

Process Optimization in Vacuum Frying of Kiwi Slices Using Response Surface Methodology

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ABSTRACT: Vacuum deep-fat frying is a new technology that can be used to improve the quality attributes of fried food because of the low temperatures employed and minimal exposure to oxygen. In this paper the effect of frying process parameters, namely frying time, frying temperature and pressure on the quality factors of fried kiwi slices was studied. A laboratory scale vacuum frying apparatus was used to study the interactions and optimization of process parameters on the vacuum frying of kiwi fruit. Considering the results of pretests, the variables ranges were assumed as 80-120 °C for the temperature, 40-150 mbar for the vacuum pressure and 5-20 minutes for the processing time. The results indicated that the color and the shrinkage were significantly ($p < 0.05$) correlated with the frying temperature and time, while the crispiness was affected only by the frying temperature. There was no significant relation between the vacuum pressure and the responses except the shrinkage. The results of sensory evaluation indicated that there were no significant differences ($p < 0.05$) between the vacuum fried kiwi slices and the dried kiwi chips except flavor. The optimum conditions for the vacuum frying of kiwi slices were found to be: 105°C, 62 mbar, and 8 min, for the frying temperature, the vacuum pressure and the frying time, respectively.

Keywords: Kiwi Chips, Optimization, Processing Conditions, Response Surface Methodology, Vacuum Frying.

Introduction

Kiwi fruit (*Actinidiadeliciosa*) is native to the mountains of southern China. (Scott *et al.*, 1986). Kiwi fruit is a highly nutritional fruit due to its high level of vitamin C and it has a strong antioxidant activity due to a wide number of phytonutrients, including carotenoids, lutein, flavonoids and chlorophyll (Cassano *et al.*, 2006). Furthermore, kiwi fruits have a very short shelf-life due to their highly perishable nature, and they are not only consumed as fresh fruits but also as processed foods in the form of jams, juices, canned fruits, frozen

and dehydrated products (Abedini, 2004; Emamjome & alaedini, 2005).

Vacuum frying is an efficient method of reducing the oil content in fried snacks, maintaining the product nutritional quality, and reducing the oil deterioration. It is a technology that can be used to produce fruits and vegetables with the necessary degree of dehydration without excessive darkening or scorching of the product. In the vacuum frying operations, food is heated under reduced pressure [< 60 Torr/8 kPa] causing a reduction in the boiling points of the oil and the moisture in the foods. Compared with other dehydration methods for fruits and vegetables, vacuum frying is a viable

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option to obtain high quality dried products in a much shorter processing time. Passos & Ribeiro (2009); Dasilva & Moreira, (2008) demonstrated that the vacuum fried snacks (blue potato, green bean, mango and sweet potato chips) retain more of their natural colors and flavors due to the less oxidation and the lower frying temperature. Dasilva & Moreira (2008); Dueik *et al* (2009) showed that the vacuum frying (driving force of 60°C) might reduce the oil content of carrot crisps by nearly 50% (d.b.) compared to the atmospheric fried crisps produced using the same driving force.

In fact most of the benefits of this technology are the results of the low temperatures employed and minimal exposure to oxygen. The benefits include: (i) reduction of adverse effects on the oil quality (Shyu & Hwang, 1998), (ii) the preservation of natural colors and flavors (Shyu & Hwang, 2001), (iii) the decreased acrylamide content (Granada *et al.*, 2004), and (iv) the preservation of nutritional compounds (Dasilva & Moreira, 2008).

The objective of this study was to employ the vacuum frying process and produce kiwi chips with good color, texture and less shrinkage. Response surface methodology (RSM) was used to optimize the vacuum frying conditions, and finally the produced fried kiwi chips were compared with the commercial dried kiwi chips by sensory evaluation.

Materials and Methods

Raw materials

Fresh kiwi fruits, *Actinidiadeliciosavar. delisiosacv. Hayward*, were purchased from an orchard located in Tonekabon, a northern city in Iran and transformed to the laboratory.

Sample preparation

Kiwi samples were stored at +4°C until required for the experiments. After one hour

stabilization at ambient temperature, the samples were washed, peeled with water and drained for 3 minutes. Washed, peeled and drained Kiwis were vertically cut into 2 mm thick slices with a slicer (Siemens, model CNAS 11ST2).

Vacuum frying

The frying behavior of Kiwi slices under vacuum has been studied experimentally with the help of a laboratory vacuum frying apparatus. The fryer contains a number of units and accessories to control and carry out an effective frying operation under vacuum. A one liter borosilicate glass flat bottom flask equipped with three joint necks (to connect vacuum pump, thermometer probe and lift rod) was used as a frying vessel to observe the product changes during the process. A Ventury instrument was used to provide and retain the pressure in the vessel. In order to hang the sample in the frying oil, a thin glass rod with a small fishing hook attached to one end was used. Heating was performed by a 400 watts electric heater (Isopad model RM4002) and there was a pressure control valve near the pressure gauge. Before running, the sample was placed on the hook and the glass rod attached on it, was lowered into the frying oil. After frying, the vacuum fried kiwi chips were centrifuged at 750 rpm for 4 minutes and blotted dry with the paper towel to remove the oil. Kiwi chips were then nitrogen packed in the Poly ethylene bags and stored at the room temperature for further analysis.

As selecting the significant ranges for the variables is the most important step in response surface methodology, thus the pretests were setup and it was found that the pressure range from 40 to 150 mbar, the temperature range from 80 to 120°C and the frying time range from 5 to 20 minutes, could be considered for the design. The design experiments were conducted, and the obtained results were entered in the table of

design (Table 1). The response surface methodology was employed to optimize the vacuum frying conditions.

Table 1. Layout of the design and corresponding quality values for vacuum fried kiwi chips

| Runs | Frying temperature (°C) | Vacuum Pressure (mbar) | Frying Time (min) | Moist. Content (%) | Color (ΔE) | Shrinkage (%) | Breaking force (N) |
|------|-------------------------|------------------------|-------------------|--------------------|------------|---------------|--------------------|
| 1 | 112 | 128 | 8 | 8.22 | 14.3 | 46.6 | 11 |
| 2 | 88 | 128 | 17 | 8.77 | 14.1 | 55.1 | 21.8 |
| 3 | 88 | 128 | 8 | 10 | 10.5 | 57.7 | 69.8 |
| 4 | 120 | 95 | 12.50 | 5.27 | 27.8 | 41 | 14.3 |
| 5 | 112 | 62 | 17 | 7.62 | 18.5 | 42.8 | 17.2 |
| 6 | 100 | 150 | 12.50 | 10.2 | 15.1 | 61 | 15.2 |
| 7 | 100 | 95 | 12.50 | 9.61 | 12.2 | 55.3 | 16.1 |
| 8 | 100 | 95 | 12.50 | 10.5 | 7.63 | 50.1 | 16.5 |
| 9 | 100 | 95 | 20 | 9.19 | 14.6 | 60.7 | 25.5 |
| 10 | 100 | 95 | 5 | 9.24 | 9.71 | 37.4 | 27.8 |
| 11 | 112 | 128 | 17 | 9.58 | 22.1 | 52.4 | 11.2 |
| 12 | 100 | 95 | 12.50 | 10.9 | 10.5 | 47.2 | 15.7 |
| 13 | 88 | 62 | 8 | 10.1 | 10 | 52.8 | 17.5 |
| 14 | 100 | 95 | 12.50 | 6.41 | 19.6 | 58.2 | 14.2 |
| 15 | 88 | 62 | 17 | 6.86 | 12.1 | 59.9 | 23.2 |
| 16 | 80 | 95 | 12.50 | 8.51 | 15.6 | 68.5 | 34.2 |
| 17 | 100 | 95 | 12.50 | 6.85 | 14.9 | 46.6 | 27.4 |
| 18 | 100 | 95 | 12.50 | 10.5 | 13.3 | 51.5 | 12.5 |
| 19 | 100 | 40 | 12.50 | 9.99 | 12.2 | 43.1 | 13.3 |
| 20 | 112 | 62 | 8 | 10.6 | 12.9 | 41.8 | 11.3 |

Product quality attributes

Moisture content: The moisture content of the samples was determined in a vacuum oven at 70°C until the constant weight was achieved (AOAC, 2000).

Oil content: The oil content of fried product was determined gravimetrically by Soxhlet extraction with light petroleum ether (Firestone, 1994).

Color: The color was measured using a colorimeter (Hunter lab Color Flex) and expressed as Hunter *L* (lightness), *a* (redness) and *b* (yellowness) values. The colorimeter was standardized using a white tile, and color difference (Hunter Δ*E*) was calculated according to the following equation, and two readings were taken for mushroom chips by rotating the chips with a 180° angle.

(1)

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

Where *L*_{ref}, *a*_{ref} and *b*_{ref} were the *L*, *a* and *b* values of fresh mushroom slices which were used as references.

Texture: A three-point bending rig (support span of 16 mm), mounted on a Testometric Texture Analyzer (model M350-10CT) was used to determine the force required to break the vacuum fried kiwi chips. A steel blade of 3 mm thickness with flat edge was used to snap the samples at the constant rate speed of 10 mm/s. The force (N) at the fracture point (the highest value in the plot) was used as the resistance to breakage (Dasilva & Moreira, 2008). Measurements were made in triplicate order.

Shrinkage: the sample dimensions (thickness and diameter) before and after frying were measured with a stainless steel calliper. Measurements were made at six different places on each sample (Taiwo & Baik, 2007). Shrinkage was expressed as percentage changes in volume (Moreira, 2002).

$$S_v = \frac{V_0 - V_{(t)}}{V_0} \times 100 \quad (2)$$

Where V_0 is the original volume of the sample (m^3) and $V_{(t)}$ is the volume (m^3) of the sample at the time t . The volume of the sample (elliptical shaped) at any given time can be calculated by $V = (\pi Dd/4) L$ where D is the larger diameter of the sample (m) and d is the smaller diameter [m] of the sample, and L is the sample thickness (m). Ten samples were taken to determine shrinkage for each frying condition.

Sensory analysis

A 30 member consumer panel rated and compared the sensory quality of the vacuum fried kiwi chips that produced in the optimized vacuum frying conditions to the commercial dried kiwi slices on the following attributes: color, odor, texture, flavor and overall quality. The samples were placed in the capped PVC containers and presented to each panelist at once. They were presented in the containers labeled with a random three digit number and randomly displayed. Between the samples, the panelists were asked to drink some water. A nine-point hedonic scale was used to evaluate the samples. A score of 1 represented attributes most disliked and a score of 9 represented attributes most liked. Scores higher or equal to 5 were considered acceptable (Dasilva & Moreira, 2008; Kemp et al., 2009).

Statistical analysis

All data were obtained by triplicate analyses and were analyzed using the Design-Expert 7.1.3 State-ease software. Analysis of variance was performed by the ANOVA procedure. Also drawing the content plots of optimization was performed by Design- Expert. Data of sensory evaluation was analyzed by T-Student test using SPSS software. Analyses of variance were performed by the ANOVA procedure.

Mean values were considered significantly different when $p < 0.05$.

Results and Discussion

Moisture content

The results showed that the process parameters had no significant effect ($p < 0.05$) on the moisture content of vacuum fried kiwi chips (Fig. 1). It might be due to the high initial moisture content of kiwi fruit. During the vacuum frying process, a large amount of moisture has been removed from the fruit while the products have not been over processed. The water has been removed from the chips at the same level for all process conditions, and the process parameters decreased the moisture content of all the chips like the others.

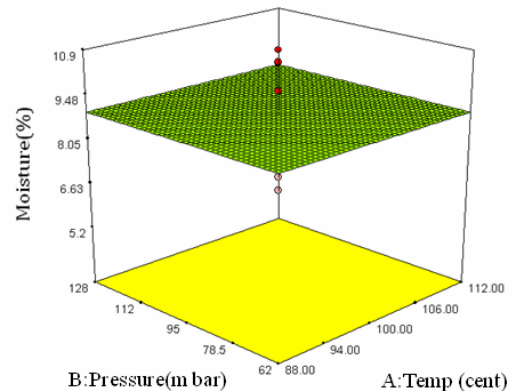


Fig. 1. 3D Response surface plot of moisture content of kiwi chips

Color

The statistical analysis showed that the frying time and temperature had a significant effect ($p < 0.05$) on the color of the final product that has been evaluated as the total color difference (ΔE). While the vacuum pressure did not have a significant effect on the color of the kiwi chips. The higher ΔE values indicate more darkness in the products. As shown in Fig. 2, by increasing the frying time and temperature, the ΔE values were increased that meant the kiwi chips were darker. The darkness of the

chips is usually due to non-enzymatic browning at higher temperatures (shyu & Hwang, 2001). The obtained results were similar to findings by other researches regarding color changes during the vacuum frying of mushroom, potato, apple and shallot (Ghiassi, 2008; Moreira *et al.*, 2009; Shyu & Hwang, 2001; Therdtai *et al.*, 2007)

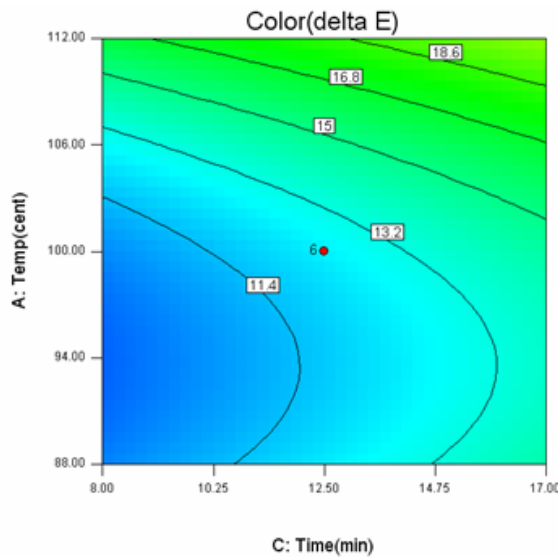


Fig. 2. Contour plot of color for kiwi chips as was affected by frying time and temperature

Texture

During frying, most of the water is removed from the kiwi slices which results in textural changes. In this study, the force required to break the chips was used to determine the crispiness of kiwi chips, which lowered breaking force (N) corresponding to higher crispiness. Data analysis showed that the crispiness of kiwi chips was significantly ($p < 0.05$) affected by the frying temperature, while the vacuum pressure of the process and frying time had not a significant effect on crispiness. As shown in Fig. 3, the longer frying time, the less breaking force. These results were in accordance with the results of the other researchers in the cases of vacuum fried carrot, button mushroom and potato chips (Fan *et al.*, 2005; Ghiassi,

2008; Moreira *et al.*, 2009; Shyu & Hwang, 2001)

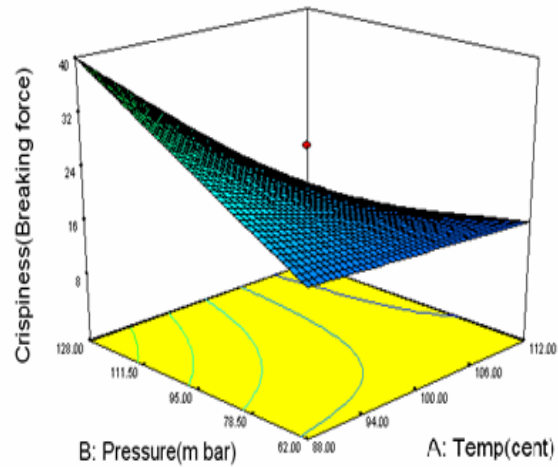


Fig. 3. 3D Response surface plot of crispiness for kiwi chips as was affected by the frying temperature

Shrinkage

Data analysis showed that the degree of the volume shrinkage was significantly ($p < 0.05$) affected by the frying temperature, the frying time and the vacuum pressure. The vacuum pressure had the least effect through three process parameters on the shrinkage. As shown in Fig. 4, by increasing the oil temperature and the vacuum pressure and also decreasing the frying time, the degree of the volume shrinkage was decreased. The observed results are in agreement with the results obtained by Garayo and Moreira (2002) in the case of potato chips.

The amount of shrinkage during early stages of frying was very nearly equal to the volume of water loss; however, in the final stages of drying, the volume of shrinkage was smaller. Therefore, the volume of shrinkage depended on the water transfer within the product. The higher temperatures resulted in the higher mass diffusivity, the higher water loss and consequently the lower volume of shrinkage. In addition, the higher oil temperature caused the kiwi chips surface to become rigid more rapidly and resulted in more resistance to the volume of

shrinkage. The results also indicated that by increasing the vacuum, the chips shrank more. The structure formed in the chips during the low vacuum temperature was less rigid than that formed under high pressure which resulted in less resistance to the volume change (Garayo & moreira, 2002).

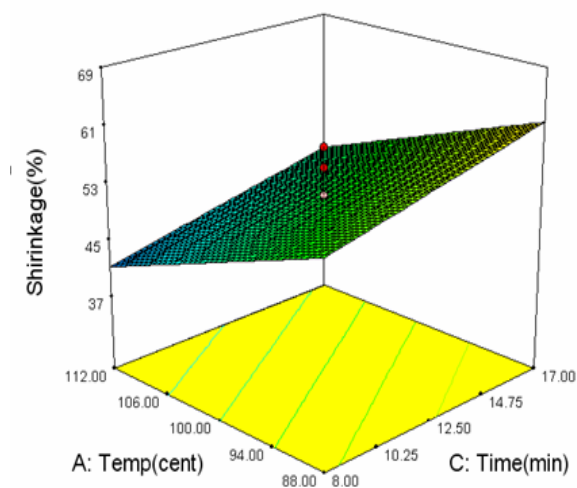


Fig. 4. 3D Response surface plot for the shrinkage of kiwi chips as was affected by the frying time and temperature

Sensory evaluation

As the panelists scores indicated in Fig. 5, commercial dried kiwi slices were preferred by color, odor, flavor and overall quality but these differences were not significant ($p < 0.05$) except flavor. Panelists significantly preferred the dried samples by the flavor that might be due to the new taste of the vacuum fried kiwi chips. On the other hand, panelists' preferred the vacuum fried kiwi chips by the texture that showed more crispiness for the vacuum fried ones.

Conclusion

The main object of using the vacuum frying in the present study was to evaluate

it's feasibility for kiwi chips production and to optimize the vacuum frying conditions. During the vacuum frying, by increasing the frying temperature, the breaking force and the shrinkage of the vacuum fried kiwi slices were decreased while the Hunter ΔE was increased. By increasing the frying time, the shrinkage and ΔE were increased. The Hunter ΔE and the shrinkage of vacuum fried kiwi slices were significantly ($p < 0.05$) affected by time and temperature of frying, however the crispiness of the vacuum fried kiwi slices was only affected by the temperature. By increasing the vacuum pressure of frying, the shrinkage was decreased and there were not significant relations between the moisture content and the processing conditions.

The results of this study based on the surface responses and the contour plots suggested that vacuum frying at 105 °C and the vacuum pressure of 62 mbar for 8 minutes could produce kiwi chips with lower shrinkage and moisture as well as good color and crispy texture which were superior to the atmospheric frying. The results of sensory evaluation indicated that there were no significant differences ($p < 0.05$) between vacuum fried and commercial dried kiwi chips by color, odor, texture and overall quality. Panelists significantly ($p < 0.05$) preferred commercial dried kiwi chips by flavor that might be due to the new taste of vacuum fried kiwi slices. It might be concluded that the vacuum frying is a process that could be an alternative for current processing methods to produce healthier types of fried foods.

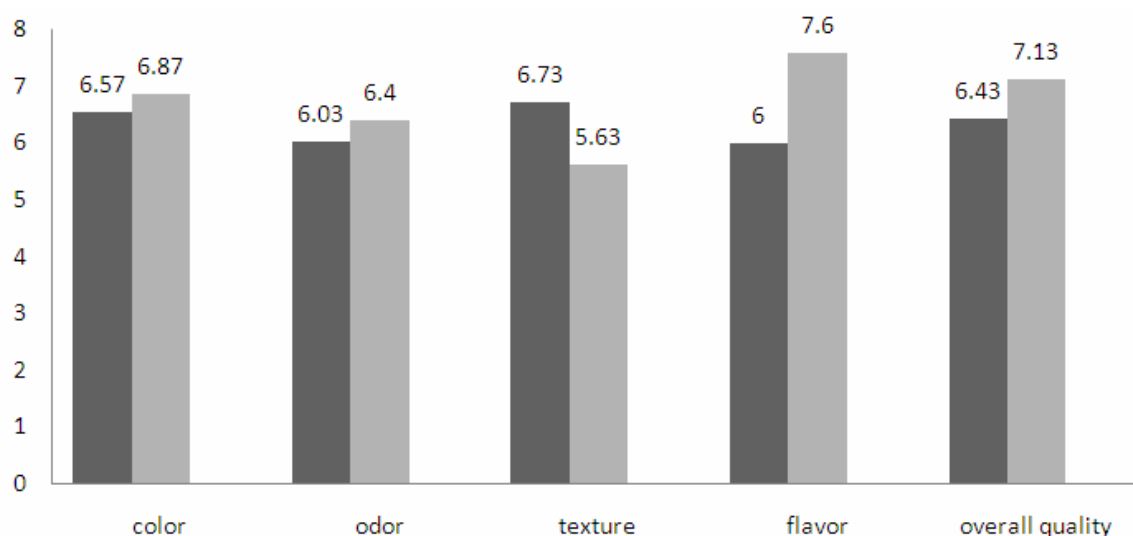


Fig. 5. Sensory scores of vacuum fried and commercial dried kiwi chips (gray-bar: commercial dried kiwi chips, black-bar: vacuum fried kiwi chips)

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