Physiochemical properties of vacuum fried durian (*Durio Zibethinus Murr.*) chips combined with microwave heating

C Thongcharoenpipat and R Yamsaengsung*

Department of Chemical Engineering, Faculty of Engineering, Prince of Songkla University, Hatyai, Songkla 90112, Thailand

*Corresponding author’s e-mail: ram.y@psu.ac.th

Abstract. This research evaluated the effects of oil temperature, ripeness of durian (*Durio zibethinus Murr.*), and microwave combined heating (MCH) on the physiochemical properties of vacuum fried durian chips. The oil temperature was varied from 90, 100, 110, and 120°C, while the ripeness was determined in term of total sugar (base on day of ripening). In addition, the effect of pretreatment of durian chips by freezing overnight -18°C before vacuum frying (VF) was also investigated.

From this study, it was found that VF at 120°C with the ripeness of day 3 gave the lowest shrinkage, and using MCH produced a higher rate of moisture loss compared to the condition without MCH. Even though it was found that the ripeness of durian lead to more oil absorption, the addition of MCH resulted in decreasing the permeability of oil into the product. Finally, an increase in the frying temperature lead to a slight significant increase in color change (p<0.05), while the microwave power intensity did not have a significant effect on the color change (p>0.05).

1. Introduction

Durian (*Durio zibethinus Murr.*) is an attractive and high economic valuable tropical fruit grown widely in South-East Asia [1]. Due to its high nutrients and uniquely unpleasant odor, Durian is known as the “king of tropical fruit” [1]. One of the most important problem occurs in durian season, where there is excessive harvesting which floods the market making it impossible to sell all ripened durians even with high consumer demands. Therefore, it is more economical to process durian in order to extend its shelf-life and add value to the product. Presently, there are several methods including drying and deep-fat frying. Due to its high temperature and oil uptake, which detract the color and nutritive values of the product, alternative methods should be considered.

Drying of fruits and vegetables have been favored for centuries around the world. Not only can they be stored for a long period of time, but dried foods are convenient for carrying and appetizing to consumers. Moreover, drying of fruits and vegetables help to maintain the color and taste similar to the original fresh products meeting the demands of customers. One of the most efficient drying process is vacuum frying. Even though oil is used, the overall oil content is low compared to conventional frying process making it a feasible alternative for many fruit varieties in today’s market.

During vacuum frying, products are dried under vacuum pressure, reducing the frying temperature required compared to traditional frying temperature (90-100°C versus 160-180°C), while maintaining high drying rate. The lower frying temperature leads to higher product qualities such as crispness, puffed
structure, color, aroma and keeping the flavor of fresh fruits, while minimizing the loss of nutrients [2]. In addition, vacuum frying help to restrict unacceptable chemical reactions, including product oxidation, oxidative degradations, lipid oxidation, browning reactions, and risk of acrylamide formation [3]. Furthermore, oil uptake can be reduced as shown by investigations of Dueik, Robert, & Bouchon [4]; Sothornvit [5] and Yamsaengsung, Yaeed, & Ophithakorn [6].

In recent years, vacuum frying combined with microwave heating have been found to help improve the rate of drying and product qualities even more. Microwaves are produced by an electron tube called a magnetron and they are reflected within the metal interior of the oven where they are absorbed by food. The microwaves excite the water molecules in food to vibrate, generating heat and a driving the moisture out of the food.

While previous researchers have considered the effects of vacuum drying on structural changes of bananas, pineapples, and apples [7], the effects of vacuum frying on the percent thickness expansion and hardness of bananas chips, and the effects of combined microwave techniques for drying of durian chips [9], none have investigated the effect of frying temperature, microwave power, and ripeness on the mechanical and physical properties (in terms of shrinkage, oil absorption, and color) using vacuum frying combined with microwave heating of durian at 90, 100, 110, and 120°C and absolute chamber pressure of 8 kPa. The effect of pretreatment of durian chips by freezing overnight -18°C before vacuum frying was also investigated in determining the most viable alternative in producing a high quality durian chip product.

2. Experimental

2.1. Materials & Methods

The schematic diagram of the vacuum fryer used in the present study of Figure 1 depicts the experimental setup comprising of a vacuum fryer, a cooling tower, a water pump, a liquid ring vacuum pump (Model ET32030, Nash Trumbull, CT), and a centrifuge. The vacuum fryer is constructed from stainless steel with a diameter of 400 mm, a height of 300, and a wall thickness of 6 mm. The stainless steel lid of the fryer has a thickness of 8 mm which is installed with generator of microwave (Magnetron) and waveguide controlled the microwave power by power monitor. The cooling tower, water pump and the centrifuge are fabricated and assembled by the Department of Chemical Engineering, Prince of Songkla University, Hatyai, Thailand. The vacuum pump is purchased from Kinetics Engineering Co. (Thailand). After frying, the products are centrifuged for 5 min at 450 rpm to remove excess oil on surface and to minimize oil absorption.

Durian chips (control and pretreatment) were fried at 90, 100, 110, and 120°C and an absolute chamber pressure of 40 mm Hg. Each batch consisted of 100 g of the products and is deep-fried in 13 L of palm oil. The palm oil is replaced after 10 batches of frying to maintain the oil fresh [10]. The sliced durians were fried using three conditions: (1) microwave-vacuum frying (combined microwave power of 640 W); (2) vacuum frying; (3) Pretreatment (frozen at -18°C, 24 hrs) before vacuum frying without MCH. The moisture content of the durian chips were continuously measured at intervals of a minute. The frying experiment were performed until the final moisture content reached 6.0% (w.b). All experiments were performed in triplicates.
Figure 1 Modified schematic of the microwave-vacuum frying operation [11]

Fresh durians (Cultivated in South of Thailand, cultivar: D159 or ‘Durian Monthong’ in Thai) were purchased from the local market. The ripeness level in terms of total sugar days of ripening (g glucose/g flesh durian) based on day of ripening (day 1, day 2, and day 3) were used in this study. The fresh durian had the initial moisture content in range of 59.72-71.32% (w.b.) and were fried until the final moisture content of 6.0% (w.b.) was reached. The fresh durian was opened and the flesh was removed and sliced using a blade to 2 - 2.5 mm thickness.

2.2. Evaluation of frying qualities

The moisture ratio (MR) of each sample during frying and the frying rate of the sample are determined by the following equations:

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$  \hspace{1cm} (1)

where: $M_0$ and $M_t$ = the moisture content (kg water kg dry solid$^{-1}$) at initial time 0 and frying time t, $M_e$ = the equilibrium moisture content (kg water kg dry solid$^{-1}$). The equilibrium moisture content ($M_e$) is assumed to be zero for this experiment because of little value compared to $M_0$ [12]

2.2.1. Shrinkage

The physical qualities of durian chips are evaluated for shrinkage. After each frying time interval, the samples are taken out and new samples are used for each set of frying. An average value of the thickness is obtained from a set of 10 random samples using a digital Vernier Caliper. The percent of shrinkage is described by equation (2):

$$\%\text{Shrinkage} = \left(\frac{D_0 - D}{D_0}\right) \times 100$$  \hspace{1cm} (2)

where: $D$ and $D_0$ are respectively the end-of-each-test and the original diameters (mm).

2.2.2. Color change of fried product

The color of the samples are measured using a Hunter Lab color system colorimeter (Juki Model JP100, Japan). The measurements of color change of the samples in each condition are performed by using ten samples and the average value is reported. The color values of fried samples are compared with those of fresh samples and the normalized color changes are then calculated by the following equation [13]:

$$\frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$  \hspace{1cm} (3)
\[
\Delta a = \frac{a - a_0}{a_0} \\
\Delta b = \frac{b - b_0}{b_0}
\]

(4) (5)

where: L, a, and b = the lightness, redness and yellowness of the fried sample, respectively, while \(L_0\), \(a_0\), and \(b_0\) represent the initial values of the lightness, redness and yellowness of the sample prior to frying, respectively.

The total color difference (\(\Delta E\)) was evaluated by using eq. (6) [14]. The results were obtained to express the effect of frying temperature, ripeness of durian, and microwave power on sample quality.

\[
\Delta E = \left[ (L_{ref} - L^*)^2 + (a_{ref} - a^*)^2 + (b_{ref} - b^*)^2 \right]^{1/2}
\]

(6)

where: \(L_{ref}, a_{ref}\) and \(b_{ref}\) = the lightness, redness, and yellowness of the initial value of the sample before frying, respectively, while \(L^*, a^*,\) and \(b^*\) = the lightness, redness and yellowness of the fried sample, respectively.

2.3. **Effect of ripeness (days of ripening)**

Effect of ripeness, or the amount of sugar content, on the degree of drying rate, shrinkage and ability of oil absorption are also studied. Samples were allowed to ripen for 1, 2, and 3 days. Fresh samples are evaluated the total sugar content by Modified Phenol Sulfuric Method [15]. The total sugar content is determined from soluble sugar, oligomeric, and polymeric sugar in original samples and is calibrated using a glucose standard curve.

2.4. **Oil content of durian chips**

Approximately 2 g of fried durian samples were weighted into soxhlet for solvent extraction (using hexane). Total oil content of durian chips were determined by using the Soxhlet extraction apparatus AOAC Official Method 972.28 [16]. All the procedures are carried out in duplicate and mean value reported.

2.5. **Statistical Analysis**

A duplicate of the entire experiments and the mean values with standard deviations are reported. The experimental data are analyzed using an analysis of variance (ANOVA). Duncan’s multiple range test is used to establish the multiple comparisons of the mean values; mean values are considered at 95% confidence level (\(p = 0.05\)). A statistical program SPSS (SPSS software for Windows, SPSS Inc., USA) is used to perform all statistical calculations [8].

3. **Results and discussion**

3.1. **Influence of process variables**

After vacuum frying, changes in the moisture ratio of durian chips during the vacuum frying at different conditions and processes are presented in Figure 2. The moisture content of the durian samples was decreased from the initial value of durian ripening day 1 of 71.3% (w.b.), durian ripening day 2 of 66.3% (w.b.), and durian ripening day 3 of 59.7% (w.b.) to less than 6.0% (w.b.). At the starting of vacuum frying, the moisture ratio of the durian chips diminished rapidly. The drying kinetics of durian chips provided this similar process to the vacuum frying (VF) combined with microwave heating (MCH) and pretreatment procedure before vacuum frying. The effects of frying temperature on the vacuum frying of durian day 1 (shortest drying) are shown in Figure 2a). The frying time could reach to the required moisture content faster with an increase in frying temperature owing to a greater driving force of heat and mass transfer at the higher frying temperature. However, using the microwave power to combine with vacuum frying enhanced the deduction of the moisture ratio, probably the quick raised of the water temperature in the material come to water boiling point [17] that consisted with those on apple pomace [18], mint leaves [19], and beetroot [20]. Furthermore, Pretreatment method (Freezing at -18°C
overnight) prior to vacuum frying also provided more increasing drying rate and leading to the reach of required final content of moisture earlier because of the molecule of water was in an ice-crystal state from freezing and could be evaporated readily compared with VF (control) as following Figure 2b).

**Figure 2** Moisture ratio versus frying time (seconds) of vacuum fried durian chips in different frying conditions of a) vacuum frying of durian day 1 at different frying temperatures, b) vacuum frying of durian day 1 at different processes at 110°C (shortest drying without burning the chips (120°C), c) vacuum frying combined with microwave heating at different ripeness of durian at 110°C.

### 3.2. Shrinkage

**Figure 3** Percent of shrinkage versus frying time (seconds) of vacuum fried durian chips in different frying conditions of a) vacuum frying combined with microwave heat (MCH) at different
ripeness of durian at 110°C (shortest drying without burning the chips (120°C), b) vacuum frying of
durian ripening day 3 (least shrinkage) at different frying temperatures.
Figure 3a) and 3b) present the percent of shrinkage as a function of frying time at different ripeness of
durian during vacuum frying combined with microwave heating (MCH) compare with vacuum frying
without MCH (control) and the percent of shrinkage as a function of frying time at different frying
temperature of durian ripening day 3 durian vacuum frying (control). From the Figure 3a), at the
beginning of frying, durian chips shrank rapidly and became less shrinkage after then because of
significant shrinkage in the product at the first minute of frying pinpointing rapid water loss. However,
after a few minutes, the degree of shrinkage slightly decreased which probably have result from the
formation of the crust and leading the gaseous vapor expands as it tries to expose [8]. Xanthopoulos,
Yanniotis, & Lambrinos [21] suggested the case hardening may be produced in the products having high
sugar content which related the lower percent of shrinkage when performed the frying with the higher
ripeness of durian (Day 3 has much more sugar content than day 2 and day 1, respectively.). In addition,
the vacuum frying combined with MCH produced less percent of shrinkage beside VF (control) at the
same ripeness as a result of during microwave heating, the molecules of water absorbed microwave
energy and vaporized inside the product which could have resulted the puffing attribute [17].
Meanwhile, it was found that the percent of shrinkage of fried durian chips at the higher temperature
were significantly lower than the product that were performed at the lower frying temperatures, likewise
the studies of Swasdisevi, Devahastin, Nganchum, & Soponronnarit [13] and Panyawong & Devahastin
[22], for bananas, (Wu, Orikasa, Ogawa, & Tagawa [23] for eggplants and Yan et al. [24] for banana,
pineapple and mango mentioned that at the highest drying temperature, the shrinkage was finally the
least as following the figure 3b).

3.3. Oil content of durian chips

![Figure 4](image-url)

**Figure 4** Percent of oil content of vacuum fried durian chips in different frying conditions on
durian ripening day 1, day 2 and day 3 at 110°C.

Figure 4 presents the percent of oil absorption at 110°C of vacuum fried durian chips by VF (control),
pretreatment prior to VF and VF+MCH at the different ripeness of durian. It could be expressed that
more ripeness of durian leading the oil content of durian chips significantly increased (p<0.05),
agreeably the study of Diamante [25] mentioned that the riper the fruit caused more oil absorption in
the vacuum-fried chips. Besides, it was seen in the Figure 4 that the vacuum fried sample that were
performed by combined with MCH always presented significantly lower (p<0.05) oil content compared to VF and pretreatment prior to sole vacuum frying. At the vacuum frying of durian ripening day 3, the oil content of the samples fried in VF+MCH (6.83%w.b.) was lower compared to VF samples (8.19%w.b.) as the results of the change of microstructural and the deduction of frying time thanks to the MCH [26]. Similar result was presented on edamame with vacuum frying assisted by ultrasound and microwave heating [27].

3.4. Effect of ripeness (days of ripening)

![Figure 5](image)

**Figure 5** Total sugar content of each durian ripening based on days of ripeness.

The effects of total sugar content based on the ripeness of durian (days of ripening) on degree of drying rate is presented in Figure 2c). From the Figure 2c), the highest degree of drying rate that reached to the required moisture content of ≤6%w.b. occurred for product from day 1 (shortest drying) compared to day 2 and day 3, respectively because of the different initial moisture content and the change of microstructural. In addition, the case hardening may be produced in the products having high sugar content (took more frying time to reach the required moisture content) which related the lower percent of shrinkage when performed the frying with the higher ripeness of sample. Moreover, From the Figure 4, vacuum frying of durian day 3 had more oil absorption than durian day 2 and day 1, respectively due to different microstructure and lower of frying time that occurred in the lower ripeness of the sample.

3.5. Color change of fried durian

| Conditions   | Temperature (°C) | Frying time (seconds) | L*        | a*       | b*       | ΔE        |
|--------------|------------------|-----------------------|-----------|----------|----------|-----------|
| VF (control) | 90               | 600                   | 75.00±1.48a | -1.45±0.17a | 27.58±0.91a | 13.45±1.65a |
| VF+MCH       | 90               | 480                   | 76.52±0.42a | -1.47±0.13a | 25.03±1.59a | 13.68±1.27a |
| Pretreatment | 90               | 540                   | 74.11±0.78a | -1.65±0.03a | 27.07±0.86a | 14.50±0.95a |
| VF (control) | 100              | 600                   | 75.42±1.69a | -1.66±0.03b | 22.40±1.91b | 16.21±2.49a |
| VF+MCH       | 100              | 480                   | 71.15±1.53ab| -1.08±0.08a | 28.27±0.90a | 16.61±1.61a |
| Pretreatment | 100              | 480                   | 69.11±1.99b | -1.28±0.14a | 29.19±0.27a | 18.28±1.97a |
| VF (control) | 110              | 600                   | 69.56±0.65a | -1.20±0.13b | 27.90±1.27b | 18.27±0.97a |
| VF+MCH       | 110              | 480                   | 68.19±1.02a | -0.40±0.29a | 31.89±0.88a | 18.65±1.07a |
Pretreatment 110 480 66.64±0.94a -0.70±0.13ab 31.98±1.10a 20.22±0.98a

VF = vacuum frying, VF+MCH = vacuum frying combined with microwave heating, Pretreatment = freezing prior to sole vacuum frying.

Mean value ± standard error of the mean.

The different superscript letters (a-b) in the same column express significant differences within different frying conditions (p<0.05).

Pretreatment (freezing at -18°C) prior to vacuum frying and vacuum frying combined with microwave heating of durian chips had no significant difference (p>0.05) on the lightness (L*-value) and the total color difference (ΔE) that are presented in Table 1. Nevertheless, the redness (a*-value) and yellowness (b*-value) of vacuum fried (control) durian chips were obviously noticed when they were performed with vacuum frying (control) even though at different frying temperatures. After vacuum frying, the lightness was clearly decreased from the L*, a* and b* of fresh durian of 86.63±0.53, 1.36±0.07 and 33.67±0.58, respectively may be as the result of more frying time that made them slightly darker [27] compared to other conditions that took less frying time to reach the required final moisture content. From the results in Table 1 present the vacuum frying combined with microwave heating could retain the natural color of durian chip as much as vacuum frying (control) and Pretreatment prior to frying, therefore, microwave heating assisted frying does not have any significant effects on the color change of durian chips whereas the higher temperature provided more change of color in L* and a* (darker and more greenness) and decreased in b* (less yellowness) including the total change color (ΔE) that had more value following the tendency of temperature.

4. Conclusions

From the experimental results, the drying rate of durian chips depended on the frying temperature, frying method, and ripeness of durian. It was found that the frying time to reach the required moisture content was faster with an increase in frying temperature meanwhile using MCH provided a higher rate of moisture loss compared to the condition without MCH. Furthermore, Pretreatment method (Freezing at -18°C overnight) prior to sole vacuum frying also provided more an increase in drying rate. Moreover, the ripeness of day 3 resulted in the lowest percent of shrinkage of durian chips; however, the highest oil absorption due to the longer frying time. Finally, vacuum frying with MCH did not whereas significantly affect the change in color of the durian chips, the higher temperature did.

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