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Effect of Pre-drying and Microwave-assisted Vacuum Frying on Elephant Apple

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Elephant apple slices were pre-dried before being microwave-fitted vacuum-fried to limit the amount of oil absorbed while maintaining the ideal quality. Elephant apple slices were initially dried at 60°C for 27.5 min to attain the MC level of 200% db, and then trials with frying were conducted using a microwave-fitted vacuum fryer. For evaluation, three frying times of 6, 4, and 2 min at power levels of 1000, 600, and 400 W were taken into consideration.The final qualities of the fresh slices and pre-dried slices were studied in terms of colour, oil absorption and hardness. The impact of oil penetration during frying indicated that drying temperature did not affect the amount of oil or moisture in the slices after they were fried. Lower oil content and rapid colour changes resulted from higher frying temperatures. Combined pre-dried and MVF may produce fried food that is crispier (lower breaking force), healthier (lower oil content), and have a better colour.

Keywords: Elephant apple slices, Microwave frying, Oil uptake, Vacuum frying

Introduction

Dillenia indica L. (locally called elephant apple or Chalta) is a wild fruit that is high in nutritional and therapeutic value. Elephant apple is consumed both in fresh and in the cooked form in different recipes. The fruit has been traditionally used for making juice, pickles, curry, jams, chutney and jellies.[1] The fruit not only has culinary uses but also appears to have health advantages. Fruit's fleshy sepals are rich in tannins, malic acid, vitamin C, arabinogalactan, and glucose.[2,3] Elephant apple's fruit also contains a large number of flavonoids and triterpenoids (lupene-type) along with phenolics, ketones, phytosterols, alcohols and anthraquinones.[4,5] They are perishable due to their greater moisture content, and seasonal availability limits their use throughout the year.[6] Hence, appropriate preservation procedures for the elephant apple should be developed to extend its shelf life and create value-added products.

The complex process of deep fat frying necessitates the simultaneous transfer of mass and heat from the food to the cooking oil. Oil absorption, moisture loss, and crust formation are likely to occur on the surface of fried items such as banana chips, potato French fries and other vegetable fries, fried chicken items, fish sticks, and doughnuts.[7,8] The price of processed foods is currently fairly high in the Indian market, making them unaffordable for the majority of people. However, people's propensity to eat packaged and processed foods is progressively growing. The popularity of processed snack foods in India is increasing because of changing socio-economic role of the present-day housewives. As a result, the market today is flooded with the various ready-to-cook, ready-to-serve packages aimed to facilitate daily cooking. The snacks industry in India has shown considerable growth during the last few years. Changing fat consumption patterns are affecting the consumer preferences for low-fat content in the products as also regarding the types of oil used in frying.[9] This trend has encouraged the food industries to lunch a variety of newer, innovative food products having lesser oil content and lower cost. The duration and temperature of frying have a significant impact on the amount of oil uptake and moisture loss in the final product. Some investigations have shown that frying time is one of the important factors in making good chips or fries. The variety and level of reducing sugar in the tubers affect the ideal frying temperature and cooking time.[10] Krokida *et al.* in 2001 studied that drying potatoes before frying may result in a significant decrease in oil uptake in the final product.[11]

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Vacuum Frying (VF) is a type of frying that takes place at pressures much below atmospheric pressure during normal frying. Other than atmospheric frying, vacuum frying offers an alternate technique to increase the quality of fried fruits and vegetables.[12] It is a technique that can be used to dry fruits and vegetables to the proper level without the product being too darkened or scorched. The low pressure at which a vacuum fryer processes food allows snacks to be produced at lower temperatures, ranging from 85 to 120°C. Carcinogens do not develop in the oil, it keeps fresher for longer, and the product's original colour, flavour, fragrance, and nutrients are preserved when fried at low temperatures. However, because of the high oil content, researchers are investigating ways to reduce oil absorption in fried foods.

A revolutionary technology, microwave (MW) heating holds great promise for use in the food industry. Using the microwave-fitted vacuum frying (MVF) technique, crispier, more enticing, and healthier fried food can be produced. When compared to atmospheric frying, MVF is also recognized as a cost-effective and ideal method of frying owing to its shorter processing time and lower processing temperature. MVF has previously been the subject of various investigations, with numerous studies focusing on the interest in using MVF for industrial uses.[13] According to the literature review, deep-fat frying can achieve high-quality desired results while using less energy by using microwave pre-treatment as a heating source. Although frying is a centuries-old method of producing food, much of the study in the literature is focused on atmospheric or vacuum frying. There is no research on the impact of microwaves on the finished product's oil content, hardness, or colour value. This study's main objective was to develop a microwave-fitted vacuum frying technique that would yield superior elephant apple slices with low oil content and excellent texture and colour.

Material and Methods

Sample Preparation

Fresh elephant apple (*Dillenia indica L.*) and rice bran oil (Fortune) was procured from Tinali Market near CITK. To ensure the quality of the raw materials, elephant apples were chosen for their relatively consistent shape, size, and lack of defects upon visual inspection. For this experiment, fresh elephant apples were cleaned, rinsed, and sliced (2 mm thickness), using a self-designed pedal-operated elephant apple cutter to produce elephant apple slices of uniform diameter (only the central core part was removed and sliced). Qualigens fine chemicals (Mumbai, India) and Sigma-Aldrich Ltd provided all chemicals and reagents (Dorset, UK). After slicing the samples and noting the initial moisture level, pre-drying was done using a Tray dryer (MAC, New Delhi, India) at 60°C for 27.45 min (to attain the moisture content of 200 percent db).

Frying Operation

A commercial stainless steel double deep fryer (Capacity: 6litres; SKU: DK-PM-2150) was used for frying. Prior to conventional frying the oil was heated at 180 ± 5°C.[14,15] The frying operation was carried out at 2, 4 and 6 min. The sample was removed from the fryer and kept in a sealed container for additional examination.

Vacuum frying was carried out using a laboratory-sized vacuum fryer (Future Tech foods Indian Pvt. Ltd., India). The vacuum vessel was preheated for about 30 min before frying followed by placing 50 grams of elephant apple slices in the frying basket. At this point, the basket was placed in the oil, and the vessel's lid was closed and vacuumed (0.095 MPa) to initiate the frying operation. The basket was lifted from the oil and the vacuum was dissipated once the slice had been cooked for the specified frying time of 2, 4 and 6 mins.[16]

The microwave-fitted vacuum frying (MVF) instrument (Fig. 1) was designed, assembled and experiments were carried out as reported earlier by Su *et al.,* 2016.[13] The capacity of the fryer is 25 kg per hour with power consumption of 10KW per hour. The research was performed at three different power levels (600, 800 and 1000 W) to determine the oil uptake, texture and colour value of final products fried in

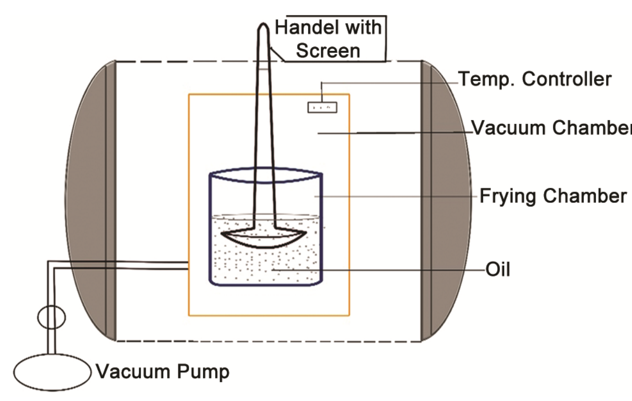

Fig. 1 — Schematic diagram of microwave-fitted vacuum frying (Adopted fromSu *et al.,* 2016.[13])

three different frying times (2, 4 and 6 min). Slices obtained after frying in each method were sealed in a plastic bag (clear low-density polyethylene) and kept in cooled dry conditions for further qualitative analysis. The detailed work flowchart has been shown in Fig. 2.

Quality Analysis

Moisture Content

Using an infrared moisture analyzer (MA 160, Sartorius, Germany) and the hot air oven approach recommended by Borah and Nayak in 2013, the initial moisture content of the elephant apple slices was assessed.[9] The initial moisture content of the sample was found to be 300% db.

Oil Uptake

A quick soxhlet extraction procedure was used to determine the oil content (Extraction System, B-811, Buchi, India). Pieces of elephant apples crushed samples from both fresh and fried samples were extracted with ether at 65°C for 5 hours. On a dry basis, the fat content was determined as g of fat/g of dry solids.[17,9]

Colour

Any food product's colour is a representation of its quality as well as a psychological aspect influencing approval for usage. Colour analysis of fresh and fried elephant apple slices was conducted in this context. A colorimeter was used to determine the colour (D25 LT, Hunterlab, USA). Prior to usage, the colorimeter was calibrated using a reference white ceramic plate. Using the Hunter L*, a*, and b* scale, the hue of slices was determined. The L* value represents the brightness to darkness, the a* value the redness (+) to greenness (−), and the b* value the yellowness (+) to blueness (−) of the colour. The trials were run three times to eliminate any room for error.[18,19]

Shrinkage Analysis of Fried Slices

It's typical for food ingredients to shrink while deep-frying. It is defined as a volume change brought on by frying processes such as protein denaturation, pore reduction and moisture loss. Volumetric shrinkage can be expressed as follows.[9]

$$S_V = \frac{V_i - V_f}{V_i} \times 100$$

where, S_v = Volumetric shrinkage;
V_i = Volume before frying
V_f = Volume after frying

Texture

Fried elephant apple slices were placed on a "crisp fracture support rig" (HDP/CFS) with a 25 kg load cell on a heavy-duty platform (HDP/90) and a 5mm spherical stainless probe (P/5S), in order to evaluate the texture using a texture analyzer (TA-XT, Stable Micro System Co. Ltd., UK). The distance was 3 mm, the trigger force was Auto - 5g, the test speed was 1.0 mm/s, the test speed was 1.0 mm/s, and the post-test speed was 10.0 mm/s. Samples with the highest homogeneity, *i.e.*, in terms of size and shape, were chosen after an hour of frying and taken out of packages. The first peak force of the sample revealed the sample's first fracture. The hardness was determined by measuring the maximal peak force during the first compression cycle.[20]

Statistical Analysis

All experiments were performed in triplicate, and statistical analysis was conducted using the SPSS trial version (Version 24). $P < 0.05$ was used to signify statistical significance.

Results and Discussion

Effect of MVF on % oil uptake

One of the most essential quality characteristics of fried foods is their oil content. Fried items with a high percentage of oil are detrimental as well as more expensive for the manufacturer to produce. Elephant apple slices quickly lose water from their surface while frying, creating a moisture gradient between the surface and the sample's interior. This may be because the unique heating mechanism of microwaves requires fewer moisture diffusion pathways. The moisture from the food inside escapes as steam thus, creating a pressure differential. The channel for diffusion increases as the water content decreases, and also increased solid and/or oil content significantly increases resistance to moisture outward diffusion. Table 1 shows that the per cent of oil absorption increased with increasing frying time for both fresh and dried slices, which can be attributed to the high rate of moisture loss that occurred during frying, but

Fig. 2 — Flowchart of frying process using microwave-fitted vacuum fryer of elephant apple slices

Table 1 — % oil content in microwave-fitted vacuum frying

Power (W)/ Frying Time (min)	Fresh slices (MC of 300% db)			Dried slices (MC of 200% db)		
	2	4	6	2	4	6
600	14.15 ± 1.02	21.99 ± 2.11	22.54 ± 2.14	11.62 ± 0.68	12.11 ± 0.99	14.01 ± 0.93
800	18.65 ± 0.98	23.08 ± 2.02	24.09 ± 2.15	13.96 ± 0.92	14.55 ± 0.92	18.98 ± 1.11
1000	22.66 ± 1.11	26.19 ± 2.09	27.53 ± 1.99	16.81 ± 0.85	17.96 ± 1.02	19.22 ± 1.21

the oil uptake of elephant apple slices gradually decreased with increasing time as power levels increased. Due to the development of crust on the surface, the rate of moisture loss has decreased, which causes a decrease in oil uptake. Fresh slices may have a higher oil uptake than dried slices because of the rapid rate of moisture loss. The findings are consistent with the study conducted by Su *et al.*[13]

Effect of microwave-fitted vacuum frying on texture

The texture of a food sample is determined by the density of the particles that make up the sample, as well as the size of other particles. In addition to being predominantly felt by touch, a food's textural qualities can also be quantitatively assessed using functions of time, mass and distance.[21] Instrumental measurement and sensory assessment are the two main types of food evaluation that are employed. Sensory testing and instrumented measuring both depended on the senses of the human body. Textural alterations in terms of hardness and crispiness were brought on by the evaporation of free water as well as a decrease in the starch concentration in the solid substance. When the solid material's moisture content was inconsistent, there was a gradual increase in hardness and crispiness; however, once it was constant, there was a sudden increase in hardness and crispiness that persisted through the end of the frying process. Fig. 3 (a) shows that the breaking force of fresh slices (300 per cent MC) and pre-dried slices decreased as the frying duration increased from 2 to 6 min (200 per cent MC). Because of the large amount of moisture and delicate texture of elephant apple slices, the breaking force was very low (8.86 ± 0.92 N) after 6 min of frying at a higher power level of 1000 W. MVF reduces the crispness of elephant apple slices by a substantial ($p < 0.05$) amount. This is owing to the quicker dehydration rate and the usage of microwave radiation, which results in a greater pore density and bigger pores in the slices. The same result was also observed by Borah and Nayak, 2013.[(9)] Fig. 3(b) also shows that increasing microwave power resulted in a drop in MVF breaking force, which dropped from 9.99 ± 0.89 to 4.55 ± 0.65 N

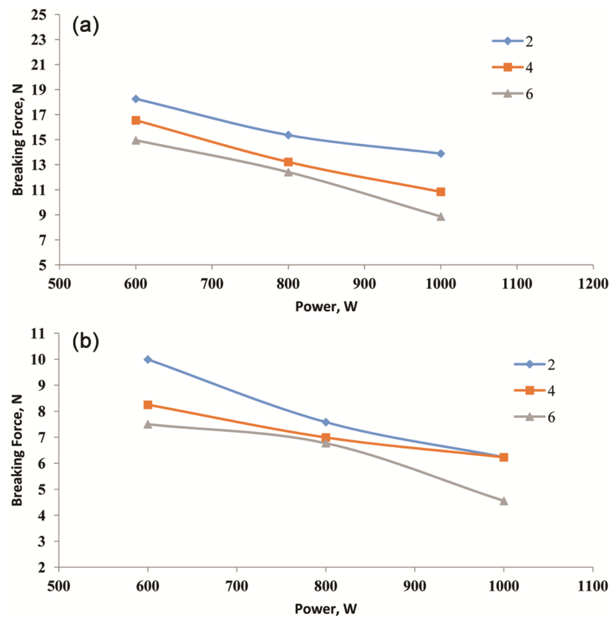

Fig. 3 – (a) Breaking strength of the fresh (300% MC) elephant apple slices during different power levels in MVF at 2, 4 and 6 min, (b) Breaking strength of the pre-dried elephant apple slices during different power level in MVF at 2, 4 and 6 min

Shrinkage as a result of vacuum frying in a microwave

Shrinkage refers to a reduction in the thickness and total volume of elephant apple slices. Product shrinkage takes place during drying due to the collapse of the product matrix owing to moisture loss, which can also occur during the frying process. Oil absorption while frying, on the other hand, may help to counteract shrinkage and even give minor expansion.[22] The shrinking of the slices was investigated in this study using measurements of volume. Density measurements were used to determine overall volumetric shrinkage after frying. The volumetric shrinkage of fresh slices varies from 43.5 to 16.6%, whereas dried slices shrink from 61.5 to 20.4% (Table 2). Shrinkage and puffing, two processes that occur during frying, have been implicated for the change in volume.[23] Shrinkage began at the surface and progressed inwards as the frying time progressed. Because of the faster drying rates with greater microwave power, the outer layers of the material become stiffer, resulting in reduced shrinkage.

Table 2 — Overall volumetric shrinkage (%) during pre-drying and frying using a microwave-fitted vacuum fryer

Power (W)/ Frying Time (min)	Fresh slices (MC of 300% db)			Dried slices (MC of 200% db)		
	2	4	6	2	4	6
600	43.5	38.9	28.0	61.5	59.6	55.5
800	21.0	21.0	21.1	22.7	22.8	22.8
1000	16.6	16.7	16.7	20.4	20.4	20.5

Table 3 — Effect of colour in microwave-fitted vacuum frying

Power	Fresh Slices			Pre-Dried Slices		
(W)	L*	a*	b*	L*	a*	b*
600	54.22	0.10	20.12	79.32	− 1.26	5.69
800	53.57	0.04	25.92	76.29	−1	7.9
1000	53.10	1.44	28.01	61.89	−0.78	8.88

Effect of vacuum frying in a microwave on colour

The changes in colour qualities that have been detected are noted in Table 3. The colour of the fried product is influenced by the degree of oil absorption and non-enzymatic browning reactions. Keep in mind that lightness (L), a key component of colour in fried foods and a common indicator of quality control, must be kept under control.[24] Fresh slices are found to have a lower L* value than dry slices. Browning response might be caused by a minor drop in L* values with respect to the power level (Table 3). The Study by Mariscal and Bouchon has reported the same results.[25] Elephant apple slices tend to become deeper (redder) as frying advances, as seen by the significant increases in a* values with microwave power level (as a result of surface non-enzymatic browning processes) (Table 3). Because non-enzymatic browning processes are strongly temperature sensitive, the greater the microwave power level, the darker the elephant apple slices become.[26]

Conclusions

Elephant apple slices were produced using combined pre-dried and microwave-fitted vacuum frying. Drying before frying enhanced the moisture evaporation and oil absorption rates. With the increase in frying time from 2 to 6 min and increased microwave power levels from 600 W to 1000 W, the per cent oil uptake in fresh slices increased from 14.15 ± 1.02 to 27.53 ± 1.99, whereas the oil uptake in dried slices ranged between 11.62 ± 0.68 and 19.22 ± 1.21. The high rate of moisture loss in fresh slices during frying, which causes a high oil uptake, can be responsible for the decrease in the percentage of oil uptake in dried slices. The rate of oil absorption and moisture evaporation was significantly accelerated by microwave irradiation. Increased power levels in MVF (from 600 W to 1000 W) led to quicker water removal and reduced hardness, with no significant differences in oil uptake or colour characteristics. The per cent oil content, texture, and colour properties investigated were found to be desirable and best preserved with combined pre-drying and MVF techniques. The crispness and colour of fried slices, which are two of the most essential quality aspects that influence customer liking, may be enhanced using the MVF along with the pre-drying approach.

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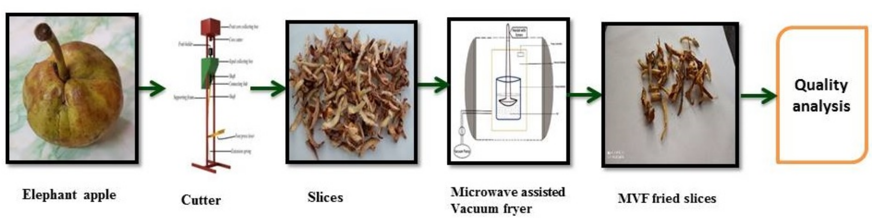

Graphical Abstract