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Optimisation of Osmotic Dehydrated Microwave Frying of Potato Slices

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ABSTRACT

In this part of the study, osmotic dehydration was applied prior to microwave frying process in order to reduce oil uptake and to evaluate the effect of osmotic dehydration with microwaves on quality of fried potatoes. The process was optimized by using both Taguchi Technique and Response Surface Methodology. Microwave power level (450W, 600W and 750W),frying time (1.5,2.0, 2.5 minutes) and osmotic dehydration time (15, 30, 45 minutes) were the parameters used in the study. Osmotic dehydration treatment was conducted in a salt solution of 20 % (w/w) at 30°C. Moisture content decreased whereas oil content, hardness and ΔE value of potatoes increased with increasing frying time and microwave power level. Dehydration of potatoes osmotically prior to frying reduced the oil content of fried potatoes. The optimum condition was found as frying at 450 W microwave power level for 1.5 min after 30 min of osmotic dehydration time according to Taguchi Technique. Microwave power level and frying time were the same as Taguchi Technique but osmotic dehydration time was 39 min for the optimum condition found using response surface methodology.

Key words: *Microwave Frying; Optimization; Osmotic Dehydration; Response Surface Methodology (RSM); Taguchi Technique.*

INTRODUCTION

Osmotic dehydration as a pre treatment is a good way of producing dried fruits of good quality with reduced energy consumption[17,19]. Osmotic dehydration also termed as 'Dewatering and Impregnation Soaking Process' (DISP), is a useful technique for the concentration of fruit and vegetables, realized by placing the solid food, whole or in pieces, in aqueous solutions of sugars or salts of high osmotic pressure[19]**.** In osmotic dehydration, food products are soaked in concentrated aqueous solutions, usually of sugar or salt. During this process, water flows out from the product to the solution and solute in the concentrated sugar/salt solution diffuse into the product. The two main mass transfers continue until the water activity (a_w) of the product and the osmo-active solution are equal.

In addition, osmotic dehydration is effective at ambient temperature with, achieving product stability, retention of nutrients and improvement of food flavor and texture.

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It results also in less discoloration of fruits by enzymatic oxidative browning; it satisfies consumers demand for minimally processed products while additionally facilitates the industrial processes requiring reduced drying times**.** For French fries, sodium chloride solution is recommended to be used in the dehydration process.

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes. It also has important applications in the design, development, and formulation of new products as well as in the improvements of existing product design [13].

Response surface methods are used to examine the relationship between one or more response variables and a set of quantitative experimental variables or factors. Designs of this type are usually chosen when curvature is supposed to be present in the response surface.

RSM is a four step process. First, the number of factors that are of interest are determined. Second, the ranges of factor levels which will encompass the physical specifications of the samples are defined. Third, the specific test samples are determined by the experimental design and tested. Fourth, the data from these experiments are analyzed by RSM and then interpreted. For RSM to be meaningful certain assumptions should be satisfied[13].

In RSM generally two types of designs are common: Central Composite Design and Box-Behnken Design. Central composite designs are often recommended when the design plan calls for sequential experimentation because these designs can incorporate information from a properly planned factorial experiment. The factorial or “cube”portion and center points may serve as a preliminary stage where a first-order (linear) model can be fit, but still provide evidence regarding the importance of a order contribution or curvature.

MATERIALS AND METHODS

In the second part, the effect of osmotic dehydration on microwave frying was evaluated and the frying process was optimized by considering the effect of microwave power level, frying time and osmotic dehydration time on product quality.

Effects of osmotic dehydration and microwave power level on the quality parameters of microwave fried potato slices

Osmotic Dehydration Treatment

In the second part of the study instead of oil type, osmotic dehydration time was used as the third factor in the experimental set up. The potatoes were immersed in salt solution (20 % w/w) at 30^{o}C for 15, 30, 45 minutes. Seven pieces of potatoes were soaked in 200 ml of salt solution at a ratio of salt solution to potato pieces of 7.5:1 (w/w). Potatoes were gently blotted dry with paper towel to remove surface solution prior to frying.

Conventional drying

In order to understand the effect of salt which diffused into the potato, the potatoes were pre-dried to the same level of moisture content as osmotic dehydration. The drying was performed in the forced convection oven at 105^{o}C .

Frying

Frying was conducted in the conditions described. However, the osmotically dehydrated potatoes were fried at the predetermined microwave power levels (450 W, 600 W, 750W) for 1.5, 2.0, 2.5 minutes respectively. For comparison, osmotically dehydrated potatoes were also conventionally fried at 170 ±1^{o}C in commercial bench top deep fat fryer for 4 minutes.

Table 1: Parameters and levels used in second part of the study

LEVELS			
PARAMETERS	1	2	3
Microwave Power (W)	450 W	600 W	750 W
Frying time (min)	1.5 min	2.0 min	2.5 min
Osmoticdehydration time	15 min	30 min	45 min

Table 2: Experimental conditions for the first part of the experiment (Taguchi design)

Experiment No.	Microwave Power (W)	Frying time (min)	Osmotic dehydration time (min)
1	450	1.5	15
2	450	1.5	30
3	450	1.5	45
4	450	2.0	15
5	450	2.0	30
6	450	2.0	45
7	450	2.5	15
8	450	2.5	30
9	450	2.5	45
10	600	1.5	15
11	600	1.5	30
12	600	1.5	45
13	600	2.0	15
14	600	2.0	30
15	600	2.0	45
16	600	2.5	15
17	600	2.5	30
18	600	2.5	45
19	750	1.5	15
20	750	1.5	30
21	750	1.5	45
22	750	2.0	15
23	750	2.0	30
24	750	2.0	45
25	750	2.5	15
26	750	2.5	30
27	750	2.5	45

Table 2 Experimental conditions for the first part of the experiment (Taguchi design)

Analysis of fried samples

The fried samples were dried in a forced convection oven at 105^{o}C up to the establishment of constant weight for moisture determination[2]**.** The oil content of the fried samples was determined by using Soxhlet extraction method with n-hexane for 6 hours after the potatoes were dried in the conventional oven[2]**.** Moisture content and oil content were calculated on % dry basis (g moisture/ g dry solid, g oil/g dry solid). Color of the fried samples was measured using a Minolta color reader (CR-10, Japan). The color readings were expressed by CIE (L*a*b*) color system. L*,a* and b* indicates whiteness/darkness, redness/greenness, blueness/yellowness values, respectively. Total color difference (Δ E) was calculated from the following equation:

$$\Delta \text{ E}=\sqrt{\{(L*-L\ standard\ *)2+(a*-a\ standard\ *)2+(b*-b\ standard\ *)2\}}$$

where, standard values referred to the BaSO4 plate (L^*=96.9, a^*=0 and b^*=7.2). Triplicate readings were carried out at room temperature at three different locations of each sample and mean value was recorded.

Textures of the samples were determined in terms of hardness. Hardness of the potato samples were measured 15 min after frying, using a texture analyzer (Lloyd Instruments, TA Plus, Hants, UK) directly without any sample preparation. A pin shaped probe was attached to the instrument for the penetration test. The instrument was set to a speed of 55 mm/min for 100% penetration of the pin into the fried sample.

Statistical analysis and optimization

For optimization by Taguchi Technique, the software, Qualitek-4 (Version 4.82.0), which is designed for Taguchi experiments, was used.

For optimization by Response Surface Methodology "multiple response optimizer" option of MINITAB was used. The contour plots for the parameters were also drawn by using MINITAB.

RESULTS AND DISCUSSION

Effects of microwave frying on the quality parameters of osmotically dehydrated potato slices

Moisture Content

The initial moisture content of potatoes was in the range 80-82% (wet basis). The osmotic dehydration process decreased the initial moisture contents of potatoes. The moisture contents of the potatoes and the water activities of the potatoes after osmotic dehydration are given in Figure 1-2 respectively. It can be seen that the decrease in moisture content was high in the first 15 minutes whereas it was quite low after 30 minutes. The water activity of the osmotically dehydrated potatoes also confirms that trend. (Fig. 2)

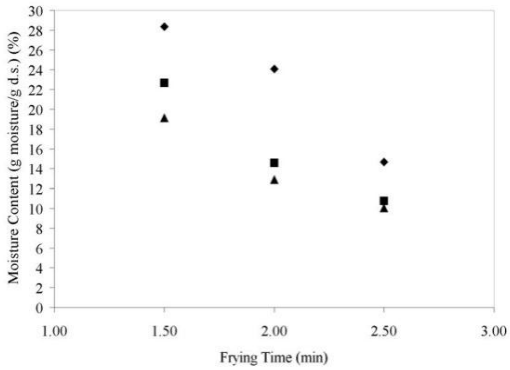

Fig. 1: Effect of osmotic dehydration on moisture content (db) of raw potatoes

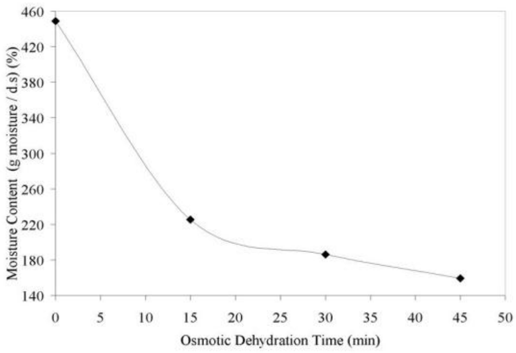

Fig. 2: Effect of osmotic dehydration on water activity of raw potatoes

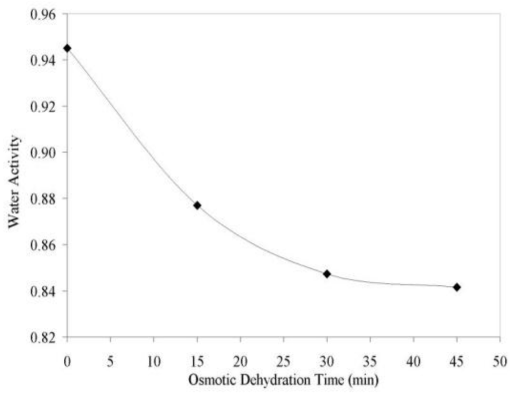

Fig. 3: Variation of moisture content of osmotically dehydrated potatoes for 15 minutes during frying at different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

It was observed that moisture was lost during frying and increasing the power level above 600 We did not increase moisture loss significantly for all dehydration times (Figure 1-2).According to test results 450 W of microwave power level was found to be significantly different from 600 W and 750 W whereas no significant difference was detected between 600 W and 750 W microwave power levels in terms of moisture content. For frying time and osmotic dehydration time, all the levels were found to be significantly different from each other.

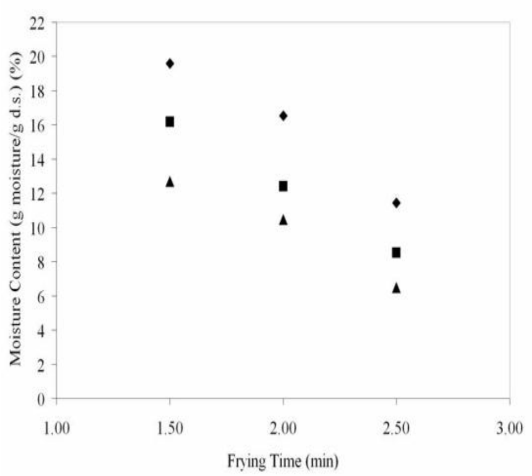

Fig. 4: Variation of moisture content of osmotically dehydrated potatoes for 30 minutes during frying at different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

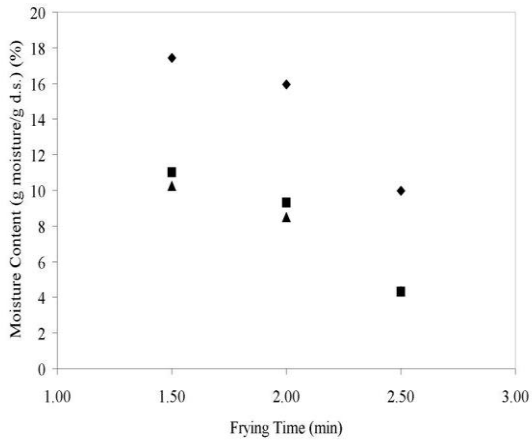

Fig. 5: Variation of moisture content of osmotically dehydrated potatoes for 45 minutes during frying at different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

When the effect of dehydration time was examined during frying at 450 W microwave power level it was seen that as dehydration time and frying time increased moisture loss increased as well (Figure 5). The rate of moisture loss was higher when the osmotic dehydration time was lower (15 min). This was an expected result in the sense that at lower dehydration times the initial moisture content was higher resulting in higher driving force during frying. According to test, there was no significant difference between osmotic dehydration time for 30 min and 45 min with respect to their effects on moisture content of fried potatoes at 450 W (Fig. 5)

Similar trend was observed during frying at higher microwave power levels (Fig 6 and 7).

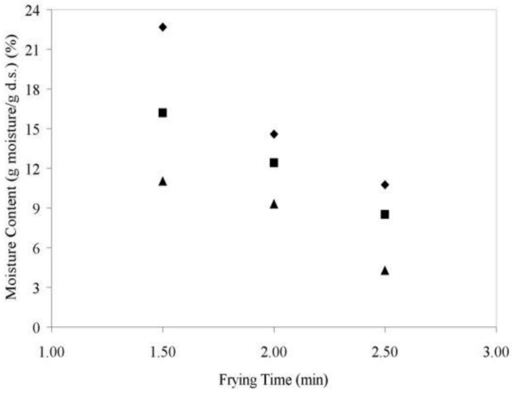

Fig. 6: Variation of moisture content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 450 W: (◇) 15 min; (□) 30 min; (Δ) 45 min.

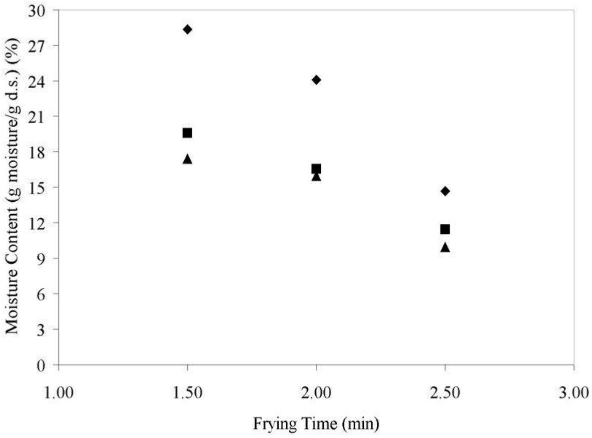

Fig. 7: Variation of moisture content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 600 W: (◇) 15 min; (□) 30 min; (Δ) 45 min.

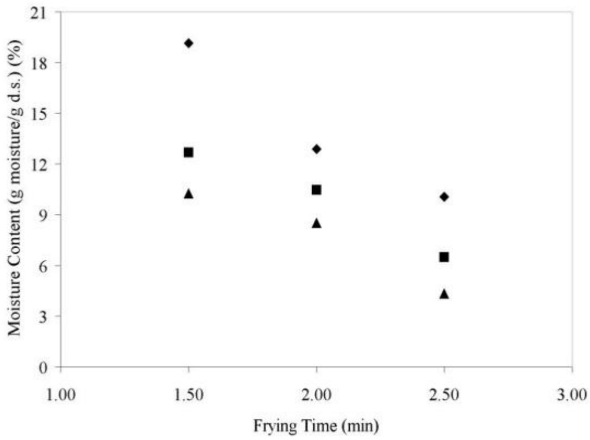

Fig. 8: Variation of moisture content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 750 W: (◇) 15 min; (□) 30 min; (Δ) 45 min.

The moisture content of potatoes fried in the conventional deep fat fryer for 4.0 minutes were 20.75 %, 16.37 %, 12.82 % (db) when soaked in the salt solution for 15, 30, 45 minutes prior to frying, respectively. The moisture content of potatoes fried in microwave oven even at low power level (450 W) for 2.5 min when soaked in the salt solution for 15, 30, 45 minutes were lower than the conventionally fried ones (14.67 %, 11.43 %, and 9.97 % db for dehydration times of 15, 30 and 45 minutes, respectively). The resulting difference between conventional deep-fat frying and microwave frying was expected since microwaves increased moisture loss significantly.

In order to understand the effect of salt which diffused into the potatoes during dehydration, initial moisture content of potatoes were reduced to the same level as osmotic dehydration by conventional drying. Frying was performed at 600 W power level for 1.5 minutes. The final moisture content of the potatoes that were equivalent in terms of their initial moisture content to the ones that were held for 30 minutes in salt solution was 29.56 % (db). On the other hand, the moisture contents of the microwave fried (600 W for 1.5 min) potatoes that were osmotically dehydrated for 30 min prior to frying was 16.18 % (db). The lower moisture content of the microwave fried potatoes after osmotic dehydration was due to penetration of salt into the product which caused an increase in dielectric loss factor. Microwave absorptivity of a material depends on dielectric loss factor and therefore, the increase in loss factor results in higher temperature of the product. In frying, the loss factor does not decrease with decreasing moisture content but increases due to the presence of salt. Foods with added salts are known to show continuous increase in dielectric constant and loss factor with respect to temperature**.** The increase in dielectric loss factor causes the product to be heated more. As a result, moisture loss increases. This result was also confirmed by the temperature profiles of the potatoes during frying (Figure 9). It is obvious from the figure that the temperature of the fried potatoes that were subjected to osmotic dehydration was higher during frying than the conventionally dried microwave fried potatoes and microwave fried potatoes that were not osmotically dehydrated.

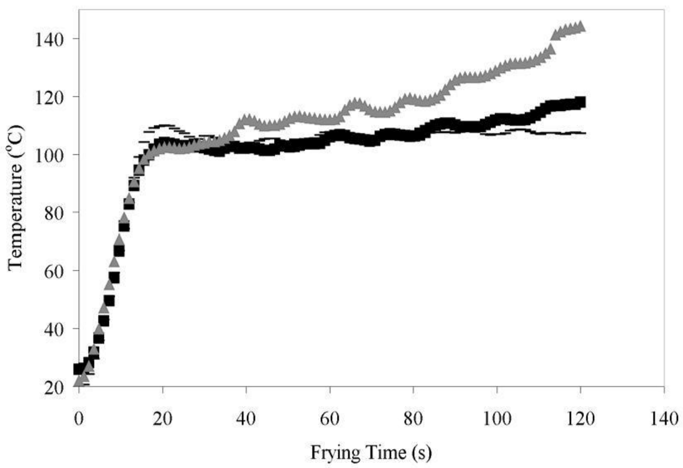

Fig. 9: Comparison of center temperature of potatoes during different frying methods: (-) Conventionally dried and microwave fried potatoes; (□) Microwave fried potatoes without osmotic dehydration; (△) Osmotically dehydrated microwave fried potatoes

Oil Content

Oil content is one of the most important quality attributes of a deep-fat fried product. Osmotic dehydration is used as a pretreatment before frying to produce low-fat fried potatoes. Figure 10, shows how oil content changed with respect to frying time for different microwave power levels when potatoes were held in salt solution for 15 min prior to frying. As microwave power and frying time increased oil content increased. This result is consistent with the fact that high moisture loss causes high oil uptake since as microwave power and frying time increased moisture loss increased (Fig. 10). The difference between microwave power levels of 600 W and 750 W was not very significant. Similar results were obtained when the osmotic dehydration times were higher (Fig.11-12).

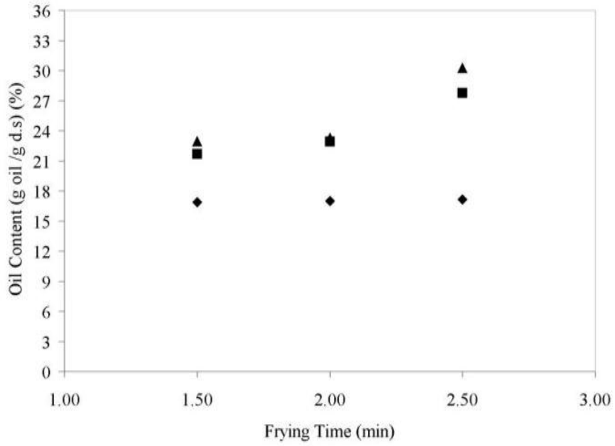

Fig. 10: Variation of oil content of osmotically dehydrated potatoes for 15 minutes during frying at different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

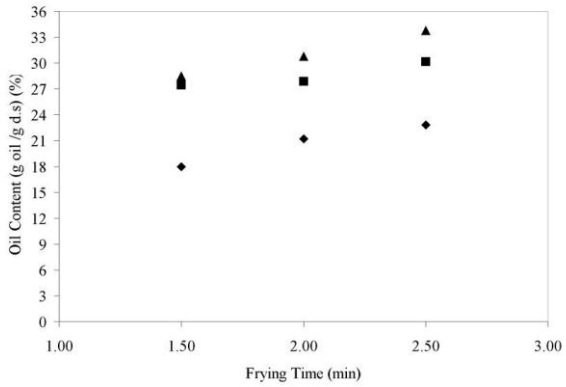

Fig. 11: Variation of oil content of osmotically dehydrated potatoes for 30 minutes during frying at different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

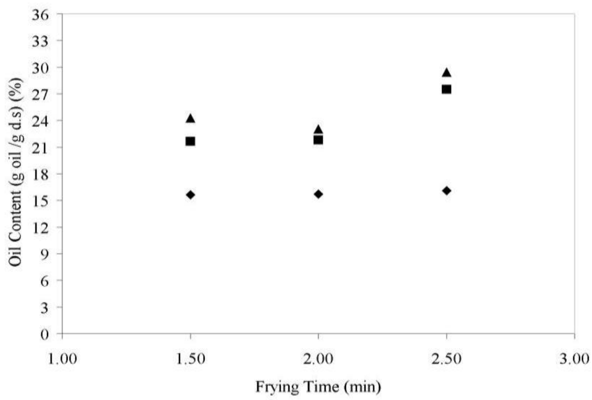

Fig. 12: Variation of oil content of osmotically dehydrated potatoes for 45 minutes during frying at different microwave power levels (◇) 450 W; (□) 600 W; (Δ) 750 W.

The lowest oil content (15.65 % db) was observed in the potatoes that were fried at 450W microwave power level for 1.5 minutes and dehydrated for 45 minutes. Oil content of these potatoes were less than the oil content of conventionally fried potatoes that were osmotically dehydrated for 15, 30, 45 minutes (27.83 %, 17.79 %, 17.95 % (db) respectively). For other microwave power levels and dehydration times the oil content of osmotically dehydrated microwave fried potatoes was not found to be smaller than the osmotically dehydrated conventionally fried ones as seen in

The high oil content of these potatoes may be explained due to structural changes that take place during conventional drying which enables easy uptake of oil. If the potatoes were dehydrated partially in conventional oven, highly porous structure was obtained which were filled with oil during frying. When they were osmotically dried there was less space for oil to enter since the pores were partially filled with salt. In accordance with this result[10] found that pre-drying decreased the oil and moisture contents of French fries whereas increased the porosity. However the oil content of the pre-dried microwave fried potatoes were still lower than the ones that were not pre-treated.

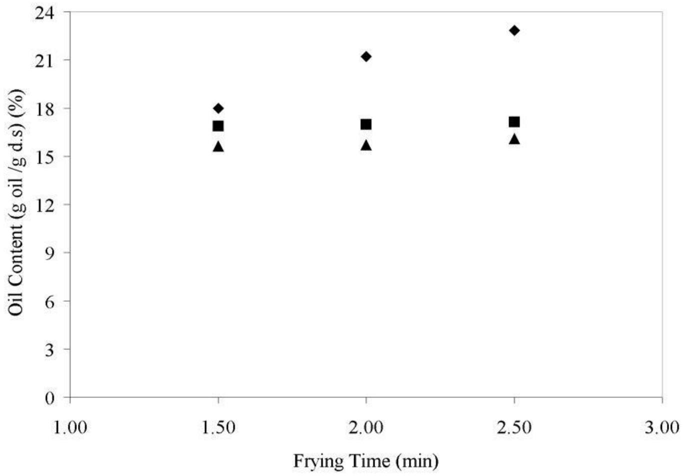

Fig. 13: Variation of oil content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 450 W: (◇) 15 min; (□) 30 min; (∆) 45 min.

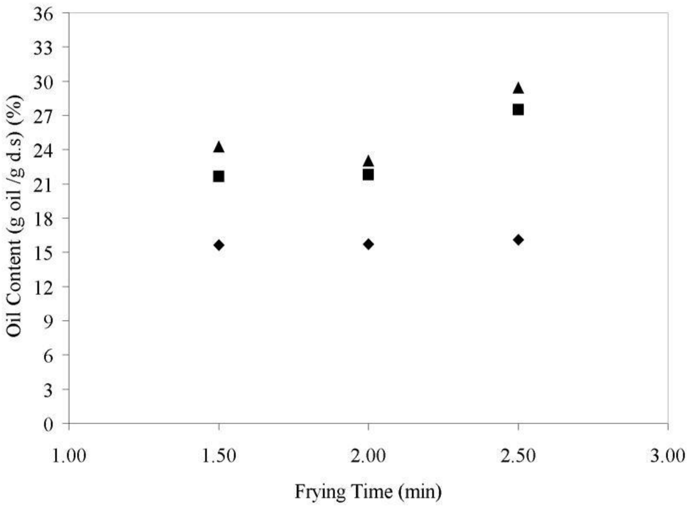

Fig. 14: Variation of oil content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 600 W: (◇) 15 min; (□) 30 min; (∆) 45 min.

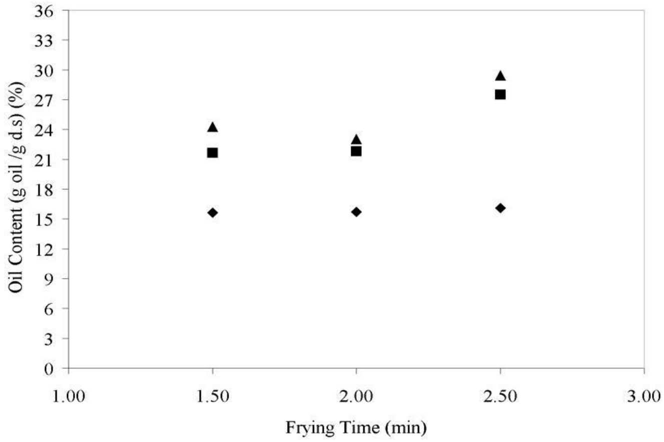

Fig. 15: Variation of oil content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 750 W: (◇) 15 min; (□) 30 min; (∆) 45 min

Color

[9]**Krokida, Oreopoulu, Maroulis and Marinos-Kauris** found out that the lightness of potato strips increased during early stages of frying while it remained almost constant afterwards. Moreover, they stated that as temperature of the frying medium increased lightness decreased. Lightness of potato strips increased during frying, in the case of 450 W microwave power level which may correspond to the initial stages of frying compared to other pow leverels as[9] stated (Fig. 16) . For microwave power levels of 600 W and 750 W, as frying time increased lightness decreased due to increase in temperature (Figure 16). A significant difference in L^* value could not be detected between the osmotically treated microwave and conventionally fried potatoes (Table 3).

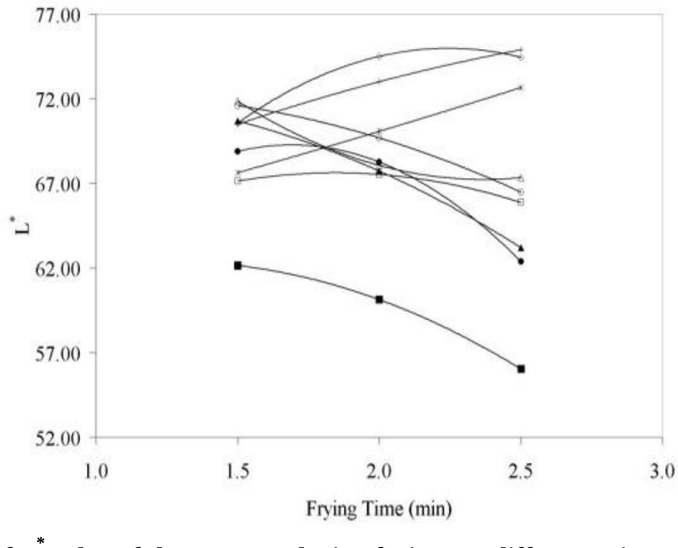

Fig. 16: Variation of L^* value of the potatoes during frying at different microwave power levels and osmotic dehydration times: (◇) 750W-15 min; (□) 750W- 30 min; (∆), 750W-45 min; (□) 600W- 15 min; (∆), 600W-30 min; (O), 600W-45 min; (◇) 450W-15 min; (□) 450W-30 min; (+) 450W-45 min

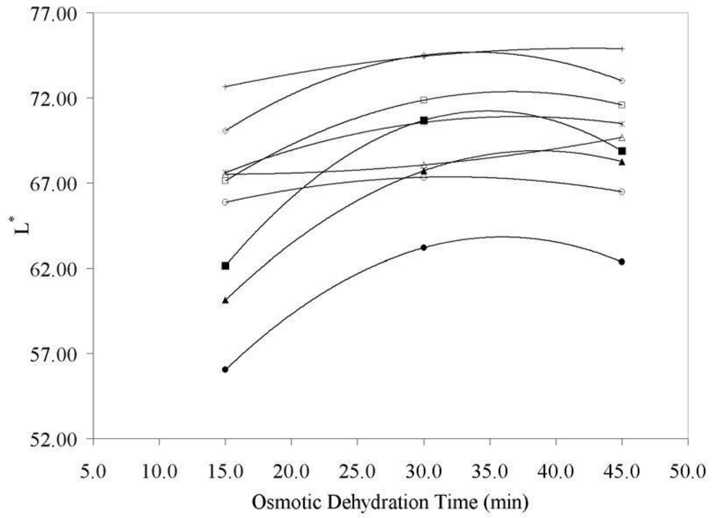

Fig. 17: Variation of L^* value of the potatoes during frying at different microwave power levels and frying times. (◇) 750W-1.5 min; (□) 750W- 2.0 min; (∆), 750W-2.5 min; (□) 600W- 1.5 min; (∆), 600W-2.0 min; (O), 600W-2.5 min; (◇)450W-1.5 min; (□) 450W-2.0 min; (+) 450W-2.5 min.

Another parameter that is considered in color analysis is the a^* value. In general an increase in a^* value is not desired since it results in a red potato. The a^* parameter of the potatoes increases significantly due to browning reactions. As the temperature of the frying increases *a* value increases for the same frying time which is negative for the color of fried products[9].

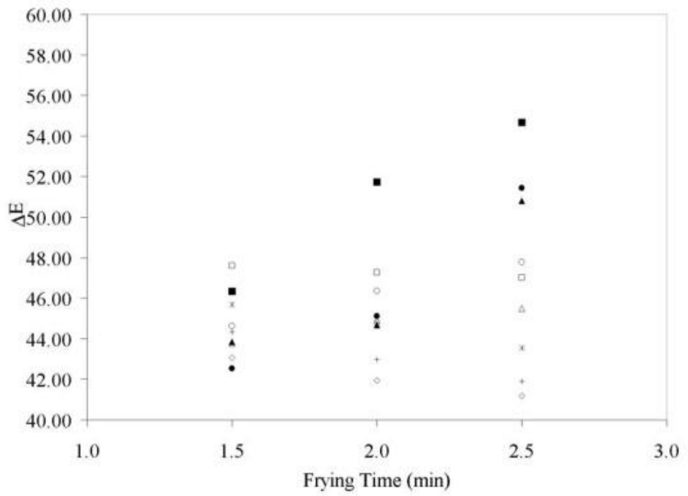

Fig. 18: Variation of ∆E value of the potatoes during frying at different microwave power levels and osmotic dehydration times. (◇) 750W-15 min; (□)750 W- 30 min; (∆), 750W-45 min; (□) 600W- 15 min; (∆), 600W-30 min; (O) 600W-45 min (◇) 450W-15 min; (□) 450W-30 min; (+) 450W-45 min.

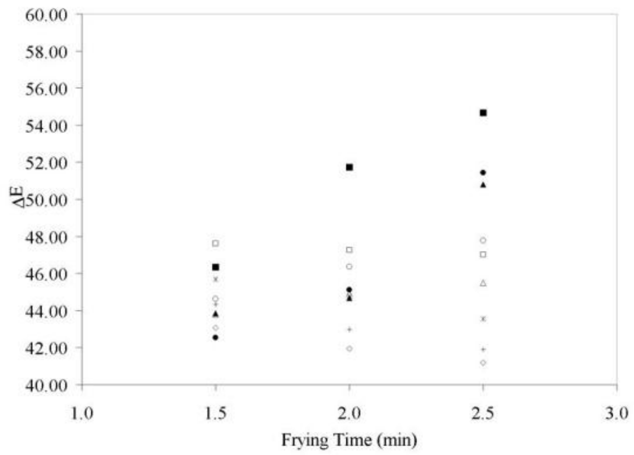

Fig. 19: Variation of ΔE value of the potatoes during frying at different microwave power levels and frying times. (□) 750W-1.5 min; (□) 750W- 2.0 min; (□), 750W-2.5 min(□) 600W- 1.5 min; (Δ), 600W-2.0 min; (O), 600W-2.5 min; (□) 450W-1.5 min; (□) 450W-2.0 min; (+) 450W-2.5 min

Texture

The effects of different microwave power levels and different osmotic dehydration times on the texture of fried potatoes were examined in terms of hardness. In Fig. 4.33, it can be seen that the hardness values increased with increasing frying time and microwave power level since as frying time and microwave power level increased, the moisture content decreased which resulted in harder products.

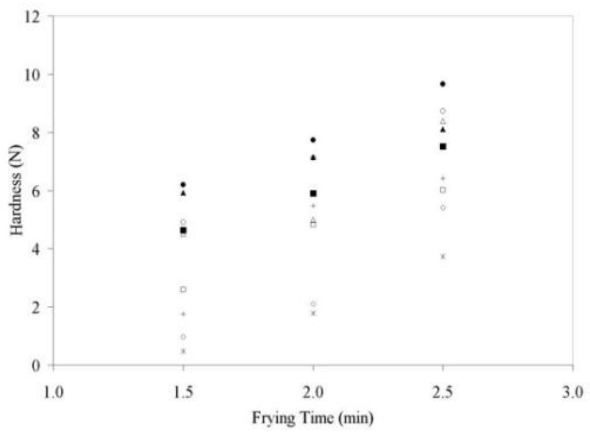

Fig. 20: Variation of hardness of the potatoes during frying at different microwave power levels and osmotic dehydration times. (□) 750W-15 min; (□) 750W- 30 min; (□), 750W-45 min; (□) 600W- 15 min; (Δ), 600W-30 min; (O), 600W-45 min; (□) 450W-15 min; (□) 450W-30 min; (+) 450W-45 min.

Bunger, Moyano and Rioseco[4] also found out that soaking in NaCl solution before frying had increased hardness values for French fries. **Bunger, Moyano and Rioseco**[4] stated that increased soaking time improved the sensory textural quality, probably due to higher diffusion of the NaCl into the tissue that resulted in an increase in tissue resistance.

The effect of osmotic dehydration on texture becomes obvious when the hardness values of the potatoes that were not subjected to osmotic dehydration were examined. As can be seen in Table C.13, the hardness values were lower for the microwave fried potatoes that were not subjected to osmotic dehydration than the ones that are osmotically dehydrated. Presence of salt increases heating rate and moisture loss which leads to harder products. The hardness of the potatoes that were dried conventionally was comparably smaller than the hardness values of the potatoes that were osmotically dehydrated. This can be explained by the interaction of salt with microwaves.

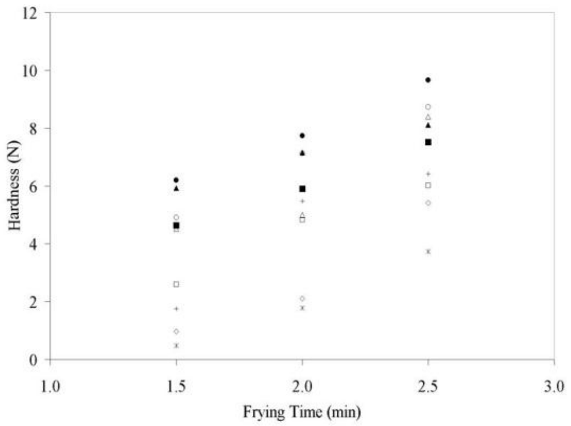

Fig. 21: Variation of hardness of the potatoes during frying at different microwave power levels and frying times. (◇) 750W-1.5 min; (□) 750W- 2.0 min; (∆), 750W-2.5 min; (□) 600W- 1.5 min; (∆), 600W-2.0 min; (O), 600W-2.5 min; (◇)450W-1.5 min; (□) 450W-2.0 min; (+) 450W-2.5 min.

APPENDIX

Table 3: Experimental data for Osmotically dehydrated microwave fried potato slices

MW POWER	FRYING TIME	OD TIME	MC	OIL	COLOR	HARD NESS
450	1.5	15	28.37	17.98	45.69	0.43
450	2	15	24.09	21.21	44.78	1.77
450	2.5	15	14.67	22.83	43.56	3.73
450	1.5	30	19.58	16.88	43.07	0.96
450	2	30	16.54	16.98	41.94	2.1
450	2.5	30	11.43	17.14	41.18	5.41
450	1.5	45	17.44	15.65	44.32	1.75
450	2	45	15.96	15.73	42.98	5.48
450	2.5	45	9.97	16.1	41.89	6.42
600	15	15	22.68	27.43	47.62	2.09
600	2	15	14.56	27.87	47.27	4.83
600	2.5	15	10.75	30.16	47.01	6.02
600	1.5	30	16.18	21.68	43.78	4.52
600	2	30	12.41	22.93	44.9	4.99
600	2.5	30	8.53	27.76	45.5	8.39
600	1.5	30	11.02	21.63	44.62	4.9
600	2	45	9.31	21.8	46.37	7.13
600	2.5	45	4.31	27.51	47.78	8.73
750	1.5	45	19.16	28.5	46.35	4.63
750	2	15	12.88	30.78	51.74	5.9
750	2.5	15	10.06	33.78	54.66	7.51
750	1.5	15	12.68	22.96	43.85	5.93
750	2	30	10.46	23.3	44.67	7.15
750	2.5	30	6.49	30.29	50.81	8.11
750	1.5	30	10.26	24.27	42.54	6.1
750	2	45	8.52	23.06	45.12	7.74
750	2.5	45	4.35	29.43	51.43	9.65
Conventional with 15 min OD			20.75	27.83	47.38	1.33
Conventional with 30 min OD			16.37	17.79	45.43	3.42
Conventional with 45 min OD			12.82	17.95	46.05	6.49
Conventional with out OD			67.44	41.28	49.08	1.63

MW: Microwave; OD: Osmotic dehydration; MC: Moisture content

CONCLUSION

When osmotic dehydration was used as a pretreatment, the moisture content of the microwave fried potatoes was lower than the ones that were not treated osmotically. However, oil content of these potatoes decreased which supported the fact that osmotic dehydration was an effective method to reduce oil uptake in fried foods. However, the hardness of these potatoes increased. In that respect, different solutions and times for osmotic dehydration may be suggested. Moreover, potatoes may be coated with materials which have high penetration depth so that potatoes will not be heated too much and texture of the potatoes will be softer.

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