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Use of Vacuum-assisted Microwave Drying for Development of Instant Soy Paneer

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Abstract: Soy paneer is a highly nutritious dairy alternative made of soybean (*Glycine max*), having high water content (above 75%), thus, making it highly perishable and impossible to consume for longer period. Therefore, to sustain their availability in the market, dehydration is the most favorable method which increments shelf life of the product to a great extent. Dehydration process not only reduces weight and volume of the product but supports lower transportation cost, limits the food waste and increases profitability. The aim of this paper to obtain best processing conditionof soy paneer to provide a high quality product by avoiding losses and maintaining nutritional profile. A comprehensive study was carried out to examine the influence of different drying treatments; Hot air convective drying (60°C temperature, 1.5±0.1 m/s air velocity) and vacuum-microwave drying (200W, 400W, 600W microwave power, 250 mbar vacuum pressure). From the resulting data, vacuum-microwave drying proved to bea promising method where hot air convective drying deteriorated product quality in terms of color, textural property and rehydration rate as well. The best quality of the dried soy paneer was achieved at 600W microwave power with 250 mbar vacuum pressure condition in vacuum-microwave dryer. Drying kinetics data supports the fact that vacuum-microwave drying could reduce drying time of soy paneer by around 80-90%, compared to hot air convective drying. Therefore, vacuum-microwave drying can be concluded as the best method for the dehydration of soy paneer to achieve alonger shelf life with a good texture, natural color and faster rehydration rate.

Keywords: Soy paneer, Dehydration, Hot air convective drying, Vacuum-assisted microwave drying

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1. Introduction

Soy paneer also known as tofu is an Indian variety of soft cheese, traditionally made by curdling soy milk using different coagulants. It is used as a low-fat replacement for paneerwith the advantages of high protein contents with a good balance of all nine essential amino acids and better digestibility. In addition, it is also a valuable plant source of vitamin (A, C, D, E, K, and the B vitamins, such as riboflavin, thiamine, niacin, pantothenic acid, biotin, vitamin B_6, vitamin B_{12}, and folate), and minerals (calcium, phosphorus, potassium, magnesium, iron, zinc, manganese, selenium, and copper. The abundantly presence of bioactive compounds such as phenolic compounds and flavonoids and a good source of omega-3 fatty acid makes soy paneer highly beneficial for health. It has been increasingly used in numerous culinary dishes, replacing dairy products due to inexpensive and high protein bioavailability.

With a moisture content of 75–81%, soy paneer is generally categorized as a high moisture food. Due to its perishable nature, the shelf life is limited to about a day in tropical conditions (Dey *et al.* 2017). Dehydration has been considered as one of the traditional but most effective techniques for perishable commodities, facilitating transportation, storage and product diversification (Si *et al.* 2015). Drying can drastically reduce or completely remove the majority of water from the product considerably prolonging the shelf life resulting from inactivated physiological, microbial, and enzymatic degradation. This is possible because drying reduces the water activity of the product to a level that impedes microbial growth or other reactions and also reduces product mass (Wojdyło *et al.* 2014). In food processing, hot air convective drying is still one of the most extensively used method for dehydration of food products (Soysal *et al.* 2009). However, the major disadvantage associated with this method is prolonged drying time which leads to shrinkage of the productdue to tissue collapse caused by volume reduction becauseof moisture loss and inner force action (Mayor and Sereno, 2004). Moreover, during hot air convective drying, the oxidationreaction caused by hot air result in significant chemical alterations in the profile of thermo-labile bioactive compounds (Marfil *et al.* 2008). Overall, hot air convective drying leads to sensory and nutritional deterioration of agricultural products (Maskan, 2001).

Vacuum-microwave drying is a novel technique that allows overcoming the conventional drying problems having the ability to enhance the quality of the dried products (Calín-Sánchez *et al.* 2020). The reduced boiling point of water at lowvacuum pressure improves the efficiency of drying by microwave heating, leading to high quality products by inhibiting oxidation, retaining product color, acceptable texture and flavor. As microwave generates heat inside the material, highly polar water molecules of the material preferentially absorb microwave radiation, thus leads to build up an internal vapor pressure resulting in uniform heating all over the material depth.The selective adsorption of energy by water and rapid response of water to heating makes process control easier (Karimi, 2010). Vacuum-microwave drying combines the advantages of both vacuum drying and microwave drying. Vacuum drying enables drying of moist material under sub-atmospheric pressures. The typical boiling condition of the water is 100°C temperature and 1 atm pressure but at a lowered pressure of 40 mbar, the boiling temperature will also be lowered to 28.96°C (Moran and Shapiro, 1996). Unlike a direct-heat dryer, in which the product is in direct contact with the drying medium, a vacuum dryer is an indirect-heat dryer that is, the heat is transferred to the material as it contacts the dryer's heated surface, drying the material by conduction. The important feature of vacuum drying is virtual absence of air during dehydration (Karimi, 2010). The combination of fast heating of microwave and low temperature processing of vacuum has been investigated by several researchers. Vacuum-microwave drying was proved to be an alternative way to improve the quality of end products due to its low drying temperature and fast mass transfer behavior. Products like orange powder, dehydrated cranberries, potatoes, bananas, and carrots has been successfully developed using vacuum-microwave dryingtechnique (Attiyate, 1979; Yongsawatddigul and Gunasekaran, 1996; Kubota *et al.* 1992; Drouzas and Schubert, 1996; Tein *et al.* 1998).

The objective of this study is to compare vacuum-microwave dryingand hot air convective drying technique to characterize drying attributes considering the impact of drying time, vacuum pressure and microwave power, and consequently changes in physical property and quality index of the dried soy paneer. The results may provide important scientific fundamental and theoretical testimonial for developing the application technology of vacuum-microwave drying in soy-paneer processing.

2. Materials and Methods

2.1. Raw Material and Preparation of Soy Paneer

Good quality and healthy soybeans were purchased from local market of Mysore, India. The production of soy paneer consists of two main steps: 1) Soy milk preparation 2) Coagulation of soy milk to form curd which is further then pressed to form soy paneer. In this experiment Soy cow machine was used in the process of making soy paneer. Soy cow is a batch processing machine that yields high quality soymilk. 2kg of cleaned and graded soybeans were soaked in water (1:5 ratio) for 8 hours in room temperature to swell the beans. Soaked soybeans were de-hulled and washed properly before further process. The de-hulled soybeans were ground with 1:6 soybean water ratio by using grinder/cooker unit of the soy cow machine. The resulting slurry was pressure cooked at 1.1kg/ cm^2 with culinary steam and held at about 110-120 °C heating temperature for 3 min. The cooked slurry was being deodorized under a vacuum pressure of 400 mm of Hg created by a vacuum pump in the deodorizing unit to remove undesirable beany flavor from soymilk. The resulted soy slurry was collected in a filter bag situated inside the perforated cylinder of filter press unit to extract soymilk from the soy slurry. The soy slurry was compressed so that the soy milk oozes out of the filter press through the opening provided at the bottom and was collected into large container placed below the opening. After completely squeezing the soy slurry in the filter bag, the entire soy milk was collected in the container. To coagulate the soy milk 2.0% calcium chloride solution was added to the vigorously stirred freshly made hot soy milk which should be at about 80-85 °C. A holding time of 20min was given to precipitate the solids. The coagulum was transferred to a specially designed paneer press with muslin cloth and the muslin cloth was folded over the top. The press unit was covered with cover plate and tightened the screw slowly so as to ooze out the water, and then left the curd block pressed for about 30 minutes. The obtained soy paneer was dipped into cold water and stored for further processing.

2.2. Vacuum-microwave dehydration

The drying experiments were carried out using a vacuum-microwave dehydration unit developed by Energy Microwave System, Bangalore, India (Model PTF 2712). Samples were prepared before each trial run. Soy paneer was cut into cubes of 1.5x1.5x1 mm. Samples were evenly spread and placed as a single layer on the base of sample holder. The microwave radiations were passed by a magnetron at a frequency of 2450 MHz. In order to study the drying kinetics and the microwave power absorbed by the soy paneer samples, the experiments were run at a constant pressure level of 250 mbar and different microwave power (200, 400 and 600 W) with an average moisture content of 76.0% (w.b.). Moisture loss was recorded by taking out the samples and weighing on a digital balance periodically of 0.001g accuracy until moisture content of about 5.0-6.0% (wet basis) was reached. Triplicate readings were noted for each experiment and the mean value and standard error were calculated.

2.3. Hot Air Convective Drying

The dehydration experiment was performed in a cabinet drier (Kilburn, Macneill and Magor Ltd., Kolkata, India) drying was performed at 60 °C with an air velocity of 1.5±0.1 m/s. 200g of sample were placed in the drier and in every 30 min weight loss was recorded and moisture content was determined based on wt/wt of solids (dry wt. basis).

2.4. Moisture Content

The moisture content of soy paneer was determined according to the AOAC method (AOAC, 2000). A digital balance (accuracy ± 0.001 g) was kept beside the oven to minimize reading time. The drying process was continued until the readings were constant. All drying trials were repeated three times and average of the same has been reported.

2.5. Color Measurement

The L*(lightness/darkness), a* (redness/greenness), b* (yellowness/blueness) values of the sample was measured using D-65 illuminant and 100 observer using a color meter (MiniScan XE Plus, Model No. 45/0-S, Hunter Associates Laboratory, Inc., Reston, VA, USA). For reference, standard white and black tiles were used. All readings were taken in triplicates for each sample and mean values were used for data analysis.

2.6. Rehydration Characteristics

Rehydration characteristics for the vacuum-microwave and Hot air hot air convective driedsoy paneer samples carried out in triplicate, by immersing 5g sample in boiling water for 3min according to the method (Ranganna, 1999). Then the samples were removed from the water and surface moisture was removed by gently wiping it off with a tissue paper and weighed. Dehydrated soy paneer was evaluated for rehydration characteristics from the weight of sample before and after the rehydration.

Rehydration ratio = Wr / Wd

Where,

Wr = Weight of rehydrated sample (g)

Wd = Weight of dried sample (g)

2.7. Bulk Density

Bulk density was determined as per the equation given below which is the weight of dehydrated sample by its respective volume and is reported as g/cc by using the method as described (Ranganna, 1999).

Bulk density = W_1/W_2

Where,

W_1 = Weight of dehydrated sample

W_2 = Volume of the dehydrated sample (measured using graduated cylinder)

2.8. Texture Analysis

A texture analyzer (TAHDi, Stable Micro Systems Ltd. London, UK) with a 25 kg load cell was used to perform texture profile analysis and computer supported software (Texture Expert, Version 1.22, Stable Micro Systems Ltd. London, UK) was used for the data calculation. The samples were compressed to 75.0% of their original height by two consecutive compressions using a flat plate or a cylindrical probe having dimensions greater than the sample dimensions. The crosshead speed was maintained at 1.00 mm/s. The waiting time between the two-cycles of the TPA tests was 5 sec. The texture analyzer was calibrated for force and height every time before the TPA tests. After completion of second compression cycle by the probe, care was taken to ensure that the sample separated from the probebefore its return to initial position. The mean values of triplicate data were considered for final data analysis.

2.9. Sensory Acceptability

The dehydrated soy paneersamples were evaluatedfor sensory acceptability as in fresh condition and after dehydration as well as after rehydration. The sensory was consisted of 15 trained panelistsfor judging overall sensory acceptability based on visual appearance, color, texture and taste of the samples on a 9-point hedonic scale; 9 indicating highly acceptable and 1 as least acceptable (Lawless and Heymann, 1998).

2.10. Statistical Analysis

All data were reported as mean ± standard deviation of three replicates. The data were analyzed statistically using analysis of variance (ANOVA) technique to determine significant differences among various treatments at $P<0.05$ significance level using Statistica 7 software (Stat Soft, Tulsa, OK, USA).

3. Result and Discussion

3.1. Drying kinetics

Fig. 1 (a, b) yields the drying curves of moisture content against drying time of soy paneer samples under different drying conditions. It is perceptible that moisture content and drying rate both has decreased continuously with the drying time. In any drying process, temperature and speed of vaporization depend on the water vapor concentration in the atmosphere (Lewicki, 2006). During hot air convective drying, heat is transferred through a drying agent consists mainly of hot air that simultaneously provides the energy necessary for water evaporation and eventually evacuates water vapor out of the dryer. However, it has adverse effects on final product quality which leads to color change, protein denaturisation, case hardening and poor rehydration quality due to conductive heat transfer and restricted to air convection. While in vacuum-microwave drying electromagnetic waves is absorbed by water dipoles located inside the processed material creates high pressure in the center of the dried material and allows for a rapid transport of moisture to the vacuum preventing the material structure collapse (Lin *et al.* 1998). Due to high internal pressure soy paneer samples shows noticeable physical properties alteration leading to expansion and puffing texture.

In this experiment vacuum-microwave drying was much faster than hot air convective drying. In the hot air convective drying process, drying rate decreased along with decrease in moisture content of soy paneer samples and drying air temperature, which might be attributed to slower moisture migration rate from interior to surface and evaporation rate from surface to air caused by decreased sample moistures (Hu *et al.* 2006). At 60°C drying temperature samples took 420 minutes to be dried in hot air convective drier.However, even at 60°C temperature samples are resulted in degradation of material quality due to longer exposure in heated air. On the contrary, vacuum-microwave drying investigated as a potential method for obtaining high quality dried soy paneer. A constant pressure of 250 mbar vacuum was used with different microwave power (200W, 400W, 600W) conditions to dehydrate soy paneer samples. It can be seen from the experiment that higher the microwave power density is, faster the drying rate is. To reduce initial moisture content of soy paneer samples from around 85.0% to about 5.0% under microwave drying conditions at the highest power 4min drying time required while for intermediate and low power level 7min and 15min drying time was required. Based on a report by Cui *et al.* (2006), microwave power and vacuum pressure affects the drying rate and for constant vacuum pressure, the drying rate was found to be the first order of microwave power output. Wang *et al.* (2007) reported in a microwave drying kinetics study, that almost all of the drying of biological materials takes place in the falling rate period. As shown in the Fig. 1(a,b), the falling rate period mostly observed in both of the techniques dried soy paneer samples.

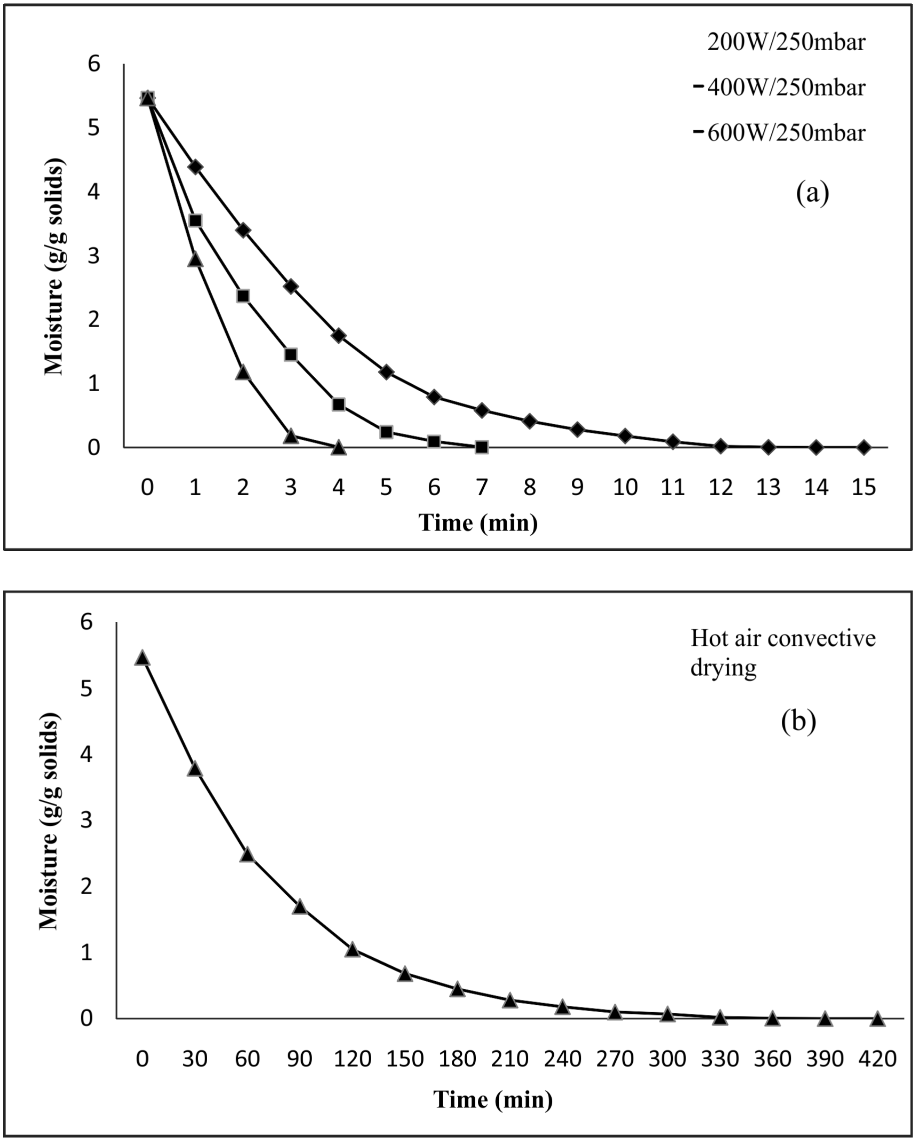

Figure 1: Dehydration curve for soy paneer under different drying conditions, (a) at 250mbar vacuum with variable microwave power (200W, 400W and 600W), (b) hot air convective drying at 60 °C

The drying curve begins with a warm-up period, the drying rate increases to a peak rate that is maintained for a period of time known as the constant drying rate period (Antal, 2015). The moisture content of the material eventually declines to a critical moisture content, at which point the rapid evaporation can no longer be maintained. This is the start of the phase of falling drying rate (Haghi, 2001).

The bulk density was found to be maximum (0.72 g/cc) in the sample dehydrated under hot air convective drying condition, whereas, minimum (0.53 g/cc) bulk density was recorded in the sample dehydrated at 600 W microwave power and 250 mbar vacuum (Table 1). Longer drying time resulted in increased bulk density, which can be explained by the fact that a prolonged drying period encourages shrinkage in a drying material.

Table 1: Drying characteristics of dehydrated soy paneer

Microwave Power (W)	*Vacuum (m bar)*	*Bulk density (g/cc)*	*Rehydration ratio*	*Drying time*
200	250	0.62 ± 0.08^{b}	2.5 ± 0.03^{c}	15 min
400	250	0.59 ± 0.04^{b}	2.7 ± 0.02^{b}	7 min
600	250	0.53 ± 0.05^{c}	3.0 ± 0.02^{a}	4min
Hot air drying	-	0.72 ± 0.08^{a}	2.0 ± 0.01^{d}	7 hours

* Values with different superscripts in same column differ significantly ($p<0.05$)

3.2. *Rehydration Characteristics*

The rehydration capacity can be influenced by the drying process. It is an important quality parameter for dried products as its complex procedure indicates the chemical and physical changes caused by drying treatments (Feng and Tang, 1998; Lewicki, 1998). During the rehydration process, the cell wallof the material becomes soften by absorbing water and then reverts to its original shape by drawing water into the inner cavities due to the innate elasticity of the cellular structure (Gane and Wager, 1958). The rehydration ratio of soy paneer dehydrated by vacuum-microwave drier was found to be significantly ($P<0.05$) different from hot air convective dried soy paneer samples (Table 1). Lower rehydration values indicate product shrinkage which is characterized by a hard texture induced by prolonged drying which results in irreversible physico-chemical changes promoting higher bulk density. Generation of vacuum during microwave dehydration enhanced the puffiness of the dehydrated cubes resulting in a lighter product with a low bulk density (Chauhan *et al.* 2015).

3.3. Color Analysis

Table 2 shows the color differences between fresh, dehydrated and rehydrated soy paneer samples. The L* values of fresh, hot air dehydrated and vacuum-microwave dehydrated soy paneer samples indicates hot air dried soy paneer samples significantly ($P<0.05$) darker in color compared to vacuum microwave dried at high and medium microwave powers. This may be due to prolonged drying time and presence of oxygen. Studies showed that the increase in microwave power level has increased the L* values which indicating higher microwave power yielded lighter color in the dehydrated samples. In the case of b* coordinate, the values of rehydrated soy paneer samples became increasing which means color became more yellowish as compared to fresh and hot air dried soy paneer samples. The lower b* value in hot air dehydrated samples was primarily due to the combined effect of oxygen and temperature which in turn have enhanced the formation of Maillard reaction triggering with the result of a lower color in hot air dehydrated samples (Chauhan *et al.* 2015). Similar results have also been reported by (Maskan, 2000) in the case of banana slices where the b* values were also found to be higher in the samples dehydrated under vacuum assisted microwave conditions. The higher

Table 2: CIE color values of soy paneer at different conditions

Sample	*Microwave Power (W)*	*L**	*a**	*b**
Fresh	-	62.38 ± 1.04^{a}	1.14 ± 1.3^{a}	7.45 ± 1.11^{a}
Dehydrated samples				
Hot air	-	25.10 ± 1.15^{h}	11.12 ± 1.56^{b}	14.78 ± 1.23^{b}
Vacuum-microwave	200	38.26 ± 1.20^{f}	15.03 ± 1.07^{e}	30.12 ± 1.60^{d}
	400	46.57 ± 1.17^{d}	16.57 ± 1.10^{f}	42.59 ± 1.21^{f}
	600	55.42 ± 1.08^{b}	16.12 ± 1.48^{f}	47.50 ± 0.80^{h}
Rehydrated samples				
Hot air	-	15.23 ± 1.62^{i}	17.36 ± 1.55^{g}	26.04 ± 1.14^{c}
Vacuum-microwave	200	32.79 ± 1.06^{g}	14.72 ± 1.50^{d}	36.56 ± 1.27^{e}
	400	40.70 ± 1.26^{e}	13.07 ± 1.28^{c}	44.27 ± 0.79^{g}
	600	51.17 ± 1.13^{c}	11.97 ± 0.64^{b}	48.45 ± 0.85^{i}

*Values with different superscripts in same column differ significantly ($p<0.05$)

values of a* chromaticity coordinate of hot air dried samples indicates more red hue compared to vacuum-microwave dried samples. Microwave drying at 600W microwave power under 250 mbar vacuum pressure resulted in a better appearance compared to other experimented drying treatments, which clearly indicates that to maintain color quality in soy paneer, the exposure period must be for a short time span during the drying process.

3.4. Textural Characteristics

Texture is a mechanical property of a material. The textural profile analysis of textural properties includes hardness, cohesiveness, adhesiveness, springiness and chewiness for the rehydrated samples using a compression plate probe. Peak hardness and fracturability were calculated (Table 3) from the curves obtained from textural analysis of dehydrated samples. Hot air convective dried samples showed significantly ($P<0.05$) higher hardness and fracturabilityvalues as compared to vacuum-microwavedehydrated one indicating harder nature of the product. Hot air convective dehydration caused shrinkage of the soy paneer samples leading to case hardening effect that implies a harder external layer surrounded the surface of the samples. Minimum hardness was recorded in the samples dehydrated at 600 W with 250 mbar vacuum pressure. Inclusion of vacuum during microwave dehydration further facilitated the generation of porous structure which ultimately leading to puffed and crisp texture. (Contreras *et al.* 2005) stated in a reportthat degree of porosity ultimately affects the rehydration of dried products which was less in the case of hot air dried paneer samples leading to less rehydration ratio resulting in harder product even after rehydration. Texture profile analysis of reconstituted soy paneer (table 4) revealed significantly ($P<0.05$) lower hardness (157.88g), springiness (1.56s), cohesiveness (0.65), gumminess (102.62g) and chewiness (160.08g.s) in the sample dehydrated at 600W microwave power. The hot air dehydrated sample showed maximum springiness (2.21), chewiness (301.48g.s) values after rehydration while cohesiveness was found to be maximum in the samples

Table 3: Hardness and fracturability of dehydrated soy paneer

Microwave Power (W)	*Vacuum (mbar)*	*Hardness (g)*	*Fracturability (g)*
200	250	719.98±0.17^{c}	36.98±0.11^{c}
400	250	662.70±0.07^{b}	34.95±0.16^{b}
600	250	561.78±0.13^{a}	28.66±0.09^{a}
Hot air drying	-	849.78±0.21^{d}	40.31±0.10^{d}

* Values with different superscripts in same column differ significantly (p<0.05)

dehydrated at 600 W and 250 mbar vacuum. The mechanical response of dried samples is the result of behavior of cellular matrix and soluble solid phase inside the tissue having different interactions with water (Chauhan *et al.* 2015). Depending on the water content, changes in cell walls as well as water soluble fractions cause differences in mechanical behavior of the tissue.

3.5. Sensory Evaluation

Sensory evaluation is important to assess the consumer's requirements. It is difficult to classify 100% by machine because it is a subjective factor. Sensory evaluation was assessed by a panel of 14 member based on visual quality acceptability as well as mouth feel and overall acceptability. The score ranged from 1to 9 hedonic scale which represented from "Like extremely" to "Dislike extremely". Table 5 clearly shows that the vacuum-microwave dehydrated samples had been given significantly (P<0.05) higher sensory scores as compared to hot air dehydrated samples. The maximum scores being in the case of samples dehydrated at 600 W and 250 mbar vacuum. After rehydration also the same samples showed highest sensory scores. The vacuum-microwave dehydrated samples showed faster absorption of water during rehydration due to theporosity and puffiness as compared to hot air dehydrated paneer samples which took more time for rehydration due to case hardening and shrinkage in

Table 4: Texture profile analysis of reconstituted soy paneer

Microwave Power (W)	*Vacuum (mbar)*	*Hardness (g)*	*Springiness (s)*	*Cohesiveness*	*Gumminess (g)*	*Chewiness (g.s)*
200	250	195.30±0.11^{b}	1.87±0.02^{b}	0.63±0.05^{a}	123.03±0.17^{b}	230.06±0.04^{b}
400	250	178.70±0.03^{c}	1.70±0.14^{c}	0.64±0.10^{a}	114.36±0.09^{c}	194.41±0.02^{c}
600	250	157.88±0.02^{d}	1.56±0.06^{d}	0.65±0.01^{a}	102.62±0.05^{d}	160.08±0.10^{d}
Hot air drying	-	213.17±0.13^{a}	2.21±0.02^{a}	0.64±0.08^{a}	136.42±0.11^{a}	301.48±0.08^{a}

* Values with different superscripts in same column differ significantly (p<0.05)

Table 5: Sensory evaluation of rehydrated soy paneer

Sample	*Color*	*Aroma*	*Taste*	*Texture*	*Overall acceptability*
200W	5.30±1.42^{b}	5.50±1.23^{b}	6.01±0.22^{b}	6.15±1.13^{b}	5.70±1.01^{b}
400W	6.25±1.23^{c}	5.89±1.20^{b}	6.89±1.78^{c}	6.58±1.33^{c}	6.54±1.13^{c}
600W	7.80±1.51^{d}	7.56±1.45^{c}	7.77±1.85^{d}	7.90±1.37^{d}	7.60±1.15^{d}
Hot air	4.00±1.1^{a}	4.12±1.09^{a}	4.99±1.40^{a}	4.23±1.21^{a}	4.55±1.09^{a}

* Values with different superscripts in same column differ significantly (p<0.05)

the product. Lin *et al.* (1998) reported that vacuum- microwave dried carrot slices received higher ratings for sensory properties such as texture, odor and overall acceptability as compared to air dried carrot slices. It has been reported that microwave dehydrated red peppers which was attributed to faster drying under microwave dehydration conditions had better sensory characteristics in terms of visual appearance, colour, texture and overall acceptability (Soysal *et al.* 2009).

4. Conclusion

Recent studies emphasizing on dehydration of agricultural products using vacuum-microwave technology revealed that combination drying technique can be the most promising method to ensure high quality product with lowest possible energy consumption. A shorter processing time at low drying temperature and restricted interaction of the product with oxygen was found to be more effective in maintaining desired quality characteristics of dried soy paneer. Therefore, it can be concluded that vacuum–microwave drying is better than hot air convective drying as high microwave power output at the beginning of the drying processdoes not lead to a high temperature because relatively large amounts of evaporating water require lots of energy and the total drying time is reduced as well. Drying kinetics vs moisture content relations were studied for comparison of hot air convection and vacuum-microwave drying of soy paneer. Drying took place mostly at falling rate period after a short heating period. Based on our experimental study, vacuum-microwave treated soy paneer samplesmaintain superior quality of color and textural integrity. In addition, due to porous characteristics vacuum-dried soy paneer consist crispy and puffy texture. The greater the vacuum and microwave power, the greater the rehydration ratio; rehydration ratio deteriorates if the products are excessively dried and has more shrinkage. Therefore, vacuum-microwave dried soy paneer are aimed to provide excellent health-promoting properties and attractive sensory attributes.

References

AOAC. 2000. Official methods of analysis of AOAC (17thed.). Gaithersburg, MD, USA Association of Analytical Communities.

Antal T. 2015. Comparative study of three drying methods: freeze, hot air assisted freeze and infrared-assisted freeze modes. Agronomy Research, 13, 863–878.

Attiyate Y. 1979. Microwave vacuum drying: First industrial application. Journal of Food Engineering, 51, 78-79.

Calín-Sánchez A, Lipan L, Cano-Lamadrid M, Kharaghani A, MasztalerzK,Carbonell-Barrachina AA and Figiel A. 2020. Comparison of traditional and novel drying techniques and its effect on quality of fruits, vegetables and aromatic Herbs. Foods, 9, 1261.

Chauhan OP, Bhawya D, Kumar M, Roopa N and Raju PS. 2015. Effect of variable microwave power and vacuum levels during dehydration on the quality attributes of potato cubes. American Journal of Advanced Food Science and Technology, 3, 53-66.

Contreras C, Martin ME, Martinez-Navarrete N and Chiralt A. 2005. Effect of vacuum impregnation and microwave application on structural changes which occurred during air-drying of apple. LWT Food Science and Technology, 38, 471-477.

Cui Z, Xu S, Sun D and Chen W. 2006. Dehydration of concentrated ganodermalucidum extraction by combined microwave-vacuum and conventional vacuum drying. Drying Technology, 24, 595-599.

Dey A, Prasad R, Kaur S, Singh J and Luwang MD. 2017. Tofu: technological and nutritional potential. Indian Food Industry Mag, 36, 8-24.

Drouzas AE and Schubert H. 1996. Microwave application in vacuum drying of fruits. Journal Food Engineering, 28, 203-209.

Feng H and Tang J. 2006. Microwave finish drying of diced apples in a spouted bed. Journal of Food Science, 63, 679-683.

Gane R and Wager HG. 1958. Plant structure and dehydration. Paper presented in Conference on Fundamentals Aspects of Dehydration in Food Stuffs. Society of Chemical Industry, 25-27 Mar, 1958, p 3-7.

Haghi AK. 2001. Experimental investigations on drying of porous media using infrared radiation. ActaPolytechnica, 41, 55–57.

Hu Q, Zhang M, Mujumdar AS, Xiao G and Sun J. 2006. Drying of edamames by hot air and vacuum microwave combination. Journal of Food Engineering, 77, 977-982.

Karimi F. 2010. Properties of the drying of agricultural products in microwave vacuum: A review article. Journal of Agricultural Technology, 6, 269-287.

Kubota K, Omae C, Heng JD and Hagura Y. 1992. Studies on microwave vacuum drying phenomena and models of potato. Journal Hiroshima Daigaku Seibutsu Seisan Gakubu Kiyo, 31, 37-43.

Lawless, H.T. and Heymann, H. (1998). Sensory Evaluation of Food, Principles and Practices. Springer, New York. 827p. ISBN- 083421752X 9780834217522

Lewicki PP. 1998. Some remarks on rehydration of dried foods. Journal of Food Engineering, 36, 81-87.

Lewicki PP. 2006. Design of hot air drying for better foods. Trends in Food Science & Technology, 17, 153–163.

Li ML, Durance TD and Scaman HS. 1998. Characterisation of vacuum microwave air and freeze dried carrot slices. Food Research International, 31, 111-117.

Marfil PHM, Santos EM and Telis VRN. 2008. Ascorbic acid degradation kinetics in tomatoes at different drying conditions. LWT Food Science and Technology, 41, 1642–1647.

Maskan M. 2000. Microwave/air and microwave finish drying of banana. Journal of Food Engineering, 48, 169-175.

Maskan M. 2001. Kinetics of colour change of kiwifruits during hot air and microwave drying. Journal of Food Engineering, 48, 169–175.

Mayor L and Sereno, AM. 2004. Modelling shrinkage during convective drying of food materials: a review. Journal of Food Engineering, 61, 373–386.

Moran MJ and Shapiro HN. 1996. Fundamentals of engineering thermodynamics (3rd edition). John Wiley and Sons Inc., New York. 859 p. ISBN-10: 0471076813.

Ranganna, S. 1999. Handbook of Analysis and quality control for Fruits and Vegetables Product (2nd ed.). Tata McGraw-Hill Publishing Company Limited, New Delhi. 1112 p. ISBN-0074518518 9780074518519

Si X,Chen Q,Bi J, Wu X, Yi J, Zhou L and Li Z. 2015. Comparison of different drying methods on the physical properties, bioactive compounds and antioxidant activity of raspberry powders. Journal of the Science of Food and Agriculture, 96, 2055-2062.

Soysal Y, Ayhan Z, Esturk O and Arıkan MF. 2009. Intermittent microwave-convective drying of red pepper: Drying kinetics, physical (colour and texture) and sensory quality. Biosystems Engineering, 103, 455–463.

Tein ML, Timothy DD and Christine HS. 1998. Characterization of vacuum microwave, air and freeze dried carrot slices. Journal of Food Research International, 31, 111-117.

Wang Z, Sun J, Chen F, Liao X and Hu X. 2007. Mathematical modelling on thin layer microwave drying of apple pomace with and without hot air pre-drying. Journal of Food Engineering, 80, 536-544.

Wojdyło A, Figiel A, Lech K, Nowicka P and Oszmiański J. 2014. Effect of convective and vacuum–microwave drying on the bioactive compounds, color, and antioxidant capacity of sour cherries. Food Bioprocess Technology, 7, 829–841.

Yongsawatddigul J and Gunasekaran S. 1996. Microwave vacuum-drying of cranberries: Part I: Energy use and efficiency. Part II: Quality evaluation. Journal of Food Processing and Preservation, 20, 121-156.