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ORIGINAL ARTICLE

Optimization of Vacuum Frying Parameters in Combination with Osmotic Dehydration of Kiwi Slices to Produce Healthy Product

Fatemeh Aghabozorg Afjeh[*1], Ali Bassiri[2], Abdorreza Mohammadi Nafchi[1]

[1]BiopolymerResearch Group, Food Science and Technology Department, Damghan Branch, Islamic Azad University, Damghan, Iran

[2]Institute of Chemical Technologies, Iranian Research Organization of Science and Technology (IROST), Tehran, Iran

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KEYWORDS

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ABSTRACT: Osmotic dehydration under discontinuous reduced pressure is one of the new methods of preparation fruits and vegetable processing with in view of good health. Processing of foods at high temperatures used to cook them can cause the formation of carcinogenic substances like acrylamide, and this risk remains even if the trans-fat is removed. The low temperatures employed in this method resulted in the products with the desired texture, nutritional, and colour. The purpose of this research was evaluation of the variable effects of osmotic dehydration process (ambient pressure, contact time of product and solution, concentration and temperature of osmotic solution) on the quality factors of product (colour changes, texture, moisture, oil uptake, and water loss to solid gain ratio) and achieving the optimum process conditions. Studying the quality parameters of the product, the temperature range of osmotic solution, pressure, concentration of the osmotic solution and contact time of product and solution were assumed as 30 to 50°C, 500 to 700 mbar, 30 to 50% and 60 to 180 min, respectively. The test plans involving 31 tests were obtained by using response surface statistical models and central composite design. They were fried at the condition of 108ºC, 8 min and 320 mbar by using statistical correlations, 48.71ºC for the osmotic solution temperature, 592.07 mbar for the pressure, 62.92 min for the time and 34.87% for the osmotic solution. Concentrations were obtained as optimum conditions of osmotic dehydration of kiwi slices under reduced pressure. In summary combination of osmotic dehydration and vacuum frying improved the quality of the final fried kiwi, so this method is recommended for production of healthy products.

*Corresponding author: f_afje63@yahoo.com (F. AghabozorgAfjeh).

INTRODUCTION

Anything that is fried, even vegetables, has the issue of trans fat and the potent cancer-causing substance acrylamide. Animal studies have shown that exposure to acrylamide increases the risk of several types of cancer, and the International Agency for Research on Cancer considers acrylamide a "probable human carcinogen". It has also been linked to nerve damage and other neurotoxic effects, including neurological problems in workers handling the substance. Kiwi, is a high nutritional valuable fruit due to its vitamins E, A, and C and also high contents of fiber, minerals, antioxidants, phenolic compounds and other bioactive substances that plays an important role in improving the health of gastrointestinal tract and body protection against stress. Kiwi fruit has a low shelf-life due to its highly perishable nature and it is consumed not only as fresh fruit, but also as processed products like jams, juices, and canned fruits, frozen and dried products [1]. When fresh products such as fruits are fried, a pretreatment is required to achieve better quality products, before processing them to prepare chips. Frying under ambient conditions cannot be used for fruits, because their texture and colour undesirably change and their appearance become darker reflecting over-baking. Frying process underreduced pressure is an effective method to decrease the oil content in fried snacks. In frying process under reduced pressure, the food is heated at a pressure less than ambient pressure, which reduces the boiling point of the water and the oil of food. Frying process under reduced pressure is a new method for obtaining high quality dried products in a shorter processing time compared with other methods of drying fruits and vegetables [1]. Osmotic dehydration (OD) together with frying under reduced pressure is often used to produce high-quality fruit chips. Osmotic dehydration has been used to reduce the initial moisture content, increasing the shelf-life of processed fruits and vegetables. In osmotic dehydration process, the products are placed in the concentrated solution of sugar, salt or a combination of the two and by creating a concentration gradient between the osmotic solution and product, some of the water is removed from the product. In fact, a multi-component mass transfer process occurs such that at the same time of water loss of food, the substance or osmotic agents permeate into the texture (intracellular or intercellular spaces), which its amount is much less than the water outlet[2]. Due to the high sugar content of osmotic-dehydrated product, frying under reduced pressure is an excellent technology to produce high-quality fruit chips by immersion method. Application of osmotic dehydration as a pretreatment is limited due to the slow rate of the mass transfer and being a time-consuming process. One of the factors that can help to alleviate the constraint is implementation of the process under discontinuous reduced pressure. Pressure reduction is done by both continuous and discontinuous methods. In discontinuous mode, the pressure loss is applied for a short time at the beginning of the process and then continued at ambient pressure [3]. Applying pressure loss in discontinuous mode causes the pores expansion of the product, increasing the mass transfer surface area and thus accelerating the dehydration. The pressure reduction leads to increase the water loss of product, but has almost no effect on the solid gain [4]. Various factors including type and concentration of osmotic solution, temperature and time of the process [5] stirring speed of osmotic solution [6], product to solution ratio [2] and characteristics of raw materials influence on osmotic dehydration of fruits and vegetables. The mass transfer is increased with the osmotic solution concentration. Moreover, a discontinuous reduced pressure leads to a higher mass transfer [3]. In this work, the factors affecting the osmotic dehydration under discontinuous reduced pressure (including operation pressure, contact time of sample with osmotic solution, temperature and concentration of solution) as a pretreatment in frying process of kiwi slices at reduced pressure and their effects on colour response, texture, moisture, oil uptake and ratio of water loss to solid gain were evaluated and the obtained data were analyzed and optimized by response surface methodology.

MATERIALS AND METHODS

Studied sample

This study was carried out on Hayward kiwi fruits with the highest quality. After purchasing fresh kiwi fruits, the samples were stored in the refrigerator at 4-5°C until required for the experiments. Then, they were removed from the refrigerator about 30 minutes before the process allowed for the samples reach the room temperature. After stabilization at the laboratory temperature, the samples were peeled, washed with urban water and after draining with an absorbent tissue were vertically cut into 2 mm thick slices. Before experiments, their characteristics were:

Moisture content on a wet basis of 85.31%

Texture rigidity of 1.4 N/mm

Colour of b* 15.06, a* -7.09, l* 38.54

pH of 4.36

Pretests

After reviewing previous researches, some ranges were determined for main plan of tests. The ranges of the variables under studying (including the osmotic solution temperature of 30-50°C, the concentration of 30-50% W/V, the pressure of 500-700 mbar inside of the chamber and the product with the solution contact time of 180 to 60 minutes) were considered.

Solution preparation

In this study, drinking water and edible sucrose were used in order to prepare osmotic solution. The solution was prepared with the solution to product ratio of 30:1 and the concentration of 40-50% V/W and then poured into a 1 liter beaker and agitated on a stirring heater with a mild temperature to get uniform. The prepared solution was kept in the refrigerator at +4ºC until use.

Osmotic dehydration of samples

The prepared osmotic solution was transferred into the magnetic jar and then placed on the stirrer hot plate up to reach the required temperature. The samples with 2 mm thickness were weighed and marked. They were put into a grid basket and then transferred into the jar containing osmotic solution having desired temperature and placed on the heater. Moreover, the solution was calmly stirred by a magnet allowed for the uniformity of the solution concentration around the samples. At the beginning of each experiment, the specified pressure in the experiments plan was applied in the jar for 15 min. After that, the obtained reduced pressure was broken by the pressure breaker valve and the osmotic dehydration was continued at ambient pressure till required. Then the samples were removed from the container, washed with water for 30 s, drained by a tissue and then weighed again.

Reduced-pressure frying

After dehydration, the samples were prepared for frying. They were weighed and then placed into the grid and subsequently into the fryer containing oil, already reached the desired temperature (105°C). After achieving the desired reduced pressure (about 320 mbar), the basket containing the samples was put into the oil by a lifting wire. When the frying time (8 minutes) was spent, the samples were removed from the oil and the pressure of the fryer reached atmosphere pressure by pressure breaker valve. After reaching ambient temperature, the excess oil was removed by a tissue and then weighed.

Measuring physical and chemical characteristics of samples

Measuring moisture content on a wet basis

In this study, the moisture content of raw kiwi, processed slices of kiwi and also fried kiwi were measured according to AOAC in triplicate by putting samples in an atmospheric oven at 102±2ºC until attaining a constant weight [7].

Measuring the rate of soluble solid gain (SG) and water loss of sample (WL) was calculated using the following equations.

$$SG\ (\%) = (X^{ST}_{F}\ \ M^{0}_{f} - X^{ST}_{0}M^{0}_{0}\times 100)/M \qquad (1)$$

$$WL\ (\%) = (X^{W}_{0}M^{0}_{0} - X^{w}_{f}M^{0}_{f}\times 100)/\ M \qquad (2)$$

X^{ST}_{f}: the final solid content of osmotic-dehydrated sample

M^{0}_{f}: the final weight of osmotic-dehydrated sample (g)

M^{0}_{0}: the initial weight of sample (g)

X^{ST}_{0}: the solid content of initial sample

X^{W}_{0}: the initial moisture content

X^{W}_{f}: the final moisture content

Determination of water loss to soluble solid gain ratio WL/SG in dry samples tissue

One important factor in evaluation of osmotic dehydration process performance is the water loss to soluble solid gain in an osmotic-dehydrated sample. Because the more this ratio is, the higher the osmotic dehydration efficiency is. So the water loss and solid gain ratio of samples were measured for the studied time periods of osmotic dehydration process and then the WL/SG was determined [8].

Measuring texture rigidity of samples

In this study, a three-point bending test was used for measuring the rigidity of the fried kiwi samples. The Testometric M350-10CT texture analyzer made in England was used in Tehran University. In the present study, a Probe of rod shape with a straight edge and a thickness of 2 mm and a constant speed of 60 mm per minute were used. The maximum amplitude was 50 N. It is noteworthy that the test was carried out in triplicate.

Measuring colour changes

Colour changes of the processed samples were evaluated using a Hunter Lab. In this research, Hunter Lab color system of CHOROMA METER Model CR-400, available in Karaj Agricultural Research Institute, was used to investigate the colour of products. The three colour indices of the samples including L*, a*, b* were evaluated by Hunter Lab. A*, L* and b* represent red-green, brightness and yellow-blue, respectively. The colour difference between the processed and initial samples indicated by ΔE was calculated by the following equation:

$$\Delta E = \sqrt{(L^{*} - L^{*}_{0})^{2} + (a^{*} - a^{*}_{0})^{2} + (b^{*} - b^{*}_{0})^{2}} \qquad (3)$$

Measuring fat content

In this study, Soxhlet method was used to measure the fat content of fried kiwi under optimal conditions with hexan as solution according to AOCS method No. BC 3-49. Thus, a 1 gr sample was weighed and placed into a thimble. Then placed in the extraction part of Soxhlet unit and the oil of sample were extracted by solution after 8 hr [9]. The oil content was calculated by the following equation:

$$Oil = \frac{W_2}{W_1}\times 100\% \qquad (4)$$

W_1: the weight of sample

W_2: the weight of left oil in the balon

Statistical analysis

The obtained data from all the carried out experiments was evaluated based on Response Surface Methodology (RSM). Response Surface Methodology (RSM) is a collection of statistical and mathematical methods nowadays applied by food scientists in research and development scope increasingly for manufacturing of innovative products and also process optimization. Most application of this technique is in the processes in which several variables are effective on the process performance and product quality indicators (responses). The software JMP Version 7 made by SAS Co. was used to determine and analyze experiment plans and to attain optimal condition.

Optimization of process condition

In this research, first by conducting pre-experiments at the range of the variables under investigation (osmotic solution temperature of 30-50°C, pressure of 500-700 mbar inside the chamber, osmotic concentration of 50-30% w/v, contact time of product and osmotic solution of 60-180 min) was considered and after the investigation of the obtained qualitative indicators of products, statistical model of response surface was used to determine experimental design and process optimization. The quality factors of final product (the responses) included moisture, water loss to solid gain ratio and rigidity of texture, colour changes and oil absorption. Then 31 tests were conducted at the suggested conditions and experiments plan. These tests were performed in triplicate to determine the qualitative indicators and finally the mean value is given (Table1).

Table 1. The results of the experiments (continue of table 1 in next page)

Test No	Osmotic solutionconcentration	Time contact	Osmotic pressure	Temperature solution	ΔE	Texture	moisture	Oil absorption	WL/SG
The rawcontrol						1.4	85.31		
The fried control					13.58	2.245	18.42	41.34	
1	50	60	500	30	13.03	3.604	7.98	22.56	2.74
2	40	120	500	40	12.62	3.202	8.72	12.84	1.82
3	40	60	600	40	12.24	2.316	9.32	10.27	2.09
4	50	120	700	50	10.11	5.752	8.2	23.22	4.13
5	30	180	600	40	11.13	2.073	9.47	11.48	3.19
6	30	120	700	50	13.86	5.864	8.67	19.24	3.29
7	40	180	600	40	12.42	2.492	9.2	10.41	2.26
8	50	180	700	30	11.04	2.704	8.99	25.2	2.24
9	40	120	600	40	12.72	2.231	9.38	10.05	2.14
10	40	60	600	40	13.01	2.9	9.3	9.36	2.62
11	40	120	600	40	12.24	2.456	9.15	10.22	2.29

Test No	Osmotic solutionconcentration	Time contact	Osmotic pressure	Temperature solution	ΔE	Texture	moisture	Oil absorption	WL/SG
12	30	180	700	30	12.17	2.256	8.95	12.67	4.62
13	50	120	600	40	9.89	3.125	8.3	14.82	2.5
14	50	180	500	50	5.98	6.714	5.35	23.61	3.01
15	30	180	500	50	12.3	3.863	8.17	15.33	3.27
16	40	120	600	40	12.21	2.309	9.71	10.11	2.29
17	30	60	500	50	11.86	5.876	6.1	22.45	3.57
18	30	60	700	50	13.07	5.91	6.86	23.05	2.83
19	50	60	700	30	13.11	3.226	6.45	20.93	2.52
20	50	180	500	30	10.43	2.819	9.3	21.88	1.48
21	30	60	500	30	11.81	2.905	8.92	19.22	4.66
22	40	120	600	40	12.66	2.506	9.37	10.1	2.6
23	50	60	700	50	12.97	6.131	7.08	20.75	3.9
24	40	180	600	40	12.29	2.015	12.52	8.25	2.35
25	40	120	600	40	12.37	2.611	9.78	10.98	2.66
26	50	60	500	50	11.01	8.18	5.87	22.13	4.33
27	30	60	700	30	10.82	2.518	5.89	20.59	3.66
28	40	120	600	50	12.83	4.411	6.21	12.88	3.66
29	40	120	700	40	12.87	3.09	7.98	13.1	1.87
30	30	180	500	30	13.92	2.243	13	7.75	3.78
31	40	120	600	40	12.35	2.557	9.56	10.35	2.33

According to the desired quality factors of kiwi chips (the moisture, the lower colour changes, the higher rigidity of texture, the higher WL/SG ratio and the lower oil absorption) and analysis of the above data by statistical correlations and response surface methodology, optimum condition of the process were determined as:

Osmotic solution temperature: 48.71ºC

Osmotic solution concentration: 34.87% w/w

Contact time of the product and the osmotic solution: 62.92 min

Table 2. Comparison between the results of the tests conducted at the optimum condition and those of the statistics.

Results	oil absorption	moisture	rigidity of texture	colour changes	WL/SG rate
Results of response surface methodology	14.9	9.27	2.85	12.28	2.70
Resultsof experiments	14.82	9.07	2.78	13.63	3.45

The results of the optimum experiment were compared with those of the response surface methodology.

Although the results of the optimization of the experiments are not the same as the statistical results, but have had better responses compared to the previous conducted tests. As a result, the specified conditions assumed as the optimum, are favorable and the selected model has high accuracy in the determination of optimum conditions.

RESULTS AND DISCUSSION

As can be seen in diagram 1, color changes of the product are increased with osmotic solution temperature compared to the control sample. Pressure does not significantly affect the trend of increasing and decreasing the color variation. The results of the colorimetric test with Hunter Lab are reported, indicated by ΔE representing the difference between the colour of the processed product and the raw material. This means that increasing values of ΔE factor is indicative of the loss of color quality. In fact, it represents increasing the difference between the colour of product and raw material. Final colour variation of product is significantly affected by osmotic solution temperature of process, while pressure does not have significant effect on that. According to the diagram 1, by increasing the temperature of osmotic solution, the difference between the colour change and raw material increases. This is because by increasing the temperature, sugar is caramelized and the colour turns to brown. Furthermore, when the temperature increases, the requirements for non-enzymatic browning reaction (Maillard) is provided. In this reaction, the aldehydeof sugars and amins of proteins reacted with each other and produced brown pigments. The other reason is that by the temperature rise of the solution, the cell wall gets thin and causes the substances enter between cells space and then the effective enzymes in browning reaction and the substrate come together. The obtained results are consistent with the foundings of [10, 11 and 6]. As diagram 2, the increase of the osmotic solution concentration resulted in the reduction of colour changes compared to the control. According to this figure, by increasing of the osmotic solution concentration, the colour changes were reduced. The reason is that the rise of the osmotic solution concentration increases the rate of dehydration process and limits the activation chance of effective factors in colour alterations and browning reaction. As we know, the sugars relatively deactivate and inhibit the enzymatic activities which create browning reaction. So that osmotic dehydration prevents colour variations during the process. Therefore the product has superior colour than products of other processing method (frying, drying).

As diagram 3 shows, by increasing the concentration of osmotic solution, the rigidity of texture decreases and gets softer and more elastic and needs more force. Pressure does not have significant effect on texture of fried kiwi. In this work, minimum force was used to penetrate to fried kiwi slices in order to determine the rigidity of product texture. As the less force represents the less softness and tenderness of the product. As diagram 3 indicates, by increasing of the concentration of osmotic solution, the texture becomes softer and more elastic. The reason is that increasing of the concentration of osmotic solution, increases sucrose absorption to the inside of the texture and increasing of the mass transfer rate followed by the permeation of calcium ions from the sample to the solution. So that the lower concentration of calcium ions inside of the texture of sample causes increasing of the texture resistance to shear forces and then a soft and elastic texture for product is created. The results obtained in this work are consistent with Kalbasi and Fatemian's foundings [12].

As can be seen in Figure 4, increasing of the concentration of osmotic solution reduces the texture rigidity and gets softer and more force is needed. Time factor does not significantly affect the texture. Az diagram 4, we can see that by increasing of the osmotic solution temperature, the texture becomes softer and more elastic. Because of decomposition of some effective components on texture consistency due to high temperatures, texture of samples gets softer by increasing solution temperature. In addition, it seems that increasing solution temperature leads to solid gain of osmotic solution into texture of product and reversely affects rigidity of dried samples. The results are consistent with those of [12]. By studying Figure 5, we can understand that the rate of WL/SG increases with the increase of the osmotic solution temperature and time. As diagram 5, increasing of the contact time of product and osmotic solution causes the rate of WL/SG increases.

The reason is that by contact time increasing, sample loses more water into the solution and also causes osmotic agents gain into the texture of sample. In this work, the increasing trend of water loss was more apparent and so the WL/SG rate increased. As diagram 5, we understood that this proportion is increased with the rise of osmotic solution temperature. Osmotic dehydration at the high temperatures causes the changes of the permeability of the cell wall and so the permeability of the texture against the moisture loss and sucrose gain. The use of high temperature leads to inflammation and plasticity of cell membrane and consequently faster moisture release of texture. The obtained results are consistent with the foundings of [13, 14]. As can be seen in Figure 6 by increasing osmotic solution concentration and decreasing pressure, moisture rate is reduced. The more solution concentration is the more moisture the sample loses. The reason is increasing of osmotic gradient between product and osmotic solution. Presence of high amounts of solute causes high osmotic pressure and easiness of moisture loss. Moisture loss of fruit by applying reduced pressure pulse is explained by hydrodynamic mechanisms. Applying reduced pressure, water of product and confined gases in space of between cells of vegetable texture is removed and after reaching ambient pressure, food pores becomes full of osmotic solution. This event increases mass transfer at available area of product. Researches of [3] approved of the obtained results.

Figure 7 shows that oil absorption rate is reduced by increasing osmotic solution concentration. Pressure does not have significant effect on oil absorption rate. Osmotic dehydration affects total amount of oil in fruit chips, also defatting systems remove some of the surface oil (about 45%) and then final amount of the oil in fruit chips is reduced. During osmotic dehydration, sugar gain occurs that cause's oil absorption reduction. This event results from increasing of water loss (or solid gain) during osmotic dehydration. Diagram 7 indicates that oil amount is considerably reduced when solution concentration increases.

CONCLUSION

Nowadays, one of the most important goals in food industry and food engineering is the exertion of new facilities and technologies for manufacturing new products by new processing methods. The main objective of using the new methods of quality and safety improvement of food is simultaneous. Moreover, the mentioned methods cause providence of energy consumingand reduction of environmental problems. One of the new methods of food processing is frying under reduced pressure with discontinuous osmotic dehydration under reduced pressure as pretreatment. Osmotic dehydration processing followed by frying, is one of the processing methods that despite all its individual characteristics such as reducing thermal damage of colour and aroma of product in frying has not attracted enough attention compared to immersion frying. In addition to increasing the shelf life of product and no need to low temperatures for keeping, use of this technology has the benefit of easiness of food consumption. The result obtained from this work showed that increasing of osmotic solution temperature causes decreasing of texture rigidity, moisture, increasing of colour changes and WL/SG. Damage of the cell wall and physicochemical transition resulted from temperature increment inside of product can be assumed as the main reason of these alterations. Colour change, oil absorption and texture rigidity were decreased with the increase of osmotic solution concentration. But WL/SG ratio was increased. Moreover optimum conditions for osmotic dehydration under reduced pressure of kiwi slices were osmotic solution of 48.71ºC, osmotic solution concentration of 34.87% w/v, time contact of product and osmotic solution of 62.92 min, pressure of 592.07 mbar. According to the efficiency of osmotic dehydration of the final quality improvement of fried products and possibility of reducing the need of additives like sulphuric components and also regarding economizing in energy consumption of osmotic dehydration compared to conventional methods, continuity of researches is suggested in order to achieve much more information in osmotic dehydration and its applications in dried fruits industry.

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