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Application of microwave-assisted vacuum frying on frying apple slices

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Abstract

Microwave combined with vacuum frying (MVF) of apple slices was studied experimentally. Apple slices were fried using MVF and Vacuum frying (VF) technologies, and three microwaves (MW) power levels (800, 900 and 1000 W) were used for frying up to 14 min. The effect of frying time and MW power on moisture content, oil uptake, textural crispness and color parameters was measured and analyzed. The MW power significantly increased the moisture evaporation rate, reduced the oil uptake, increased the hardness and produced more desirable yellow color compared to VF. With increasing the MW power, the moisture evaporation rates increased significantly and at the same time MVF reduced the oil uptake compared with VF. The crispiness and yellowish color of the apple slices increased with increasing MW power and frying time respectively. Results revealed that the MW application is one of the foremost determinants that induce the quality frying of apple slices and improve the frying rate. Therefore, MVF is a helpful and promising method to intensify the frying process.

Keywords: Apple, microwave, vacuum frying, oil uptake, texture, color.

Introduction

Apples constitute a major global source of fruit, with an estimated world production in 2017/2018 of 76.2 million tons[1]. China produces 35 million ton of apple per year, of which 70% of apple were used for direct consumption, and other 30% were processed for jam, juice, and other dehydrated products[2].According to several investigations, producers have been losing 30% to 40% of their fresh fruits and vegetables before they reach to the ultimate consumer[3]. Improper processing and preservation procedures can induce damage to fruits and vegetables. During the past several years, dehydration becomes an excellent method to preserve fruits and vegetables by not only keeping nutrients but also evading quality deterioration[4].Heating methods are frequently utilized for the processing and preservation of food product[5].Frying is regarded as traditional methods to preserve fruits and vegetables with low-fat content including beautiful texture and flavor qualities. The production of crunchy snacks with low oil content and essential fiber content are assumed to be highly acceptable to customers.

Among several kinds of dehydration method, a favorite method for snack food processing is vacuum frying[6]. VF is very popular in food industry for making low oil contentfried products, keeping nutritional quality of the fried products, and reducing oil deterioration[7].VF is a kind of deep-fat frying method, where food is fried in a closed-door system under atmospheric pressures, consequently lowering the boiling point of water and decrease the frying temperature considerably[8]. Frying at low temperatures and minimal exposure to oxygen are the main characteristics of VF and which helps to preserve natural color and flavor, reduce oil uptake, and prevents to generate toxic compound[9]. It also helps to reduce acrylamide content and preserve the nutritional compounds[10].

Microwave (MW) heating is a new technology and the combination MW with VF is promising in food industry. Microwave-assisted vacuum frying (MVF) process can be used to produce more desirable fried products with crispy texture and more healthy products. MVF is also considered as an effective and ideal method of frying as compared to atmospheric frying method due to the shorter time and the lower temperature of processing[11]. MWs are electromagnetic waves and frequency varies from 300 MHz to 300 GHz. Household MW appliances operate at a frequency of 2.45 GHz, while industrial MW systems perform at frequencies of 915 MHz and 2.45 GHz[12]. MW heating of food materials primarily occurs due to dipolar and ionic mechanisms[13].

When a food materials place in the oscillating electric field, the permanent dipoles of the material tend to realign in the direction of the electric field Because of the high-frequency electric field, this change happens at million times per second and creates inner friction of molecules, which is responsible for the volumetric heating of the substance[12]. Dipolar rotation and ionic conduction generally control MW heating method. During ionic conduction, charged particles would undergo an alternating force, and MW frequency will accelerate the particle in one direction to another, and this accelerated particle strikes with a nearby particle set it into more agitated motion, and heat is produced[14]. Dipolar rotation mechanism is the fundamental principle of MW heating and affects the heat of electrically insulating elements by a dielectric. Compare to the traditional frying methods; MVF can affect the higher temperature inside the product than on its surface. Further benefits of MVF are its ease of operation, low maintenance cost, and immediate heating[15]. MVF has already been the theme of many researches, and numerous studies have focused on the interest which exists in applying MVF for industrial purposes. However, its industrial application is still limited.

Experts in the field have focused a great deal on developing a low-fat fried product that presents the desired quality attributes. MVF technique may be an alternative option to produce novel quality snacks that offer the desired quality attributes and correspond with new health trends. The objective of this research work was to investigate the impact of VF technology that combines with MW on quality parameters (moisture removal, oil uptake, textural crispiness, and color) of apple slices and compares the impact mentioned above with that of vacuum frying technology.

Materials and methods

Sample preparation: Apples and soybean oil were obtained from Wuxi, China. Apples were washed, peeled, and sliced (2±0.2 mm). The apple slices were dipped in citric acid solution (5%, w/w) for 5 s then blanched at 90°C for 1 min, and then cooled below running tap water for 5 min, followed by wiping out the surface water till the surface was nearly dry.

Microwave-assisted vacuum frying instrument: A schematic diagram of the MVF equipment (Aorun Microwave Industry Company Limited, Nanjing, China) is shown in the diagram in Figure-1 (provided by the manufacturer). It consists of oil tank, vacuum frying chamber, condenser, vacuum pump, microwave heating system, vacuum pressure gauze system and circulation pump. A centrifugation system was also assembled in this fryer to remove the excess oil from the surface. The oil holding capacity of the instrument was 15 L.

Three microwave devices are attached to the vacuum chamber and served as heating elements. The maximum power output of each microwave device is 1200W (2450MHz). The maximum attainable temperature and vacuum absolute pressure of the chamber is 150°Cand 0.001 MPa, respectively.

Frying methods: Flowchart for the production of fried apple slices is shown in Figure-2. Apple slices were fried using a microwave-assisted vacuum fryer at three power levels, 800W, 900W and 1000W respectively. In both VF and MVF process, an absolute vacuum pressure of .01 MPa and a temperature of 95^0C we used.

The frying times were 4, 6, 8,10, 12, and 14 min. Each frying experiment was conducted in triplite by using 50 gm slices of apples for each frying time. Frying time was estimated with a chronometer (877-GYM-BOSS, St. Clair, USA). At the completion of the preset frying time, the slices were taken out of the fryer and the oil adsorbed on the surface was removed using the adsorbent paper.

The slices were cooled at an ambient temperature placing on the absorbent paper. The fried apple slices stored in a sealed plastic bag for further tests.

Measurement and analysis of quality parameters: Moisture Content: The moisture content of the apple slices was determined by using an oven method[16]. 5g of fried apple slices were dried in an oven at 102±1°C. These experiments were conducted in triplicate.

Oil content: The oil content was estimated by Soxhlet extraction method using petroleum as the solvent[16]. Oven dried (Section 2.4.1) and ground samples were used to extract the oil content, and the extraction process was carried out for 8 hours. Then, the dehydrated samples were moved to a thimble, and then oil was extracted gravimetrically.

The flask holding oil was dried to constant mass in a vacuum dryer-controlled temperature at 55°C. The oil content in the fried apple slices was represented as g oil/100 g dry mass. These tests were conducted in triplicate.

Color parameters: The color parameters (L*, a*, b*) of the fried apple slices were estimated by a Hunter Lab Colorimeter (Shanghai Medical Appliance Factory, Shanghai, China). The apparatus was calibrated with white and black ceramic plates. The samples were illuminated with the standard light of the instrument and the L*, a*, and b* values were recorded. The L*, a*, and b*values of the raw apple slices were L*0(70.94 ± 0.13), a*0 $\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$, respectively. The samples were examined at three different spots and the average values of the measurements are reported.

Finally, the total color difference (ΔE) between the raw apple slices (L^*_0 a^*_0 b^*_0) and fried apple slices (L*,a*,b*) was calculated by using equation (1) given below. (1)

Texture hardness: A texture analyzer (TA-XT2i, Surrey, UK) was utilized to measure the textural property of the fried slices. The apple slices were placed on the testing platform of the TA-XT2i and compressed (50%) using a stainless steel spherical (6.35mm diameter) probe (P/0.25 s). The pre-speed, test-speed, and post-speed of the probe were 2.0, 5.0, and 2.0 mm/s, respectively and trigger force was 20 g. The experiment was carried out five times and an average value are reported.

Statistical analysis: Statistical analysis was undertaken by the SPSS software package 20.0 (Chicago, Illinoi, USA). Evaluation of variance (ANOVA) between means was analyzed by Duncan's multiple using a one-way analysis of variance. Significance difference between any two mean values was determined at 95% confidence level ($P < 0.05$).

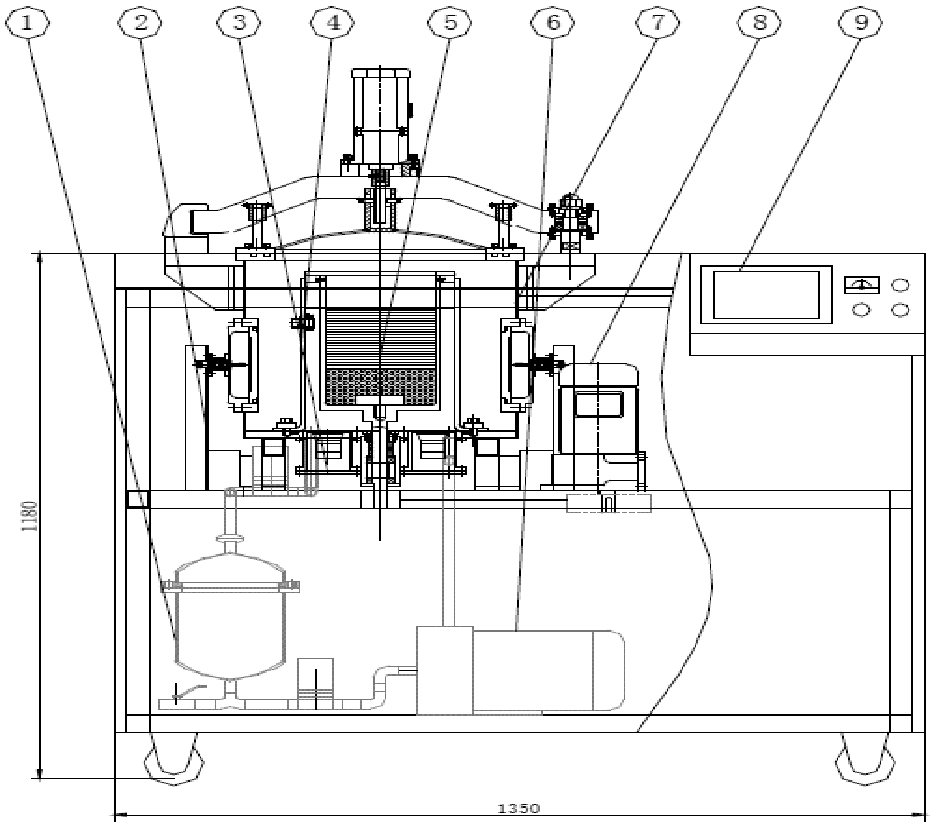

Figure-1: Schematic diagram of microwave-assisted vacuum frying instrument.1. Oil tank; 2. Microwave source and heating system; 3. Vacuum pressure gauze system; 4. Vacuum chamber; 5. Frying chamber; 6. Circulation pump; 7. Electric cabin door system; 8. Centrifugation system; 9. Controller and operation panel.

Selection of Apple
↓
Washing
↓
Core removing and slicing (2±0.2 mm)
↓
Blanching (1min,90 ^{0}C)
↓
Cooling
↓
Immersed in citric acid (5%w/w, 5s)
↓
Wiping out the surface water
↓
Frying at different process conditions
↓
Cooling
↓
Packaging (Nitrogen packing in gas barrier plastic bags)
↓
Quality evaluation
(Moisture content, Oil uptake, Texture, Color)

Figure-2: Flowchart for the production of microwave-assisted vacuum frying apple slices.

Results and discussion

Moisture content: During the frying process, when food is heated, moisture evaporates very swiftly from the surface of the frying food, which forms a moisture gradient between the surface and inside portion of the frying products[17]. As the evaporation process continues, the areas from which moisture was evaporated, it is converted to a dry area and lost their hydrophilicity[18]. In MVF condition, food is fried at lower frying temperature due to the provision of low absolute pressure (or high vacuum) in a closed. If the oil temperature nears the boiling point of water, the free water in the fried product can be evaporated rapidly[19]. Figure-3 shows the removal of moisture during frying apple slices at VF and MVF conditions for the different frying time used in this study. After 14 min of frying the higher to lower moisture contents of these frying systems were VF > MVF (800W) >MVF (900W)> MVF (1000W). It also can be observed that the moisture content of fried apple slices decreased with progressing frying time in all frying process. Which is predictable and whichreach an agreement with other scientists conclusions that the frying timesignificantly ($P<0.05$) affects the moisture loss in bothVF and MVFprocess[18,20]. It also can be seen that the moisture content off ried apple slices significantly affected by MW power. The slices fried at 1000W MV power showed lower moisture content then the slices fried at 800W and 900W at same frying time. At MW power 1000W the moisture removal was faster and maximum moisture loss was removed at 14 min of frying. These results come to an agreement with Quan, Zhang et al.[20] who described that with increasing MW power, the rate of moisture removal increased gradually in microwave-assisted vacuum fried potato chips.

During MVF, the surface water molecules of the apple slices were heated by the hot oil and then the heat transfer to the interior part of the apple slices. Therefore, there is more significant temperature gradient and less driving force for water molecules to evaporate. Because of this reason MVF provide faster moisture removal than VF. This phenomenon is in accordance with other researcher's where they found MW application shorten the frying process by removing higher moisture at the given time[21,22]. These results have shown that with increasing the frying time and MW power, the rate of moisture loss increased significantly and MVF process has shown faster rate of moisture loss compare to VF process.

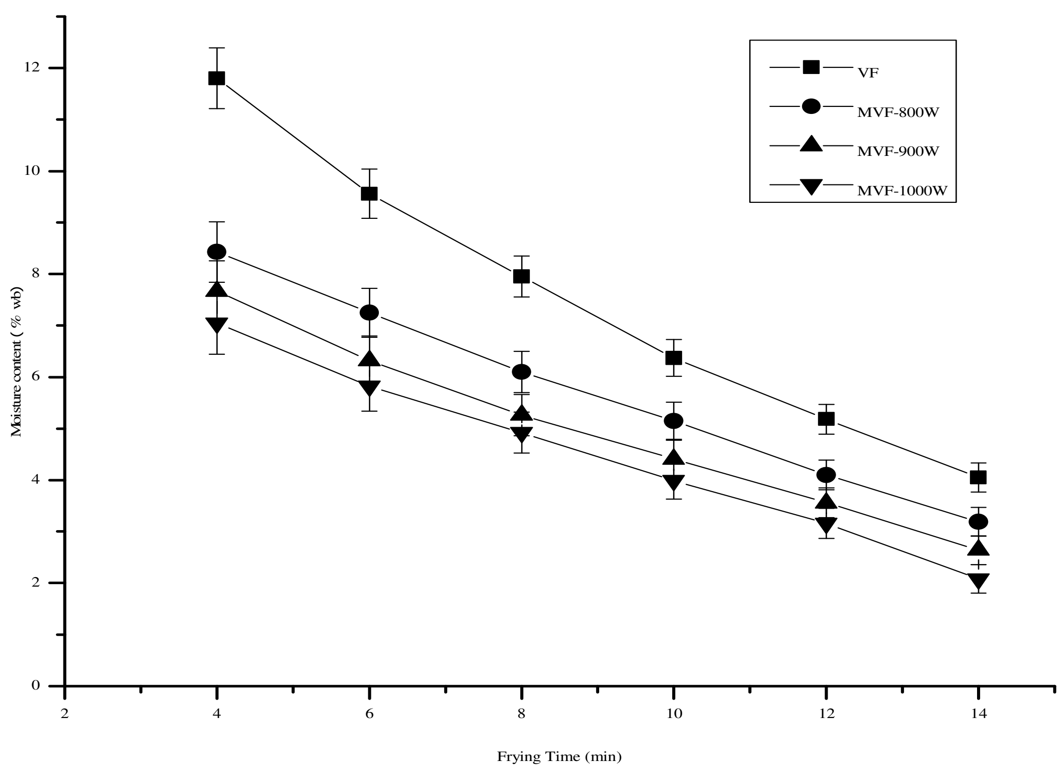

Figure-3: Decrease of the moisture content of fried apple samples during microwave-assisted vacuum frying.

Oil uptake: Oil uptake is a significant quality characteristic of frying products, which undermines modern customer trends moving healthier food with low oil content[23]. It is a complex mechanism and all determinants such as the product structure, the behavior of the product and the heating medium, and the chemical reactions between food constituents are created it a more complex phenomenon[24]. As stated previously, frying process increases the evaporation rate rapidly with increasing frying time and MW power. With increasing the evaporation rate, slices become more dryer and less hydrophilic as mention before. As it become more dryer then it makes pore and even non-pore area of the slices[20]. The pressure inside the pores changes, thus creating a pressure difference between the surface and inner parts of the product and this pressure variation produces a driving force for the oil at the exterior part to penetrate the pores area[25]. Figure-4 shows the progress of oil uptake when apple slices frying at VF and MVF condition with different frying time. After 14 min frying, the oil content of the apple slices was 38.93g, 33.81g, 34.02g, 34.64g, oil/100 g dry solid in VF, MVF(800W), MVF(900W), MVF(1000W) respectively. From Figure-4, it also can be seen that with increasing MW power and frying time the oil content of fried apple slices increased significantly ($p<0.05$). The VF samples absorbed much oil compared to MVF samples and this result corresponding with those obtained during MVF by other authors[22]. In the MVF process, after 14 min of frying the amount of oil uptake was almost similar in all MW power levels. Because at the beginning of frying process, the evaporation rate of moisture was high, which produce large pores on the product. This large pore area helps to absorbed more oil into the frying product. On the other hand, with increasing the frying time the residual moisture either remained held in the slices' matrix by multi-molecular adsorption and capillary condensation or evaporated slowly. This mechanism slowed down the creation of micropores, which lead to very slow oil absorption[25]. The combination of the MW with VF delivers extra energy for water molecules to evaporate quickly. Due to the higher heating efficiency, MVF makes fewer pathways for moisture diffusion. During the pressurization step and cooling period, the MVF process make less moisture pathway within the dry part and oil compared to VF process[26]. For this reason, the final oil uptake of MVF fried sample was less compared to VF. It may be also possible that the MVF fried products suffer smaller structural changes then VF fried products and which may help to reduces oil uptake.

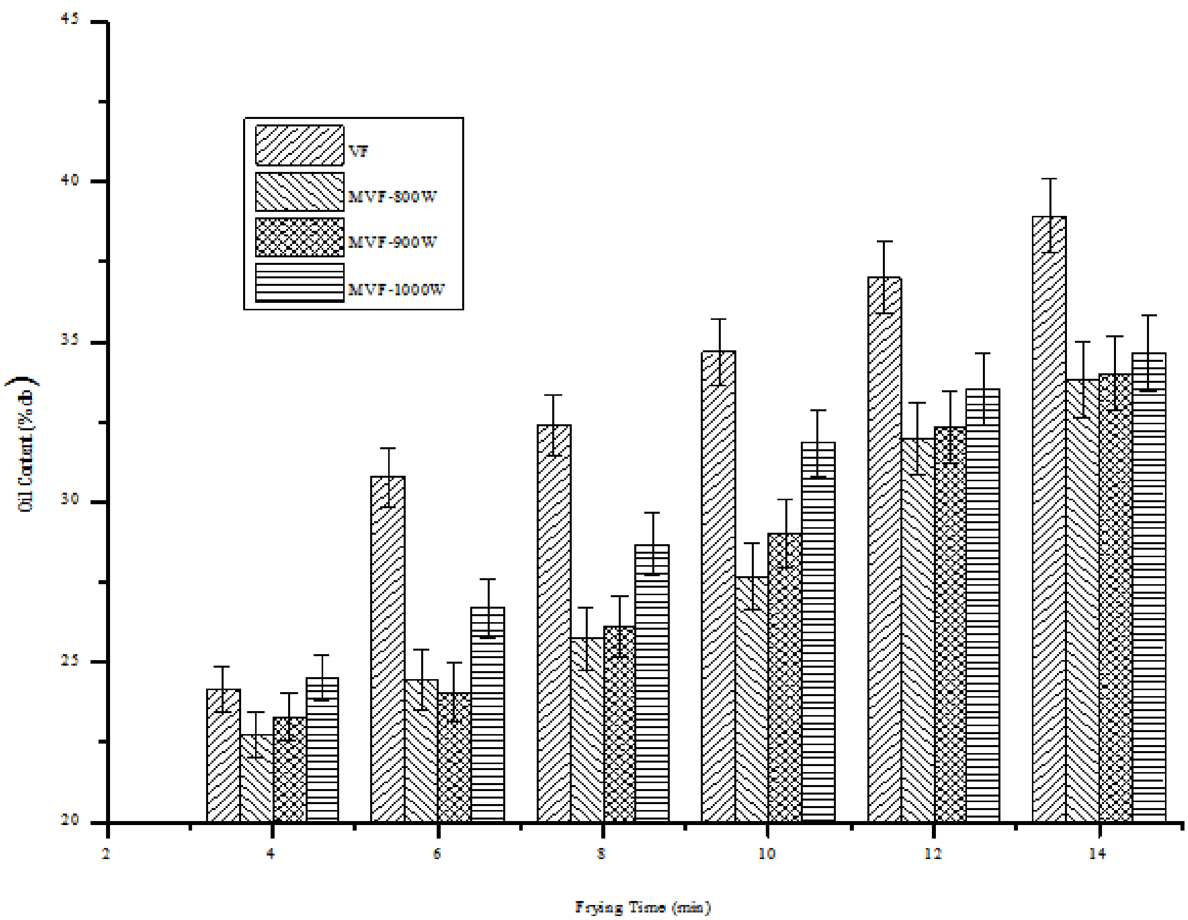

Figure-4: Variation of oil content over time in apple slices during microwave-assisted vacuum frying.

Texture: The most significant textural property of frying product is crispness, which indicates freshness and noble quality. A crispy should be sturdy and snap easily when twisted, blowing a crunchy sound. The breaking force was utilized as an indicator of crispiness of apple slices in this investigation. The crispiness increases with decrease the breaking force. The impact of MW on the breaking force of Apple slices with frying time is shown in Figure-5. It can be observed in Figure-5 that the breaking force of MVF sample significantly higher than VF sample. It also can be seen as the breaking force decreased with increasing frying time and MW power. The sample provided maximum crispiness at 14 min minimum crispiness at 4 min. At the beginning of the frying process, the texture of the apple slices was too soft to be measured owing to the high moisture content. As the frying process progress water is evaporated rapidly, which create a porous area on the surface. This type of porous on the apple slices surface increase the crispness[20]. In generally with increasing the frying time, the slices become drier and provide the higher crispy product. As shown in the Figure-5 the crispiness ofMVF samples always higher than VF sample at any time.Becausethe combination of MW energy with VFincreased the moisture evaporation rate. As the evaporation rate increases, it makes a vapor pressure differential between the core region and surface area of the frying products[27]. Consequently, by decreasing the chamber pressure, the pressure differential was probably increased and thus the outside force was increased[27]. Thismechanism of MVF process could have provided the puffing features and crispness of the fried apple slices. This result indicates that MVF process can produce more crispy frying products than VF process.

Color: In color analysis, parameter L*indicates lightness of the products and higher the L* value means more white color and low L* value means more dark color. Lower L* value is also responsible for non-enzymatic browning reactions[28]. The apple slices fried under MVF had significantly higher ($p<0.05$) L* values compared to the apple slices fried under the VF condition (Figure-6). It also can be seen that the value of L* significantly decreased with MW power and frying time. This findings come to an agreement with that of Shyu and Hwang who reported that the lightness of apple slices decreased with frying time[19]. It also appears that the application of MVF decreases the non-enzymatic browning than the application of VF.

In color analysis, parameter a* indicated the green–red chromaticity of the sample. From the Figure-7 it can be seen that the a* values of the apple slices were negative, indicating a tendency of the apple to have more of a greenish color rather than red. It also can be seen that the a* value remained negative and increased to positive side (increasing redness) with increasing frying time and MV power. Thus a* values of fried apple slices were significantly higher ($p<0.05$) for apple slices at VF than for those fried at the MVF conditions, which also indicating that more Millard reaction occurred at the VF conditions. This result indicates that MVF process can reduce the Millard reaction and provide more red color fried products compared to VF process.

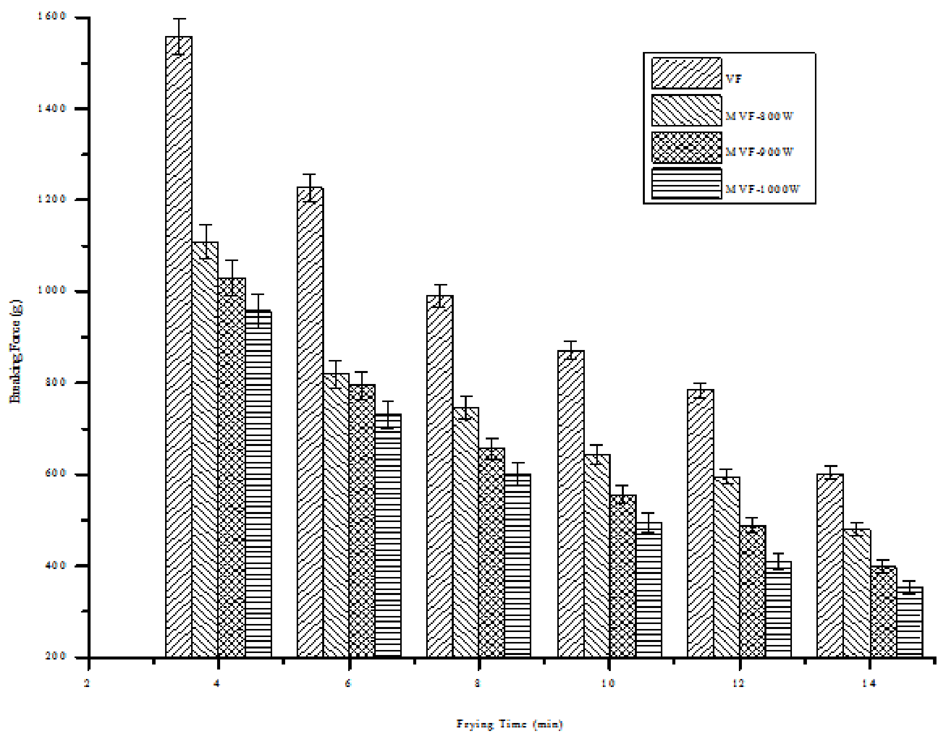

Figure-5: Effect of microwave power and frying time on the textural crispness (breaking force) of apple slices during microwave-assisted vacuum frying.

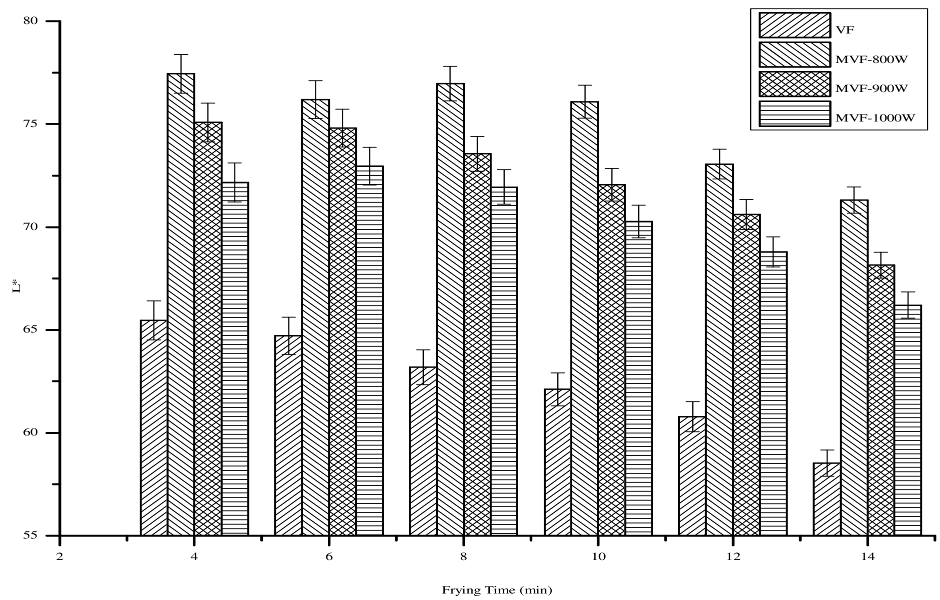

Figure-6: Effect of microwave power and frying time on lightness (L*) of apple slices during microwave-assisted vacuum frying.

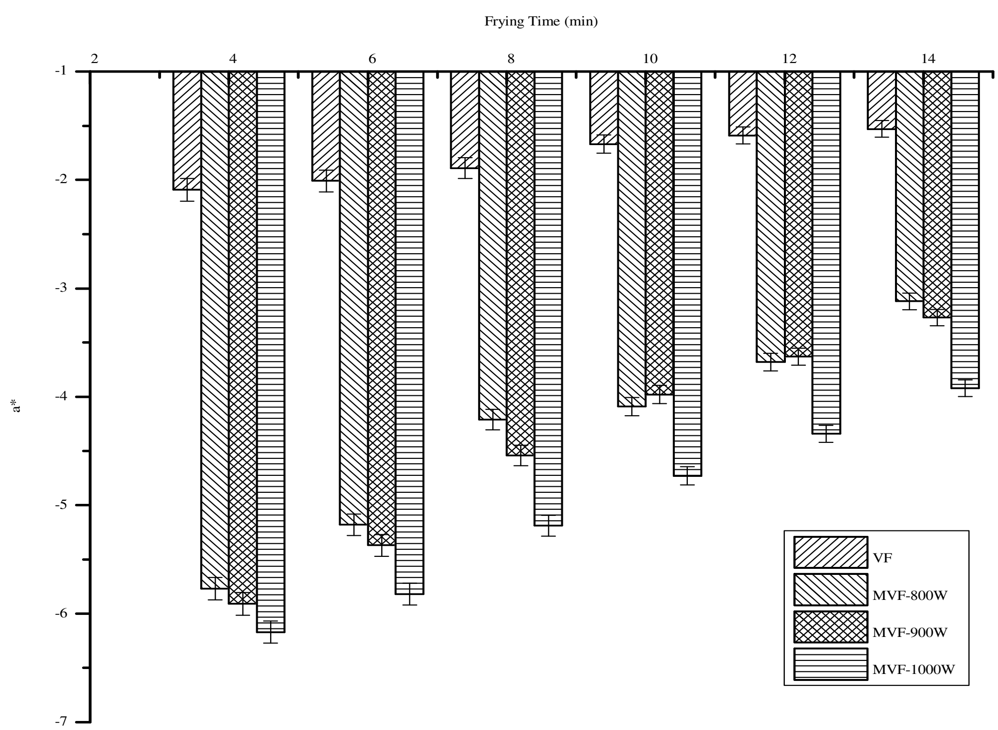

Figure-7: Effect of microwave power and frying time on green–red chromaticity (a*) of apple slices during microwave-assisted vacuum frying.

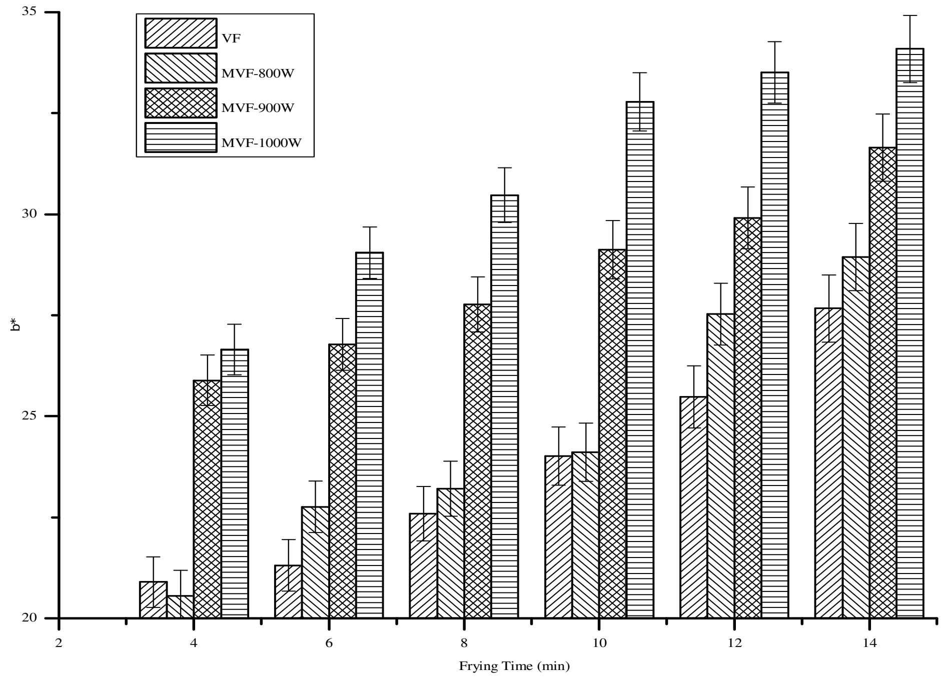

Figure-8: Effect of microwave power and frying time on blue–yellow chromaticity (b*) of apple slices during microwave-assisted vacuum frying.

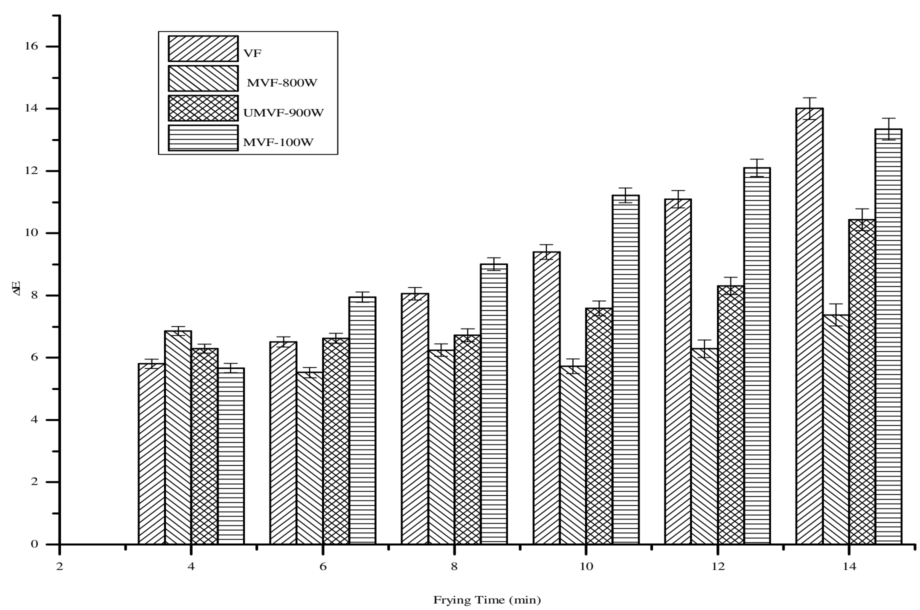

Figure-9: Effect of microwave power and frying time on total color change(ΔE) of apple slices during microwave-assisted vacuum frying.

In general, b* values indicate blue–yellow color of products and higher b* value means more yellowish product, which is acceptable for fried products[29]. Figure-8 showed that the b* values of fried Apple slices increased considerably in MVF than VF conditions. It also can be observed that the b* value of apple slices is higher at 1000W than that at 800W and 900W MV power compared to VF. The result indicates that MW power and frying time significantly effect on the b* of apple slices and MVF condition provide higher yellowness (b* value) in the final products.

The color parameter ΔE indicates that lower the ΔE values will lead to smaller the color difference between unfried and fried apple slices and preserve better natural color. Figure-9 shows the changes in the color difference of apple slices. The total color difference (ΔE value) increased with the frying time and MW power. The ΔE value of MVF fried chip was significantly lower than that of VF fried slices. It may be due to the removal of water and progress in non-enzymatic browning including Maillard reaction and caramelization all of which happen more efficiently at higher enthalpy[22].

Conclusion

From the obtained results, it can be seen that the MVF can produce better apple slices at low temperature with conserving the natural flavor, color, and heat-sensitive nutritious ingredients. It was observed that MW has a positive influence on the frying process acceleration by intensifying the heat and mass transport and provided to the shortening of frying time. The MVF process significantly increases the water evaporation rate, reduce oil uptake, provide better crispness and preserve the better natural color of the sample compared to VF process. The outcomes of this work show that MVF can concurrently be applied to increase the production rate and reduce the energy loss in VF process without endangering product feature. This finding may be very beneficial when there is a need to heat sensitive products efficiently or during less frying times are needed to obtain the better preservation of the functional and nutritional qualities of the product.

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