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Study on Optimisation of Microwave Frying of Potato Slices

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ABSTRACT

In this study, the effects of microwaves on quality of fried potatoes (moisture content, oil content, color and hardness) were studied and the process was optimized by using Taguchi Technique. Microwave power level (450W, 600W and 750W), frying time (2.0, 2.5, 3.0 minutes) and oil type (sunflower, corn and ground nut oil) were the parameters used in the study. Moisture content of potatoes decreased whereas oil content, hardness and ΔE values of the potatoes increased with increasing frying time and microwave power level. The potatoes with the highest oil content were found to be the ones that were fried in the hazelnut oil. The optimum condition was found as frying at 600W microwave power level, for 2.5 minutes in sunflower oil. The potatoes that were fried at the optimum condition were determined to have lower oil contents compared to the ones fried conventionally.

Key words: *Microwave Frying; Optimization; Frying time; Different oil; Taguchi Technique*

INTRODUCTION

When the food products are subjected to microwaves enhanced moisture loss due to pressure driven flow is observed[7]. Therefore, the evaporation rate is higher in microwave processing that indicates be higher and consequently oil absorption will be higher compared to conventional deep-fat frying. However, the frying time is less in the case of microwave frying which in turn may lead to less oil absorption. So, there is a trade off between the high moisture loss and short frying time.

The effect of microwaves on the fatty acids is an important concern for microwave frying. However it was found out that, microwave heating hardly modified the fatty acid profiles of both chicken and beef patties, whereas frying in olive oil increased oleic and eicosapentaenoic acids and decreased linoleic and hexaenoic acids in both types of products[6].

The experimental design technique of Genichi Taguchi that was devised specifically to improve the quality of Japanese manufactured goods in the post war period in conjunction with analysis of variance (ANOVA) has been extremely successful. Originally applied in the field of engineering, it can be used to optimize any complex process[5]. Taguchi design can determine the effect of factors on characteristic properties and the optimal conditions of factors.

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The word "design" in "design of experiments" implies a formal layout of the experiments that contains information about how many tests are to be carried out and the combination of factors included in the study. There are many possible ways to lay out the experiment. A number of standard orthogonal arrays (number tables) have been constructed to facilitate designs of experiments. Each of these arrays can be used to design experiments to suit several experimental situations. Orthogonal arrays are balanced matrices. Pair wise orthogonality is present when all possible combinations of test levels between pairs of columns occur and when each of these possible combinations occur an equal number of times.

Orthogonal arrays and ANOVA are used as the tools of analysis for Taguchi Technique. ANOVA can estimate the effect of a factor on the characteristic properties and experiment can be performed with the minimum replication using the orthogonal arrays. Conventional statistical experimental design can determine the optimal condition on the basis of the measured values of the characteristic properties while Taguchi method can determine the experimental condition having the least variability as the optimal condition. The variability is expressed by signal to noise (S/N) ratio. The experimental condition having the maximum S/N ratio is considered as the optimal condition as the variability characteristics is inversely proportional to the S/N ratio.The traditional method of calculating average factor effects and thereby determining the desirable factor levels (optimum condition) is to look at the simple averages of the results. Although average calculation is relatively simple, it doesn't capture the variability of results within a trial condition.

MATERIALS AND METHODS

Preparation of potato slices

Potatoes were peeled, washed and cut by using a manually operated cutting device into disc shaped slices of 5 mm in thickness and 3.5 cm in diameter. The uniformity of thickness of slices was checked using a caliper **.** The slices were washed to remove free starch and surface was blotted with a paper towel before frying. Three different types of oil used in the study were sunflower oil **,** corn oil and ground nut oil

Methods

This study was divided into two parts. In the first part of the study, microwave frying conditions were optimized by considering the effect of microwave power level, frying time and oil type on product quality.

Effects of microwave frying on the quality parameters of potato slices

Frying

Microwave frying was conducted in a domestic microwave oven. Three power levels, 450W, 600W, 750W were used in the experiments. Power levels were determined by IMPI 2-L test[4] Microwave frying was performed using a glass container containing 400 mL oil. First, the oil which is at room temperature is heated to a temperature of 170±1^{o}C at the maximum power level of the microwave oven (800 W). Then, potato slices were placed in hot oil and frying was performed at a specified microwave power and time. Seven pieces of potatoes were fried in each experiment. The oil was replaced after frying in three different conditions.Three different types of oil, sunflower, corn and ground nut oil were used in this part of the study. In addition to oil type and microwave power level, a third factor in the experimental design was the frying time. The potatoes were fried for 2.0, 2.5 and 3.0 minutes. As control, conventional deep fat frying was conducted at a temperature of 170±1^{o}C in commercial bench-top deep fat fryer (TEFAL, France) containing 400 mL sunflower oil. Samples were fried for 4.5 min. Potato oil ratio was kept same as 0.0675 (w/v) in both microwave and conventional deep-fat frying.

Orthogonal array and experimental parameters (Taguchi Design)

For Taguchi design and subsequent analysis, the software named as Qualitek-4 (Version 4.82.0) was used. The appropriate orthogonal array for the experiment was determined by the software. Since the interactions between the factors are also sought for, an L27 array was chosen by the program. This means that 27 experiments with different combinations of the factors should be conducted in order to study the main effects and interactions. It is important to note that the design is also a full factorial design (3^3=27). However, in general, Taguchi design is preferred since it reduces the number of experiments significantly. But in this study, since it is sought to observe all the interaction effects between the factors as well, the resulting Taguchi design became a full factorial design. Table 1.1 shows the parameters and levels used. Table 1.2 shows the 27 trial conditions to be performed.

Table 1.1 Parameters and levels used in first part of the study

	LEVELS		
PARAMETERS	1	2	3
Microwave Power (W)	450 W	600W	750W
Frying time (min)	2.0 min	2.5 min	3.0 min
Oil type	Sun flower	Ground nut	Corn oil

Table 2.2 Experimental conditions for the first part of the experiment (Taguchi design)

Experiment No.	Microwave Power (W)	Frying time (min)	Oil type
1	450	2.0	Sun flower
2	450	2.0	Ground nut
3	450	2.0	Corn oil
4	450	2.5	Sun flower
5	450	2.5	Ground nut
6	450	2.5	Corn oil
7	450	3.0	Sun flower
8	450	3.0	Ground nut
9	450	3.0	Corn oil
10	600	2.0	Sun flower
11	600	2.0	Ground nut
12	600	2.0	Corn oil
13	600	2.5	Sun flower
14	600	2.5	Ground nut
15	600	2.5	Corn oil
16	600	3.0	Sun flower
17	600	3.0	Ground nut
18	600	3.0	Corn oil
19	750	2.0	Sun flower
20	750	2.0	Ground nut
21	750	2.0	Corn oil
22	750	2.5	Sun flower
23	750	2.5	Ground nut
24	750	2.5	Corn oil
25	750	3.0	Sun flower
26	750	3.0	Ground nut
27	750	3.0	Corn oil

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[1].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[1]**.** 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:

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

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. Hardness was defined as the peak force for this penetration.

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. When a product or process under study is to satisfy more than one objective, performance of samples tested for each trial condition are evaluated by multiple criteria of evaluation. Such evaluations can be combined into a single quality, the overall evaluation criterion (OEC) that is considered as the result for the sample. But the evaluation of each individual criterion may have different units of measure, quality characteristics and relative weighting.

RESULTS AND DISCUSSION

Effects of microwave frying on the quality parameters of potato slice

Moisture Content

The initial moisture content of potatoes was in the range 80-82% on wet basis (449.1 % db on average). It was observed that moisture loss of fried potatoes increased as power level and frying time increased for all types of oils (Fig.1-3). The experimental data are available in Table .3 in Appendix.

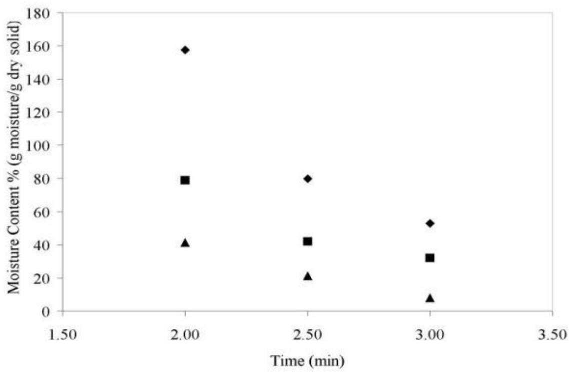

Fig. 1: Variation of moisture content of potatoes fried in sunflower oil with different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

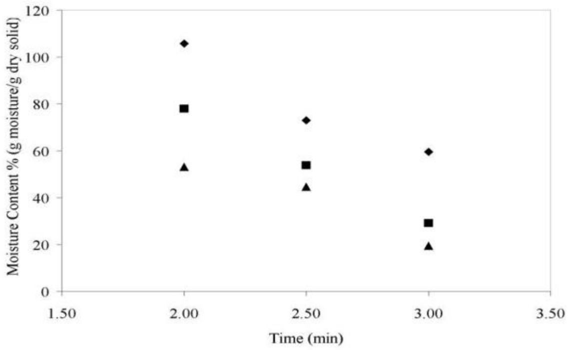

Fig. 2: Variation of moisture content of fried potatoes fried in corn oil with different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

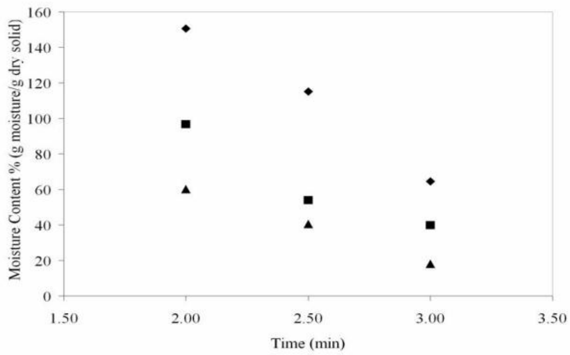

Fig. 3: Variation of moisture content of potatoes fried in ground nut oil with different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

When the ANOVA results was examined, it was seen that the most significant main factors on affecting moisture content were microwave power and frying time ($p < 0.05$). The oil type was found to be insignificant on affecting moisture content ($p > 0.05$). The cycling of temperatures seen in Fig. 4.4 is due to the on-off cycling of microwaves.

The lowest moisture content was obtained when potatoes were fried at the highest microwave power level (750 W) for the longest frying time (3.0 min) for all oil types. The moisture content of potatoes fried in microwave oven even at low power level (450 W) for 3 min were lower for sunflower, corn and ground nut oil (52.89 %, 59.56%, 64.55 %) as compared to those fried conventionally (67.44%).The resulting difference between conventional deep-fat frying and microwave frying was expected since microwaves enhance moisture loss significantly. Various researchers have shown that microwave dried vegetables lost more moisture than conventionally dried ones[17, 18].

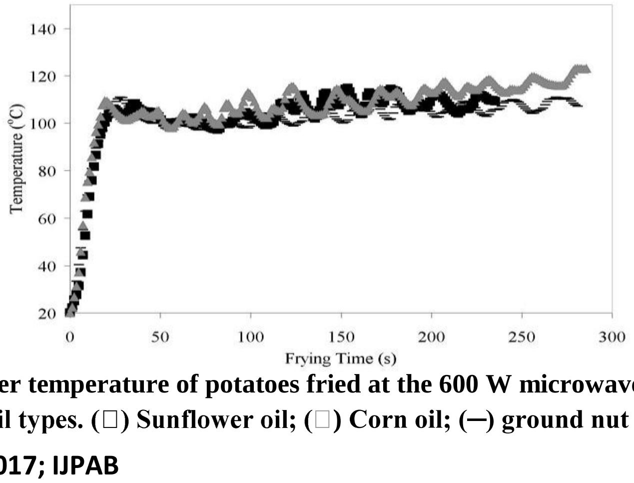

Fig. 4: Variation of center temperature of potatoes fried at the 600 W microwave power level in different oil types. (□) Sunflower oil; (□) Corn oil; (─) ground nut oil

Oil Content

Oil content is one of the most important quality attributes of a deep-fat fried product. The texture of a low-oil-content product can be soft and unpleasant. However, the high oil content is costly to the processor and results in an oily and tasteless product[15]**.** Fig. 5-7, show how oil content change with respect to frying time on the basis of microwave power levels for different oil types. It is common for the three oil type that as microwave power level and frying time increased the oil content of the fried samples increased. Foods with more moisture loss also show more oil uptake. Some even argue that the total volume of oil uptake will be equal to the total volume of water removed[16]. Although microwave frying resulted in high moisture loss even at low power levels, lower oil uptake in microwave frying process was observed as compared to conventional frying. For example, the oil content of potatoes fried at the lowest microwave power level, 450 W for 3 min were 25.48, 29.05, 68.98 % for sunflower, corn and ground nut oil respectively while it was 41.28 %, 37.22 %, 71.82 % for conventionally fried ones. In other words, microwave fried potatoes had lower oil contents compared to conventionally fried ones. The short frying time may be responsible for this. This may also be explained by the high evaporation rate of water compared to diffusion of oil into the potato due to pressure driven force that is generated by microwaves.

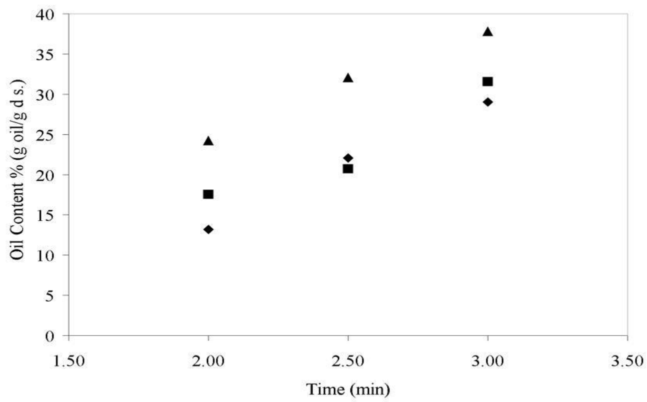

Fig. 5: Variation of oil content of potatoes fried in sunflower oil with different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

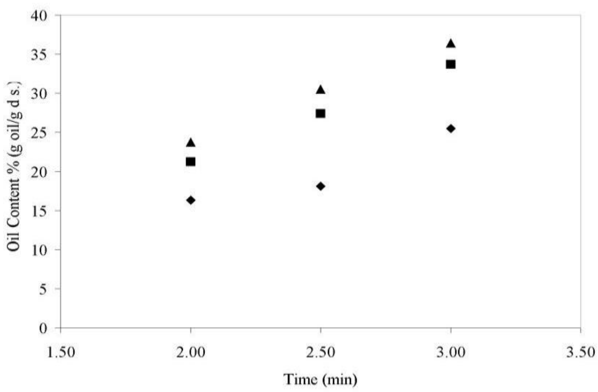

Fig. 6: Variation of oil content of potatoes fried in corn oil with different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

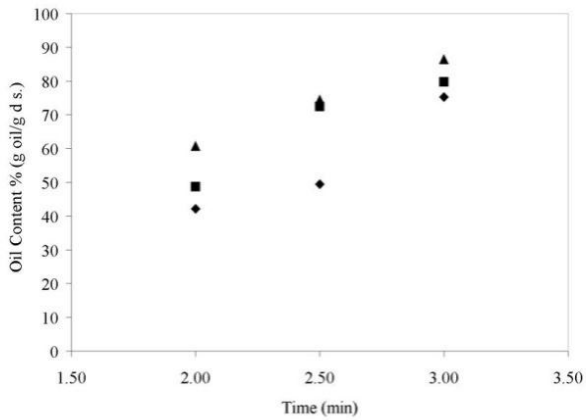

Fig. 7: Variation of oil content of potatoes fried in ground nut oil with different microwave power levels: (◇) 450 W; (□) 600 W; (Δ) 750 W.

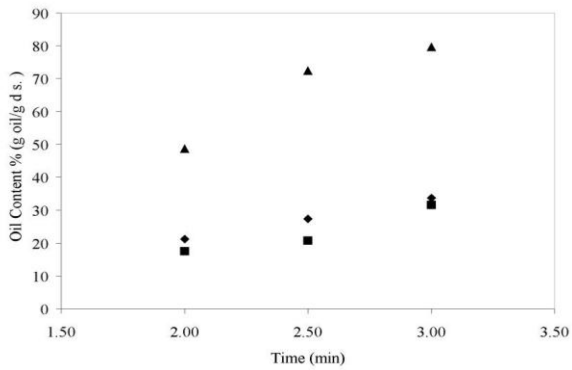

Fig. 8: Variation of oil content of potatoes fried at the 600 W microwave power level in different oils. (◇) Sunflower oil; (□) Corn oil; (Δ) ground nut oil.

Fig 8. shows the effects of oil types on oil contents of potatoes fried at 600W microwave power level. Potatoes fried in the ground nut oil had significantly higher oil content than the ones fried in sunflower and corn oils. The same results were obtained in the other power levels as well. Therefore, it can be concluded that the potatoes fried in ground nut oil are far away from satisfying consumer's needs in terms of its high calorie.

Gamble, Rice and Selman[8] suggested that most of the oil enters the final product from the adhered oil being pulled into the product when it is removed from the fryer due to condensation of steam producing vacuum. Moreira[15], Sun and Chen also observed that only 36 % of the final oil content was absorbed by the tortilla chips during frying and 64 % during cooling leaving only 36 % at the chip's surface.

It was also observed that the higher the viscosity of oil could cause the oil to adhere to the products surface[15]**.** Therefore, the viscosities of the sunflower, corn and ground nut oils were measured and found to be 42.67 cP, 43.72 cP and 54.94 cP at room temperature, respectively. Boyacı[3], Tekin, Çizmeci and Javidipour, also found out that viscosity of ground nut oil was higher compared to sunflower and corn oils. According to this result, the higher oil contents of potatoes fried in ground nut oil may be explained by more accumulated oil at the surface due to its high viscosity.

When ANOVA was performed it was seen that the residuals for the oil content (db) were far away from satisfying the assumption of normality and constant variance similar to moisture content value for the oil content data was found by using MINITAB 14, and it was found to be -0.23. The transformed form of the oil content data satisfied the assumptions. In ANOVA and further optimization studies *Oil Content-0.23* values were used.

When the ANOVA results in Table 3.1 were examined it was seen that microwave power level, frying time and oil type are all significant on affecting the oil content ($p<0.05$). However, all two-way interactions and the three-way interaction were found to be insignificant ($p>0.05$).

According test results, no significant difference in terms of oil content is detected between sunflower and corn oil whereas ground nut was found to be significantly different from the other two. It is very well known that there is an inverse relationship between moisture and oil contents. While the moisture is evaporated, oil enters the product during frying. However, the effect of oil type on oil content was found to be significant while this was not the case in moisture content. Like microwave frying in conventional frying, the oil type was found to be insignificant on moisture content as well ($p<0.05$). This also explains that most of the oil uptake occurred during cooling.

Color

Color is an important factor influencing consumer acceptance of a fried product. It can indicate high-quality products such as the golden yellow of a potato. The consumer generally uses the color of a product in order to determine the end of the frying process. The final color of the fried product depends on the absorption of oil and the chemical reactions of browning of reducing sugars and protein sources[2]**.**

The total color difference (ΔE) of potatoes increased as microwave power level and frying time increased (Fig. 9). As microwave power level increases the temperature of the frying oil increases, which in turn increases the rate of non-enzymatic browning reactions. Consequently the color of potatoes becomes darker.

According to ANOVA results for the ΔE values it was seen that microwavepower level, frying time and oil type are all significant in total color difference ($p<0.05$) (Table 3.1). Among the interactions, except the microwave power-oil type interaction, the other two way interactions and three way interactions were found to be insignificant ($p>0.05$). There were no significant difference between corn and sunflower oil whereas there was significant difference between nut oil and other oil types in terms of ΔE according to ANOVA test (Table B.8) ($p<0.05$). The lightness (L*) value decreased as microwave power level and frying time increased due to increase in temperature (Fig. 4.10). However, a* and b* values generally showed an increase as frying time increased in accordance with the results of Krokida *et al*[12,13] (Figure 11-12).

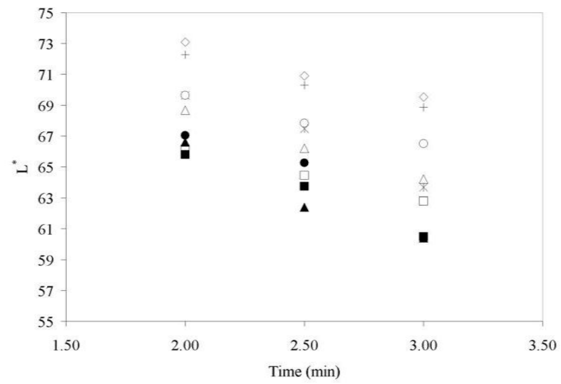

Fig. 9: Variation of ΔL of the potatoes during frying at different microwave power levels and oil types. (□) 750W-Sunflower Oil; (Δ) 750W- Corn Oil; (Ọ), 750W-Nut Oil; (□) 600W- Sunflower Oil; (Δ), 600W-Corn Oil; (O), 600W-Nut Oil; (*) 450W-Sunflower Oil; (□) 450W-Corn Oil; (+) 450W-Nut Oil.

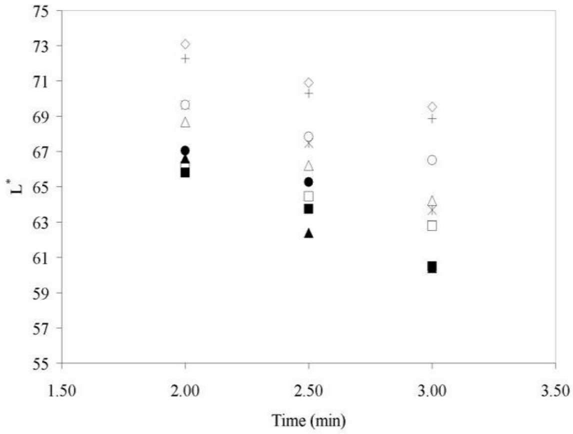

Fig. 10: Variation of L^* value of the potatoes during frying at different microwave power levels and oil types. (□) 750W-Sunflower Oil; (Δ) 750W- Corn Oil; (Ọ), 750W-Nut Oil; (□) 600W- Sunflower Oil; (Δ), 600W-Corn Oil; (O), 600W-Nut Oil; (*) 450W-Sunflower Oil; (□) 450W-Corn Oil; (+) 450W-Nut Oil.

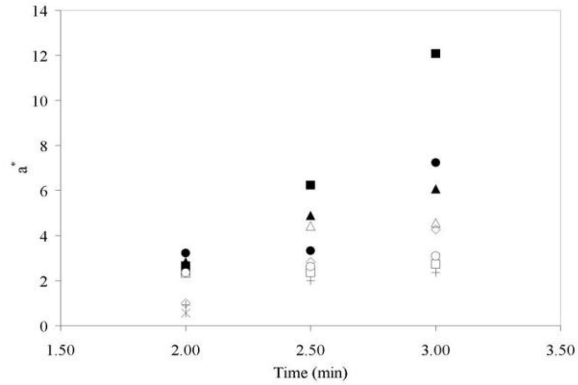

Fig. 11: Variation of a^* value of the potatoes during frying at different microwave power levels and oil types. (□) 750W-Sunflower Oil; (Δ) 750W- Corn Oil; (Ọ), 750W-Nut Oil; (□) 600W- Sunflower Oil; (Δ), 600W-Corn Oil; (O), 600W-Nut Oil; (*) 450W-Sunflower Oil; (□) 450W-Corn Oil; (+) 450W-Nut Oil.

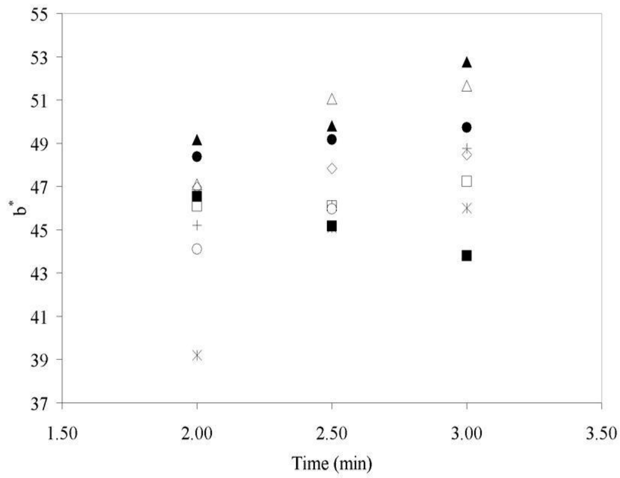

Fig. 12: Variation ofb^*value of the potatoes during frying at different microwave power levels and oil types. (□) 750W-Sunflower Oil; (Δ) 750W- Corn Oil; (Ọ), 750W-Nut Oil; (□) 600W- Sunflower Oil; (Δ), 600W-Corn Oil; (O), 600W-Nut Oil; (*) 450W-Sunflower Oil; (□) 450W-Corn Oil; (+) 450W-Nut Oil.

Texture

The effects of different microwave power levels and different oil types on the texture of fried potatoes were examined in terms of hardness. In Fig. 13, 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.

The hardness data were also far away from satisfying the assumption of normality. Therefore, transformation was performed to normalize the hardness results. Natural logarithm transformation satisfied the normality. In ANOVA and in optimization natural logarithm of the hardness values were used. The microwave power level, frying time and oil type were all found to be significant for the hardness of the potatoes ($p<0.05$). Except the frying time-oil type interaction, all other interactions were found to be significant. Test showed that the levels of the three parameters were significantly different from each other. The potatoes fried in the sunflower oil were found to be the hardest ones, which were followed by the potatoes fried in nut and corn oil respectively.

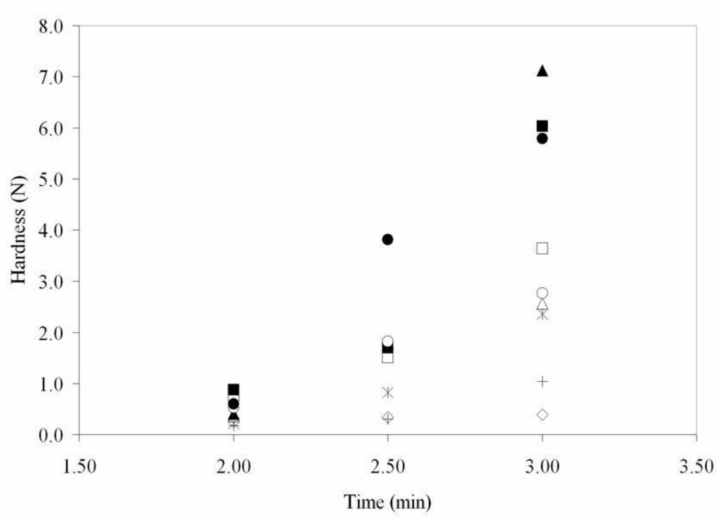

Fig. 13: Variation of hardness of the potatoes during frying at different microwave power levels and oil types. (□) 750W-Sunflower Oil; (Δ) 750W- Corn Oil; (Ọ), 750W-Nut Oil; (□) 600W- Sunflower Oil; (Δ), 600W-Corn Oil; (O), 600W-Nut Oil; (*) 450W-Sunflower Oil; (□) 450W-Corn Oil; (+) 450W-Nut Oil.

CONCLUSION AND RECOMMENDATIONS:

In this study, microwave frying of the potatoes was studied. Using microwaves as a frying method decreased oil content of potatoes and frying time significantly, but increased moisture loss as compared to conventionally fried ones. No significant difference was detected between the color of microwave and conventionally fried potatoes. Higher oil content was observed in the case of both microwave and conventionally fried potatoes when hazelnut oil was used as the frying medium. Sunflower oil can be recommended as the medium to be used in microwave frying. Moisture content of potatoes decreased but color, hardness and oil content of potatoes increased as frying time and microwave power increased. Microwave power, frying time and oil type were found to be significant factors on affecting oil content, hardness and color of microwave fried potatoes. Since oil content of potatoes were significantly reduced when microwaves were used, microwave frying of the potatoes can be suggested as an alternative to conventional deep fat frying.

APPENDIX

Table 3: Experimental data for the microwave fried potatoes

MW Power	Frying Time	Oil type	Moisture Content	oil	color	Hard Ness
450	2	Sun flower	81.5	16.3	41.8	0.21
450	2.5	Sun flower	79.6	18.1	43.4	0.81
450	3	Sun flower	52.8	25.4	46.1	2.36
600	2	Sun flower	78.7	21.2	44.3	0.76
600	2.5	Sun flower	42	27.4	45.5	1.51
600	3	Sun flower	31.9	33.7	46.7	3.63
750	2	Sun flower	41.4	23.7	44.5	0.8
750	2.5	Sun flower	21.3	30.5	46.3	1.7
750	3	Sun flower	8.02	36.4	49.8	6.03
450	2	Corn oil	80.7	13.1	46.3	0.25
450	2.5	Corn oil	72.9	22	48.3	0.33
450	3	Corn oil	59.5	29.05	49.6	0.39
600	2	Corn oil	77.9	17.5	48.9	0.36
600	2.5	Corn oil	53.7	20.7	53.7	1.79
600	3	Corn oil	29.1	31.5	55.3	2.56
750	2	Corn oil	53	24.2	51.8	0.4
750	2.5	Corn oil	44.6	32.09	55.1	1.8
750	3	Corn oil	19.4	37.8	58.6	7.12
450	2	Ground nut	81.5	42.1	45.2	0.17
450	2.5	Ground nut	80.2	49.4	47.1	0.3
450	3	Ground nut	64.5	75.3	50.1	1.04
600	2	Ground nut	96.6	48.6	45.9	0.52
600	2.5	Ground nut	53.9	72.4	48.5	1.82
600	3	Ground nut	39.8	79.7	52.3	2.76
750	2	Ground nut	60.1	60.7	59.9	0.59
750	2.5	Ground nut	40.5	74.4	52.6	3.8
750	3	Ground nut	80.1	86.5	56.4	5.78

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