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Process Optimization in Vacuum Frying of Mushroom Using Response Surface Methodology

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Abstract: Vacuum frying is a rather new technology that can be used to improve quality attributes of fried foods because of the low temperatures employed and minimal exposure to oxygen. In this paper effects of frying conditions in vacuum frying of mushroom on the quality factors of fried chips and optimization of process parameters were studied. A laboratory scale vacuum frying apparatus was used to study the interactions and optimization of process parameters on vacuum frying of fresh mushroom slices. Considering the results of pretests, variables ranges assumed as 70-140°C for temperature, 4.11 to 9.88 kPa for vacuum pressure and 1-15 minutes for processing time. Statistical analysis showed that the color difference ΔE, moisture and oil contents of fried mushroom chips were significantly ($p \leq 0.05$) affected by time and temperature of frying although pressure range from 4.11 to 9.88 kPa had no significant effect on the mentioned quality factors. It was found that by increasing frying time and temperature, the moisture content and color intensity of mushroom chips decreased while the oil content and crispiness increased; also there was no significant relation ($p \leq 0.05$) between shrinkage of mushroom chips and process conditions. The results of this study suggest that vacuum frying at 90°C, pressure of 4.25 kPa for 12.5 minutes might produce mushroom chips with acceptable quality.

Key words: Mushroom chips · Processing conditions · Process optimization · Response surface methodology (RSM) · vacuum frying

INTRODUCTION

Mushrooms are extremely perishable and the shelf life of fresh mushroom is only about a day at ambient conditions. Hence, they should be consumed or processed promptly after harvest and for this reason mushrooms are traded mostly in processed form in the world market. Vacuum frying is a cooking process that is carried out under pressures below atmospheric levels. Compared with other technologies, vacuum frying is a viable option to obtain high quality dried products with better color and flavor. In this study vacuum frying was used as an alternative for common dehydration methods in order to process fresh mushrooms. The button mushroom (*Agaricus bisporus*) is the most widely cultivated and consumed mushroom throughout the world. Without considering any special treatment, various physiological and morphological changes such as browning and withering occur after harvest at room temperature condition, which make these mushrooms unacceptable for consumption.

Vacuum frying is a relatively new technique of frying. It is carried out under pressures well below atmospheric levels, preferably below 6.65 kPa which lowers the boiling point of frying oil and moisture of the food and making it possible to reduce the frying temperature [1]. Compared with other dehydration technologies for fruit and vegetables, vacuum frying is a viable option to obtain high quality dried products in a much shorter processing time [2]. It has been demonstrated that 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 lower frying temperature [3]. Also experiments of DUEIK *et al*. showed that vacuum

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frying may reduce the oil content of carrot crisps by nearly 50% (d.b.) compare with atmospheric fried crisps [4]. It has been shown that vacuum frying can produce potato chips with lower oil content but with the same texture and color characteristics as those of regular chips fried in conventional fryers [1]. YAMSAENSUNG and RUNGSEE observed that vacuum fried potato chips and guava slices have lower oil content and more natural colorations than those fried conventionally [5]. Comparison the quality of sweet potato chips produced by vacuum frying and traditional frying indicated that oil content of vacuum fried products was significantly lower than that of traditionally fried products. Anthocyanin and total carotenoids content were significantly higher for the vacuum fried products. Most of the products retained their original colors when fried under vacuum and the traditionally fried products showed excessive darkening [3]. Comparison between atmospheric and vacuum frying of apple slices in terms of oil uptake, moisture loss, and color development showed that vacuum frying was a promising technique that can be used to reduce oil content in fried apple slices while preserving the color of the product. In particular, drying prior to vacuum frying was shown to give the best results [6]. Because of lower frying temperature and oxygen content during the vacuum frying process, the natural color and flavor could be retained better. In addition, as the exposure of the oil to atmospheric oxygen is reduced, it might be possible to increase the overall process lifetime of the oil [7].

Today's consumers are more interested in healthy products thus lower production of acrylamide might be considered as an important aspect of vacuum frying. Acrylamide is neurotoxic and classified as a probable human carcinogen by the International Agency for Research on Cancer. Acrylamide was found to be formed in a wide range of carbohydrate-rich foods cooked at high temperatures such as fried and baked foods [8]. Recent research showed that lowering the cooking temperature is an easy and effective way to reduce acrylamide in fried foods. It has been reported that vacuum frying could produce potato chips with 97% reduction in acrylamide content than the traditionally fried chips [9]. Additionally, as the carbohydrate content of mushroom is low, there is a reduced chance for acrylamide formation in vacuum frying of mushroom as well.

The purposes of the present study were to investigate the interaction and optimization of process parameters namely frying time, pressure and frying temperature in vacuum frying of mushroom chips on the quality factors (moisture and oil content, color, crispiness and shrinkage) of fried product using response surface methodology approach.

MATERIAL AND METHODS

Fresh button mushrooms (*Agaricus bisporus*) with 92.5% (wb) moisture content used in this study were obtained directly from the producer (Malard Co. Tehran, Iran). They were stored at +4°C until required for the experiments. After one hour stabilization at ambient temperature, samples were washed with water and drained for 3 minutes. RBD sunflower oil was used as medium in the vacuum frying process [10].

Preparation of Mushroom Slices: Washed and drained button mushrooms were vertically cut into 2 mm thick slices with a slicer (Siemens, model CNAS 11ST2).

Experimental Apparatus: The frying behavior of button Mushrooms 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 product changes during the process. A dual seal vacuum pump (Platinum JB industries model DV-85N-250) which could generate an absolute pressure up to 3.115 kPa was used to provide and retain pressure in the vessel. The condenser was used to condense and collect the water vapor to prevent it from entering the pump. In order to hang the basket containing sample in the frying oil, a thin glass rod with a small fishing hook was used. Heating was performed by a 400 watts electric heater (Isopad model RM4002) and there was a control pressure valve near the pressure gauge.

Experimental Design: A full factorial design of experiments with frying time, temperature and pressure at 5 levels for the kinetic study required 125 experiments, which was time and cost consuming. Furthermore, because the results of the kinetic study were required for quality optimization, the Response Surface Methodology (RSM) approach, and specifically, the central composite rotatable design (CCRD) was considered.

Experimental Conditions: As selecting the significant ranges for variables is the most important step in response surface methodology, thus pretests were setup and it was found that the pressure range from 4.11 to 9.88 kPa, temperature range from 70 to 140°C and frying time form 1 to 15 minutes could be considered for the design. The vacuum vessel was set to the target temperature and allowed to operate for 20 minutes before starting the frying process. Sunflower oil was used as the medium and the oil volume in the vessel was 500 ml. According to the experimental design layout, a batch of 20 gram mushroom slices was fried each time. Once the oil temperature reached the target value, the mushrooms were placed into the stainless steel basket and the lid closed. When the pressure and temperature reached to the regulated range, the basket was lowered to the oil and frying began for the desired time. Once the frying time was completed the basket was lifted from the oil and the vessel pressurized. The lid of the vessel was opened and the mushroom chips were removed from the basket. In the next step, fried mushroom chips were centrifuged at 400 rpm for 10 minutes in room temperature to remove the frying oil and then packed in polyethylene bags for further analysis [11].

Analytical methods: Moisture content of the samples was determined in a vacuum oven at 70°C until constant weight was achieved [12]. Oil content of fried chips was determined gravimetrically by Soxhlet extraction with petroleum ether [13]. A texture analyzer (Hounsfield, model H5K5) was used for breaking force determination. Although rupture test is commonly used for evaluation of texture properties of chips, the special texture of mushroom (stipe and pileus) and different resistance of these parts to the rupture test, need another way of determination. In this study Kramer shear press test was used as a criterion to compare the breaking force of mushroom chips with different treatments. The property used to describe the texture of the samples was hardness, defined as the force at maximum compression. It was measured by recording the average peak forces values of each sample. The system was mounted in a Hounsfield texture analyzer and fracture the sample was performed at a constant speed of 20 mm/min, load range of 500N, Extension range of 20mm and test end point of 15 mm. The force (N) at the fracture point (highest value in the plot) was used as the resistance to breakage. The color of mushroom chips was measured with 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 180° angle.

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

Where L_{ref} , a_{ref} and b_{ref} were the L, a and b values of fresh mushroom slices which was used as reference.

To determine the shrinkage of chips, ten samples were used for each shrinkage measurement. Shrinkage is expressed in terms of the percentage change of the volume of the sample as compared with its original volume by solvent displacement method [14].

$$\%S = \left(\frac{V_i - V}{V_i}\right) \times 100 \quad (2)$$

Where V_i and V are the volumes of the sample at the beginning and at the end of each frying run, respectively. The average percentage values of shrinkage from ten samples were reported and all measurements were performed in triplicate.

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 the optimization and drawing the contour plots were performed by Design-Expert.

RESULTS AND DISCUSSION

To optimize the process conditions, frying time, pressure and temperature were selected as the main process conditions which could have effect on the quality attributes of vacuum fried mushroom chips. Layout of the central composite rotatable design and corresponding quality values for vacuum fried mushroom chips has been given in Table 1. The regression coefficients and analysis of variance for the dependent variables of fried mushroom chips are given in Table 2. The high value of R^2 indicates that the variables were highly fitted to the regression equation [15, 11]. Figure 1 shows the contour plots of (a) moisture content, (b) oil content, (c) shrinkage, (d) color and (e) breaking force of vacuum fried mushroom chips as affected by frying temperature and time.

Table 1: Layout of the central composite rotatable design and corresponding quality values for vacuum fried mushroom chips

	Variables			Responses				
Run	Frying Temperature (°C)	Frying Time (Min)	Frying Pressure (Kpa)	Moisture (%)	Oil (%)	Shrinkage (%)	Color (ΔE)	Breaking force (N)
1	115	8.2	6.0	0.56	82.58	68.0	32.69	18.41
2	140	4.0	7.8	0.45	74.70	62.8	34.15	13.73
3	90	4.0	4.2	10.87	62.27	60.6	46.25	23.54
4	90	12.5	4.2	0.60	75.80	71.2	31.13	27.61
5	115	8.2	6.0	0.21	82.17	58.7	36.85	15.47
6	115	8.2	6.0	0.52	83.4	63.0	35.89	15.58
7	115	8.2	6.0	0.50	82.04	61.0	36.11	15.72
8	115	15.5	6.0	0.03	80.00	65.0	38.03	21.69
9	140	12.5	4.2	0.11	78.56	62.0	37.12	16.42
10	140	4.0	4.2	0.38	75.49	64.6	33.29	20.48
11	157	8.2	6.0	0.15	77.33	65.4	39.34	12.16
12	115	8.2	6.0	0.01	84.17	74.9	35.36	22.93
13	115	8.2	9.0	0.05	84.47	71.7	33.63	21.54
14	115	8.2	6.0	0.52	81.74	60.0	29.35	20.65
15	90	12.5	7.8	0.69	77.63	61.7	32.25	24.05
16	115	1.1	6.0	9.58	67.46	50.0	47.83	24.50
17	140	12.5	7.8	0.22	76.70	67.2	34.10	16.52
18	115	8.2	3.0	0.54	82.34	58.3	32.34	18.22
19	90	4.0	7.8	14.90	64.64	58.3	55.17	20.34
20	73	8.2	6.0	14.74	63.03	60.0	46.61	37.82

Table 2: Regression coefficient and analysis of variance for dependent variables of vacuum fried mushroom chips in the central composite rotatable design

	Moisture content (%)	Oil content (%)	Shrinkage	ΔE	Breaking force (N)
Lack of fit	0.55	0.09	0.67	0.47	0.32
R^2	0.97	0.96	0.55	0.92	0.60
Intercept	0.53	82.59	63.22	33.69	20.37
X_1	-0.91	3.61	-	-2.81	-5.24
X_2	-0.80	3.85	-	-3.72	-
X_1X_2	+0.63	-2.67	-	5.23	-
X_1X_1	+0.53	-4.86	-	2.71	-
X_2X_2	+0.36	-3.59	-	2.69	-

Moisture and Oil Content: In vacuum frying operation, food is heated under reduced pressure in a closed system that can lower the boiling points of both frying oil and water in the food. Therefore, the unbound water in the fried food can be rapidly removed when the oil temperature reaches the boiling point of water [11]. The effects of temperature and time of process were significant ($p \leq 0.05$) on the moisture content. Counter plot (Figure1-a) showed that the moisture content of mushroom chips decreased by increasing time and temperature which was not significantly affected by vacuum pressure of the process. By increasing the temperature, the rate of moisture loss has increased and the longer the time, the higher loss of moisture from the mushroom slices.

Vacuum frying reduces the oil content, preserves natural color and flavors of the fried product and has less adverse effects on the oil quality [7]. In this study the oil content was significantly ($p \leq 0.05$) affected by the temperature and time of the process. Contour plot (Figure1-b) showed that by increasing time and temperature of the process, the oil content increased, which was not significantly ($p \leq 0.05$) affected by vacuum pressure of the process. SHYU *et al*. studied the effects of pretreatment and vacuum frying conditions on the quality of fried carrot chips. They found that by increasing frying temperature and time, the moisture content of carrot chips decreased while the oil content increased [16]. This result is in agreement with the work of FAN *et al*. [17], which is in accordance with our results. Also it has been found that the amount of oil absorbed after vacuum frying of potatoes slices was significantly lower than those fried at atmospheric condition [1, 5].

Shrinkage: The amount of oil entering the slice has been shown to be directly proportional to the amount of lost moisture [18]. The statistical analysis indicated that there was no significant relation ($p \leq 0.05$) between shrinkage of mushroom chips and process conditions (Figure1-c).

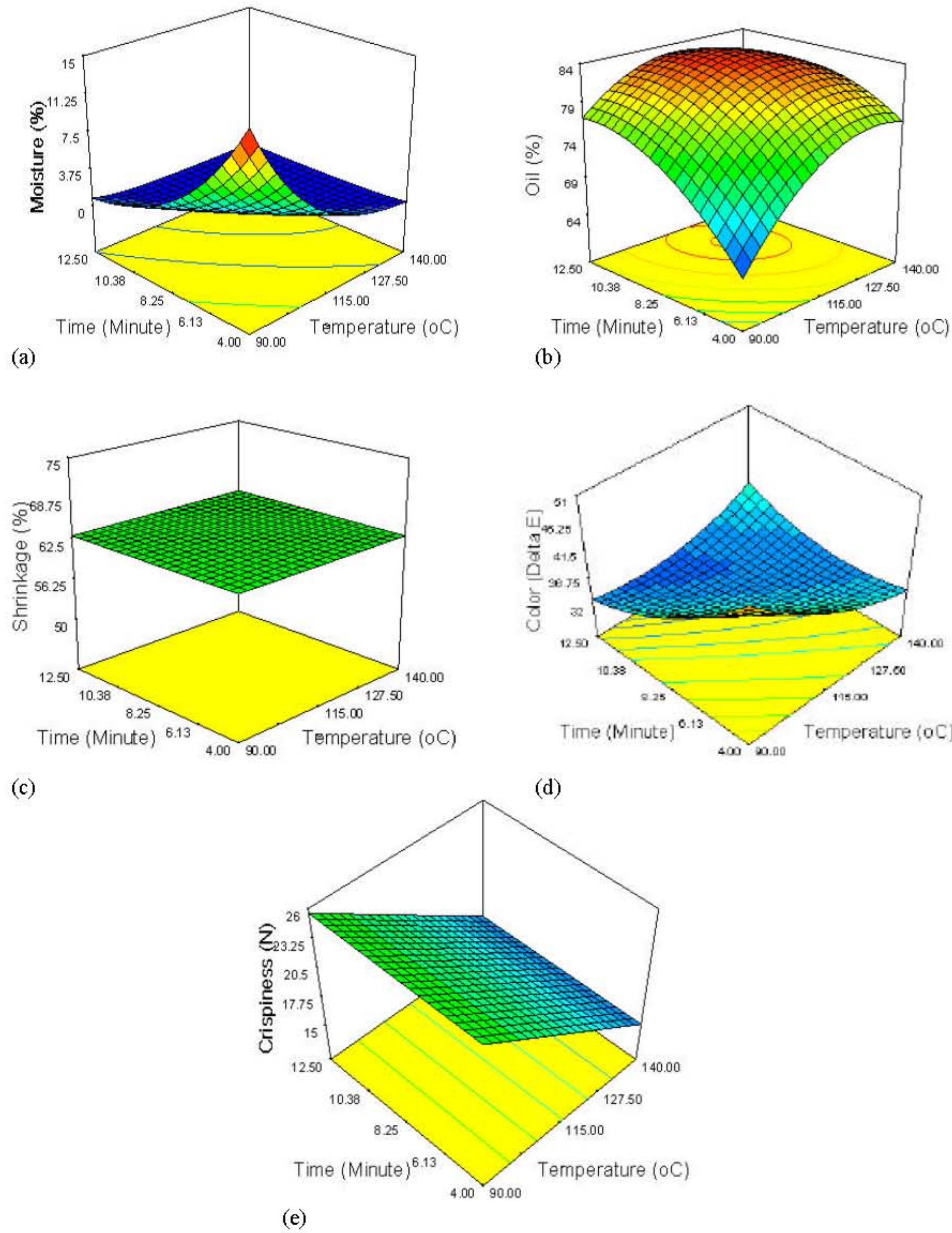

Fig. 1: The contour plots of (a) moisture content, (b) oil content, (c) shrinkage, (d) color, (e) breaking force of vacuum fried mushroom chips as affected by frying temperature and time.

Conversely, results for potato chips showed that, frying at lower vacuum pressure and higher temperature had less volume shrinkage [1], which is in contrast with our results. This might be due to the relative replacement of moisture with oil and hence the majority of mushroom is consisting of moisture, oil is replaced and shrinkage showed a rather constant range during the various conditions of frying.

Color: Most of the products retained their original colors when fried under vacuum [3]. The effects of temperature and time of process was significant ($p \leq 0.05$) on ΔE. Figure1-d shows the changes in color difference (Hunter ΔE) of mushroom chips. This indicates that higher Hunter ΔE values will lead to lower color quality on the surface of mushroom chips. ΔE values of mushroom chips decreased progressively as the frying temperature and time increased. However because of burning phenomena, when the frying time and temperature rise to more than a specific limit, ΔE value started to increase. In vacuum fried apple chips it has been shown that by increasing frying temperature and concentration of immersing solution the hunter ΔE increases significantly [11]. MARISCAL and BOUCHON reported that apple slices fried under vacuum conditions showed only minor changes in ΔE by increasing frying times [6]. Also color of potato chips was not significantly affected by the oil temperature or the vacuum level [1]. When carrot chips were vacuum fried, there was no apparent changes in the total color difference (Hunter ΔE) with time when the frying temperature was below 100°C and the frying time was below 25 min [16]. These contrasts might be due to the nature of substrate used in the experiments. For example differences in initial moisture content, texture and specially sugar content may influence the temperature, time and pressure effects differently due to the various browning phenomena.

Breaking Force: The most important textural attribute of crisps and chips is crispness, which denotes freshness and high quality. A crisp should be firm and snap easily when bent, emitting a crunchy sound [4]. In this study breaking force was used to represent the crispness of fried mushroom chips. A mushroom chip with a lower breaking force value was considered to have higher crispiness. Results showed that the effects of temperature were significant ($p \leq 0.05$) on the crispiness of the mushroom chips which was not significantly affected by vacuum pressure and time of processing (Figure1-e). The results obtained from vacuum frying of potato chips also indicated that the texture was not significantly affected by vacuum pressure [1], although applying vacuum frying to cook doughnuts showed that the texture of doughnut was directly related to both vacuum and frying temperature [19].

The results of this study based on surface responses and contour plots by desirability of 0.608, suggests that vacuum frying at 90°C and vacuum pressure of 4.25 kPa for 12.5 minutes can produce mushroom chips with lower shrinkage, moisture and oil contents as well as good color and crispy texture.

CONCLUSIONS

Vacuum frying can be a viable option for production of snacks from fruits and vegetables, with desirable qualities. During vacuum frying of mushroom, the moisture content, color and breaking force of mushroom chips decreased while the oil content increased and shrinkage did not change with increasing frying time and temperature. The Hunter ΔE, moisture and oil contents of fried mushroom chips were significantly ($p \leq 0.05$) affected by time and temperature of frying while the crispiness of mushroom chips was only affected by the temperature and the relation between shrinkage and processing conditions was not significant. To promote the efficiency of vacuum frying, some physical pretreatments prior to vacuum frying, such as blanching, osmotic pretreatment, freezing and etc, can be applied that affect the texture, yield, moisture content, fat content, shrinkage and color of vacuum fried foods.

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