest value for Tg was observed in case of microwave dehydration without vacuum followed by hot air drying (45.43°C), while minimum observed in case of microwave dehydration with vacuum followed by hot air drying (13.11°C). Some workers tried to establish a direct relationship between T_g and a_w. Contreras *et al*. (2004), reported that microwave

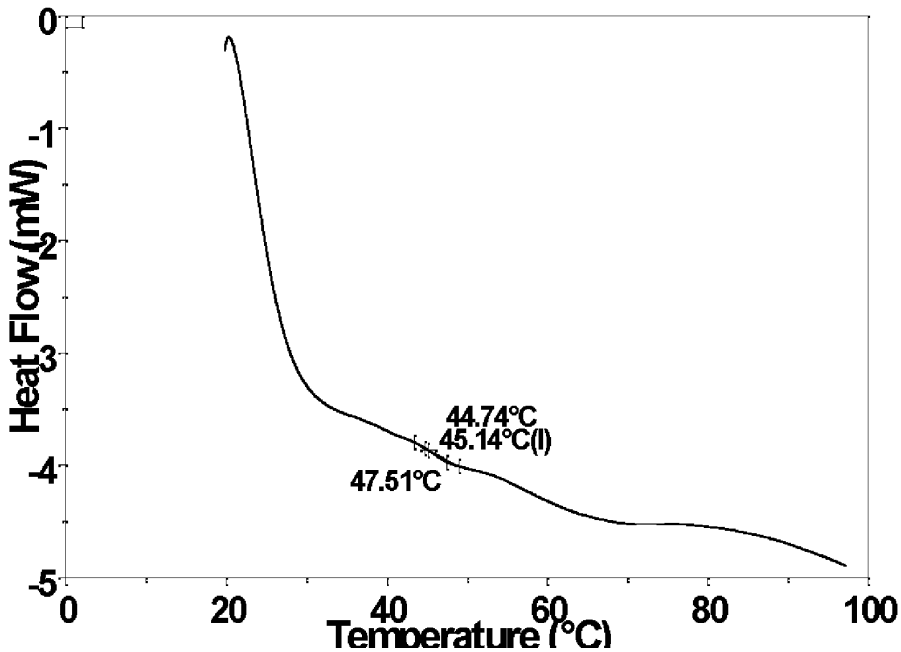

Figure 5: Represents a DSC thermogram of sample containing no freezable water

application implied a slight increase (about 2°C) of T_g in the samples in relation to a_w and soluble pectin.

5. Conclusion

MW-vacuum dehydration of apple slices was much faster than that without vacuum and the conventional hot-air drying, particularly towards the end of the drying process. Statistical analysis of the drying data showed that drying rate constant was highly influenced by MW power while system pressure had the highest influence on the rehydration characteristics of the dehydrated apple slices in a $p \leq 0.01$. MW-vacuum dried apple slices also created a more porous dehydrated product that rehydrated more quickly and more completely than the air dried products. On the basis of the investigation carried out under this project, it can be concluded that freeze-drying followed by microwave finish drying at a power level of 200 W with vacuum (150 mm Hg) produced the best quality product. Freeze-thaw microwave dehydration (at 200 W) using vacuum (150 mm Hg) also yielded good quality product comparable to freeze-dehydrated ones and therefore, vacuum assisted freeze-thaw microwave dehydration can be used as a an economical process for the preparation of apple slices, as freeze-drying technique is as such a costly process.

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