Optimization of leavened dough frying conditions using the response surface methodology

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In this study, the optimum frying conditions of leavened doughs to minimise the oxidation products were investigated. Fifty repeated deep frying of leavened doughs with 0-2% salt content was performed for 1-5 min at 160-200°C. While K_{232}, K_{270}, *p*-anisidine and polymer triglycerides contents of fried dough oil (FDO) were noteworthy ($p < 0.05$) affected by the frying temperature and the frying time, the dough salt content did not affect these values significantly ($p > 0.05$). The combined effects of frying temperature and time on K_{270}, *p*-anisidine and polymer triglycerides contents were significant ($p < 0.05$). The effects of interaction of frying temperature and dough salt content on *p*-anisidine value were found to be significant ($p < 0.05$). The optimum frying conditions to minimize the K_{232}, K_{270}, *p*-anisidine values and polymer triglyceride content of FDO were observed where the frying time was 1 minute, the frying temperature was 160°C and the salt content was 2%.

Keywords Repeated frying; polymer triglycerides; K_{232} and K_{270} values, *p*-anisidine value

1. INTRODUCTION

Deep frying is a food cooking process which is commonly used for domestically and commercially. During this process, food is immersed in an oil bath at 175-190°C, which improves sensorial (flavour, taste) and textural (colour and crispness) properties of food products [1-5].

Frying oil serves as a heat transfer medium. Different types of fats/oils are used for frying purposes. The quality of fried foods is based on the frying conditions, the type of oil, and foods being fried [6, 7]. Lipid oxidation of fried foods varies depending on food and frying oil composition and water activity [8]. Water removes from capillary of foods and thus, oil is absorbed by food. The other changes in food are gelatinisation of starch, denaturation of proteins, and loss of some heat sensitive nutrients and the development of flavour [3]. In addition to these changes, chemical (formation of primary and secondary oxidation products), physical (such as density, viscosity and colour) and thermal (convective heat transfer coefficient) alterations occur in frying oil at high temperatures in the presence of air and moisture. The repeated and longer re-use of frying oil cause undesirable flavour, taste, colour, stability and texture in food. Furthermore, many harmful oxidation products are formed [7]. It was reported that fried food consumption and risk of developing chronic diseases in human is highly correlated [9].

Optimum frying conditions have been determined in several studies according to the chemical and textural characteristics, as well as sensory properties. Generally, response surface methodology (RSM) has been used to investigate the optimal frying conditions. RSM utilises the quantitative data from the suitable empirical designs to determine and solve the multivariate equations which is useful approach to study the effects of all the test variables on the responses [10]. Optimisation of process conditions for the preparation of puri, a traditional product made from whole wheat flour, were examined by Vatsala et al. [11] using RSM according to sensorial and textural properties as well as oil uptake. Sobukola et al. [12] studied optimisation of pre-fry drying of yam (sweet potato) slices according to the colour, crispness, oil and moisture content. The optimisation details of pre-fry microwave dried French fries with respect to the moisture content, oil content, texture and color parameters explained by Hashemi Shahraki et al. [13]. During the preparation of sweet potato chips, optimization of processing variables was investigated by Singh et al. [14] to obtain the product with desired textural and sensorial properties. Characterisation of the fresh and blanched potato strips' frying process was carried out by Alvarez and Canet [1] according to similar quality attributes. In other respects, the influence of vacuum microwave pre-drying and vacuum frying conditions on the physical and chemical characteristics of potato chips were investigated by Song et al. [15]. Perez-Tinoco et al. [16], using central composite experimental design, prepared hybrid pineapple slices using vacuum frying. In other study, the effects of processing conditions on the quality of vacuum fried apple chips were studied [17]. Vacuum frying of kiwi slice was also optimised by Maadyrad et al. [18]. As it is seen, optimisation of processes conditions was done according to the textural and sensorial properties of the fried food products in literature.

Despite the many studies on the changes of oil properties during the frying process, little information has been compiled about the changes in oil, which is extracted from the fried substrate, especially fried dough. In our previous studies we determined the changes in sunflower oil during frying of leavened dough using response surface methodology (RSM) [19]. Thermal oxidation products transfer from oil to the frying material. Therefore, in this study we aimed to find the optimal frying conditions (frying time, frying temperature and dough salt content) to minimise specific absorbance values (K_{232} and K_{270}), *p*-anisidine value and polymer triglyceride contents of FDO.

2. MATERIALS AND METHODS

2.1 MATERIALS

Refined sunflower oil, wheat flour, yeast and salt were taken from a local market (Bolu, Turkey). *p*-anisidine (99%) and heptadecanoic acid were taken from Sigma-Aldrich (Buchs, Switzerland). Tetrahydrafuran, isopropyl alcohol, cyclohexane, iso-octane and glacial acetic acid were purchased from Merck (Darmstadt, Germany).

2.2 METHODS

2.2.1 Preparation of leavened dough

The dough was prepared according to Turan et al. [20] using refined flour, instant yeast, water, and salt (0, 1, 2%). The dough was kneaded (Kitchen Aid, Belgium) and fermented at 35°C and 80 ± 5% relative humidity for 45 min. Subsequently it was thinned and divided into small square pieces (3 cm × 3 cm).

2.2.2 Frying process

Frying of leavened doughs was carried out as described by Turan et al [20]. The leavened doughs were fried at different temperatures (160, 180 and 200°C) and times (1, 3 and 5 min) in a domestic fryer with a capacity of 1 L (Tefal Minuto, France). Fifty frying operations were conducted in sunflower oil per day. Number of the frying cycle was determined according to the polar material content of frying oil. The limit of polar material content of oil is 25% legally. Above this value, oil is discarded and not used in further frying processes in food industry. Oil replenishment was not performed during the repeated frying. At the 50th frying, fried dough samples were taken from the fryer, cooled to room temperature and put into plastic bag, labelled and kept frozen.

2.2.3 Extraction of oils from fried doughs

Oil was extracted from fried doughs according to Troncoso et al. [21] using Folch lipid extraction method. Briefly, the dough (approximately 5 g) was divided into pieces and oil was extracted from dough pieces using 20 mL of chloroform/methanol/water (1:1:0.8, v/v/v) mixture and then filtered through a filter paper. Extraction process was repeated twice. After the removing of upper methanol/water phase, the chloroform phase was evaporated using stream of nitrogen gas. The extracted oil was used for the analyses of K_{232}, K_{270}, *p*-anisidine values and polymer triglyceride content.

2.2.4 Analysis of oils extracted from the fried doughs (FDO)

K_{232}/K_{270} and *p*-anisidine values were determined according to of AOCS Official Methods [22] Ch 5-91 and Cd 18-90 by Shimadzu UV 1700 spectrophotometer, respectively. The polymer triglyceride content of FDOs were measured according to official method of AOCS [22] numbered Cd 22-91 and Gertz [23]. Two gel permeation columns (GPC, Agilent PL-Gel 100°A, 2 × 300 × 7.5 mm, 5 µm, UK) was used for the separation of polymer triglycerides in HPLC system (Shimadzu Prominence, Japan) equipped with refractive index detector. Tetrahydrofuran: isopropyl alcohol (99.5:0.5, v/v) was used as the mobile phase with 1 mL/min of flow rate. The column oven temperature was set 35°C. Percentages of polymer triglycerides (dimeric and oligomeric) in samples were calculated by dividing individual peak area to total areas.

2.3 EXPERIMENTAL DESIGN

A central composite design was carried out to find the effects of three factors (dough salt content, frying temperature and time) on response during deep frying of leavened doughs. Design Expert version 10.0.5 program (Stat-Ease, Inc., Minneapolis, MN) was utilized for statistical evaluation, modelling and determination of the combined or individually effects of variables on the responses. The selected factors as independent parameters were frying temperature (A, 160-180°C), dough salt content (B, 0-2%) and frying time (C, 1-5 min) at three different levels (1, 0, +1). K_{232}, K_{270}, *p*-anisidine values and polymer triglyceride content of FDOs were designed as the response variables. Twenty frying experiments were conducted with six replicates at the central points. The details of the central composite design were explained in Turan et al [20].

3. RESULTS AND DISCUSSION

Scanning the content of primary or secondary oxidation products is commonly used to determine the rate at which the oxidation process is progressing [24]. In foods, the oxidation examination of fats and oils in food is important to protect against the deterioration of foods for human health [25].

3.1 K_{232} VALUES

K_{232} value shows primary oxidation products which is related to the content of hydroperoxides and conjugated dienes [26]. The K_{232} values of FDOs at the 50th frying operation is given in Table I. The K_{232} values of FDOs were in the range of 7.60 and 16.06. The highest K_{232} value was observed during frying of unsalted dough for 5 min at 200°C. We also determined the oxidation products of counterpart frying oil which were similar to oil extracted from leavened dough [19]. Bou et al. [27] confirmed the similarity of oxidation products of fried snacks from large scale producers and those obtained for their counterpart frying oil. Additionally, Wong et al. [28] reported high K_{232}, K_{268} and *p*-anisidine values of oil samples extracted from fried potatoes in repeated deep frying.

The effects of individual factors and their interactions on K_{232} values were well described by quadratic model with high R^2 values of 0.9665. High adequate R^2 (0.9364) and predicted R^2 (0.8304) values were also determined. According to the proposed models, the Eq. (1) is given for K_{232} values.

$$K_{232}=-55.59+0.63A+2.03B+1.99C-0.01AB+0.01AC-0.31BC-1.60A^2+0.20B^2-0.44C^2 \quad (1)$$

Where:
A is the frying temperature (°C)
B is the dough salt content (%)
C is the frying time (min).

The ANOVA results for K_{232} values are given in Table II. K_{232} values of FDOs were significantly affected by frying temperature and time ($p < 0.01$). As seen from *F* values for K_{232}, frying time was found to be more effective than frying temperature. The salt content of the dough did not lead significant effect on K_{232} values ($p > 0.05$). The influence of the dough salt content and frying time interaction (BC) on the K_{232} values of FODs-was determined significant ($p < 0.05$). K_{232} values increased with the prolonged frying time. This result was also confirmed by Wong et al. [28] in fried potatoes and by Lee et al. [29] in fried doughs containing carrot powder. Additionally, the K_{232} values of FODs decreased slightly as the dough salt content raised at 5 min frying times (Fig. 1). Chu and Luo [30] stated that adding sugar or salt in dough resulted in

Table I - Some properties of oil extracted from fried dough at the 50th frying

Run	Frying Temperature (°C)	Dough Salt content (%)	Frying time (min)	K_{232}	K_{270}	*p*-anisidine value	Polymer triglycerides (%)
1	160	0	5	11.91	5.26	71.12	6.13
2	160	1	3	11.24	5.27	81.05	5.03
3	180	0	3	14.16	3.60	95.70	6.70
4	180	1	3	13.25	4.60	103.66	7.93
5	180	1	3	13.75	4.73	111.80	7.64
6	200	2	5	14.12	4.88	144.50	10.89
7	180	1	3	12.93	4.78	93.82	6.82
8	200	0	5	16.06	4.98	121.65	9.39
9	200	2	1	10.70	4.36	71.51	6.19
10	160	2	1	8.98	3.27	58.32	4.24
11	200	1	3	13.98	6.02	99.50	7.88
12	180	1	3	14.41	4.49	104.00	8.94
13	180	1	3	13.52	5.04	116.44	8.86
14	160	0	1	7.60	3.45	84.90	3.97
15	180	1	5	12.64	4.32	111.11	8.46
16	200	0	1	10.63	4.44	62.99	5.80
17	180	1	3	13.57	4.75	99.35	7.69
18	180	1	1	10.32	3.80	77.00	5.30
19	180	2	3	12.75	3.39	103.69	8.04
20	160	2	5	10.30	4.50	64.22	5.83

Table II - Analysis of variance for response of K_{232} and K_{270}

Source	Sum of squares		Degrees of freedom	Mean square		F value		*p*-value, Prob > F	
	K_{232}	K_{270}	K_{232} /K_{270}	K_{232}	K_{270}	K_{232}	K_{270}	K_{232}	K_{270}
Model	79.88	9.02	9	8.88	1.00	32.06	19.09	< 0.0001**	< 0.0001**
A	23.89	0.86	1	23.89	0.86	86.29	16.42	< 0.0001**	0.0023**
B	1.23	0.18	1	1.23	0.18	4.45	3.34	0.0612	0.0974
C	28.21	2.13	1	28.21	2.13	101.92	40.64	< 0.0001**	< 0.0001**
AB	0.34	0.072	1	0.34	0.072	1.23	1.38	0.2936	0.2677
AC	1.31	0.49	1	1.31	0.49	4.72	9.31	0.0549	0.0122*
BC	3.13	0.045	1	3.13	0.045	11.32	0.85	0.0072**	0.3787
A^2	1.13	3.64	1	1.13	3.64	4.07	69.40	0.0713	< 0.0001**
B^2	0.12	2.74	1	0.12	2.74	0.42	52.14	0.5303	< 0.0001**
C^2	8.63	0.51	1	8.63	0.51	31.18	9.75	0.0002**	0.0108*
Residual	2.77	0.52	10	0.28	0.052				
Lack of Fit	1.52	0.35	5	0.30	0.070	1.21	1.99	0.4188	0.2335
Pure Error	1.25	0.18	5	0.25	0.035				
Cor Total	82.65	9.54	19						

[a]Letters A, B, C indicate frying temperature (°C), dough salt content (%) and frying time (min), respectively.
$^{*}p < 0.05$, $^{**}p < 0.01$

a better quality of soybean oil since salt or sugar had the ability to absorb water. Also, quadratic effects of frying time (C^2) on K_{232} values was found significant ($p < 0.01$). When 1% salt containing dough was fried for 1 minute at 180°C (Run 18), the K_{232} values of the oil was 10.32. This value was found as 12.64 after frying 5 min (Run 15). In agreement with our results, Lee et al. [29] observed that as the number of the frying cycle increased, conjugated dienoic acids of fried dough increased. In another study, conjugated dienoic acid content of fried dough increased with storage time of the fried dough. Also, the lipid oxidation of the fried products made from longer time stored flour tended to be higher than that of those made from unstored or short time stored flour [8]. Additionally, Farmani et al. [31] observed a sharper conjugated diene formation in sunflower oil compared to canola oil by frying bamiyeh pastry due to its higher PUFA content. More intense oxidative degradation was determined in oils with high PUFA content. Besides, Farhoosh et al. [32] stated that the conjugated diene value showed linear raise with the frying time at 180°C for 7 min intervals for 8 hours interval and increased from 7.9 to 70.9 µmol/g after 32 hours. Further, they stated that the sunflower oil should be discarded after 20 hours of frying.

3.2 K_{270} VALUES

Ultraviolet (UV) absorption at 270 nm is mainly stems from the secondary oil oxidation products (conjugated dienals and ketodienes and ethylenic diketones) of oils [26]. During the deep-frying, hydroperoxides are unstable due to the applied high temperature and decompose to secondary oxidation products [2]. In this study, hydroperoxides formed for this reason were measured with K_{232} value, and secondary oxidation products were measured with K_{270} and *p*-anisidine values.

The K_{270} values of FDOs at the 50th frying operation are given in Table I. The K_{270} values of FDOs were in the range of 3.27 and 6.02. The highest value was found in dough sample where frying temperature, frying time and dough salt contents were 200°C, 3 min and 1% salt, respectively (Run 11). A quadratic model with R^2 of 0.9450, adequate R^2 of 0.8955 and predicted R^2 of 0.6944 well described the effects of factors (frying temperature, dough salt content and frying time) on K_{270} values of FDOs. Eq. (2) calculated for K_{270} values is shown as follows:

$$K_{270}=+90.07-1.00A+1.12B+2.03C+4.75AB-6.18AC-0.04BC+2.88A^2-0.10B^2-0.11C^2 \quad (2)$$

Where:
A is the frying temperature (°C)
B is the dough salt content (%)
C is the frying time (min).

In a similar manner with the K_{232} values, frying temperature ($p < 0.01$) and frying time ($p < 0.01$) significantly affected the K_{270} values of FDOs. However, salt

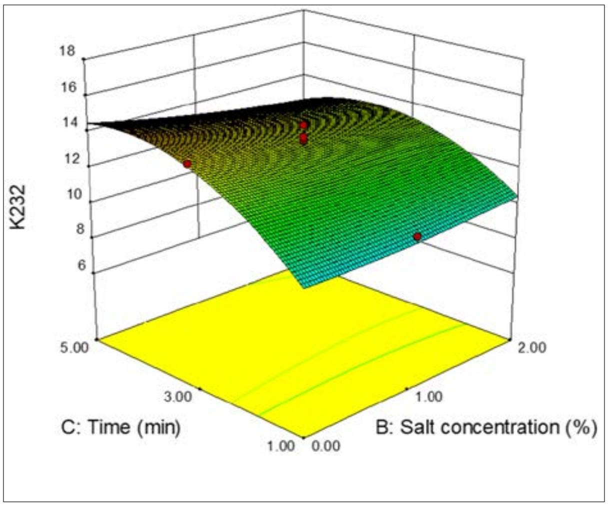


Figure 1 - Effects of dough salt content and frying time on K_{232} values of oils extracted from fried doughs at the 50th frying

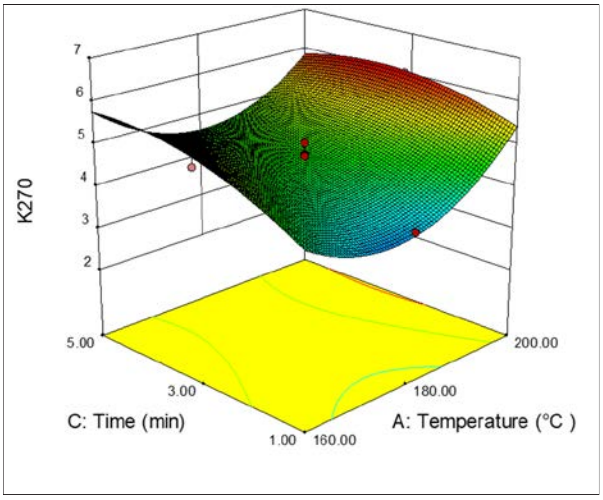
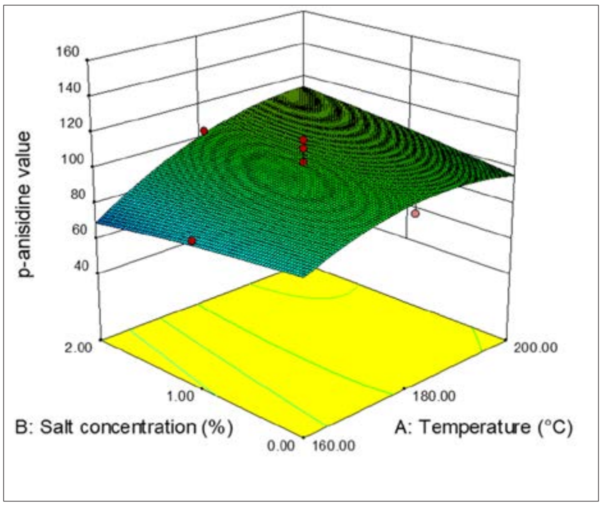
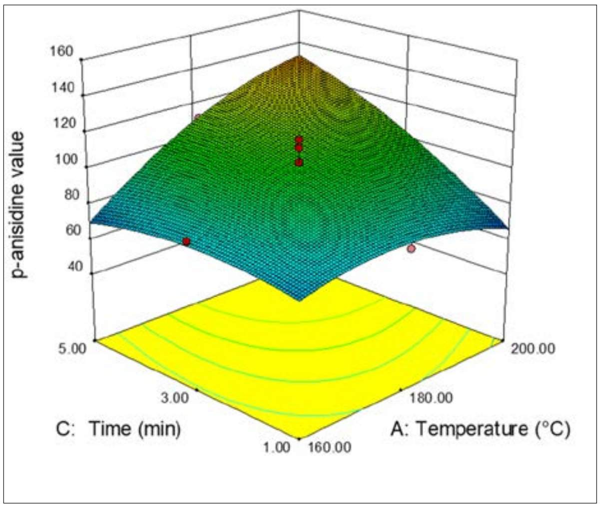


Figure 2 - Effects of frying temperature and frying time on K_{270} values of oils extracted from fried doughs at the 50th frying



a) - Frying temperature and dough salt content



b) - Frying temperature and frying time

Figure 3 - Effects of frying parameters on p-anisidine values of oils extracted from fried doughs at the 50th frying

content of the dough did not influence the K_{270} values remarkably ($p > 0.05$) (Tab. II). In contrast to our findings, Wong et al. [28] reported conjugated dienes and trienes increased as the amount of salt increased. In 1% salted doughs, K_{270} values of FDOs increased as a result of longer frying time and higher temperature (Fig. 2). Similarly, temperature increase, and prolonged frying duration increased conjugated trienes slightly in fried potatoes [28]. While the K_{270} value of FDO for 1% salted doughs and fried at 180°C for 1 min was 3.80 (Run 18), it was 4.32 (Run 15) fried at 180°C for 5 min with the same conditions. Since the frying oil is subjected to heat for longer periods with prolonged frying time, an increase in the K_{270} values were observed. Besides, the K_{270} value of FDOs increased from 5.27 (Run 2) to 6.02 (Run 11) when the frying temperature was raised from 160°C to 200°C for 1% salted doughs fried for 3 min.

3.3 P-ANISIDINE VALUES

p-Anisidine value shows the amount of the secondary oxidation products, 2-alkenals and 2,4-alkadienals [25, 26]. The *p*-anisidine values of FDOs at the 50th frying operation are given in Table I. The *p*-anisidine values of FDOs were in the range of 58.32 and 144.5. Bou et al. [27] reported lower p-anisidine values for oils extracted from potato chips or potato extruded snacks during five consecutive weeks frying at the large-scale producers. The effects of different factors on *p*-anisidine values of samples were described by a quadratic model with determination coefficient of 0.9493 ($p < 0.0001$). Adjusted R^2 and predicted R^2 were found as 0.9036 and 0.8491, respectively. The Eq. (3) is found from the proposed model as follows:

$$p\text{-anisidine} = -618.69 + 8.65A - 76.13B - 62.30C + 0.41AB + 0.44AC + 2.13BC - 0.03A^2 - 1.31B^2 - 1.74C^2 \quad (3)$$

Where:
A is the frying temperature (°C)
B is the dough salt content (%)
C is the frying time (min).

As in the K_{232} and K_{270} values, frying temperature and frying time had a significant effect on the *p*-anisidine values of FDOs ($p < 0.05$) whereas the effect of the dough salt content on the *p*-anisidine values was not significant ($p > 0.05$) (Tab. III). Inversely, Wong et al. [28] observed an increase in p-anisidine value as the amount of salt increased in fried potatoes.

The combination of the frying temperature and dough salt content resulted in significant increase ($p < 0.05$) in *p*-anisidine values of FDOs (Fig. 3a). The *p*-anisidine value of FDOs increased, as the temperature increased while the frying time was 3 min. Whilst the *p*-anisidine value of FDOs was 81.05 (run 2) at 160°C, it rose up 99.50 (run 11) at 200°C during frying of 1% salted doughs.

The combination of the frying time and temperature significantly affected the *p*-anisidine value of FDOs

Table III - Analysis of variance for response of *p*-anisidine and polymer triglyceride content

Source	Sum of squares		Degrees of freedom		Mean square		F value		*p*-value, Prob > F	
	p-anisidine	Polymer triglyceride	*p*-anisidine	Polymer triglyceride	*p*-anisidine	Polymer triglyceride	*p*-anisidine	Polymer triglyceride	*p*-anisidine	Polymer triglyceride
Model	8986.23	56.08	9	7	998.47	8.01	20.79	17.71	$< 0.0001^{**}$	$< 0.0001^{**}$
A	1975.27	22.32	1	1	1975.27	22.32	41.13	49.35	$< 0.0001^{**}$	$< 0.0001^{**}$
B	3.47	1.01	1	1	3.47	1.01	0.072	2.23	0.7935	0.1608
C	2492.61	23.05	1	1	2492.61	23.05	51.90	50.95	$< 0.0001^{**}$	$< 0.0001^{**}$
AB	525.55	0.46	1	1	525.55	0.46	10.94	1.01	0.0079^{**}	0.3343
AC	2433.57	2.58	1	1	2433.57	2.58	50.67	5.71	$< 0.0001^{**}$	0.0342^{*}
BC	144.74	-	1	-	144.74	-	3.01	-	0.1132	-
A^2	316.58	2.31	1	1	316.58	2.31	6.59	5.10	0.0280^{*}	0.0433^{*}
B^2	4.69	-	1	-	4.69	-	0.098	-	0.7611	-
C^2	132.69	0.57	1	1	132.69	0.57	2.76	1.27	0.1275	0.2820
Residual	480.30	5.43	10	12	48.03	0.45				
Lack of Fit	143.56	2.17	5	7	28.71	0.31	0.43	0.47	0.8145	0.8207
Pure Error	336.74	3.26	5	5	67.35	0.65				
Cor Total	9466.54	61.51	19	19						

[a]Letters A, B, C indicate frying temperature (°C), dough salt content (%) and frying time (min), respectively.
$^{*}p < 0.05$, $^{**}p < 0.01$

($p < 0.05$). The *p*-anisidine value ascended at the increased frying temperature or prolonged frying time (Fig. 3b). Similar results have been reported by Lee et al. [29] during frying of carrot powder containing doughs at 160°C for 1 min and by Wong et al. [28] during frying of potatoes. While the *p*-anisidine value of oils of the 1% salted doughs fried at 180°C was 77.00 (Run 18) when fried for 1 min, it was 111.11 (Run 15) when fried for 5 min. Besides, the *p*-anisidine value of oils of the 2% salted doughs raised from 58.32 (Run 10) to 71.51 (Run 9) for 1 min frying when the temperature was increased from 160°C to 200°C.

3.4 POLYMER TRIGLYCERIDE CONTENTS

The polymer triglyceride contents of FDOs at the 50th frying operation is given in Table I. The polymer triglyceride contents of FDOs in the range of 3.97 and 10.89. Lower polymer triglyceride contents were reported by Bou et al. [27] for oils extracted from fried potatoes and snacks. The determination coefficient (R^2) was found as 0.9117 for reduced model. Adjusted R^2 and predicted R^2 for the model were 0.8603 and 0.8006, respectively.

The equation (4) found from the proposed model as follows:

$$\text{Polymer triglycerides (\%)}=-68.24+0.78A-1.83B-1.16C+0.01AB+0.01AC-2.12B^2-0.11C^2 \quad (4)$$

Where:

A is the frying temperature (°C)
B is the dough salt content (%)
C is the frying time (min).

According to the results obtained from central composite design, it was determined that both frying time and temperature affected the polymer triglyceride contents of FDOs significantly ($p < 0.05$), whereas the effect of the salt content of the dough on the polymer

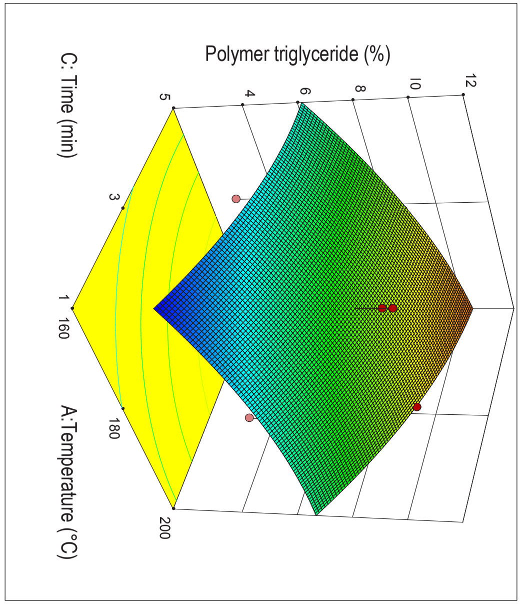


Figure 4 - Effects of frying temperature and frying time on polymer triglyceride contents of oils extracted from fried doughs at the 50th frying

Table IV - Optimization of frying conditions according to physicochemical characteristics of frying oil

	Goal	Lower limit	Upper limit	Optimized values
Frying temperature (°C)	In the range	160	200	160.0
Dough salt content (%)	In the range	0	2	2.0
Frying time (min)	In the range	1	5	1.0
K_{232}	Minimize	7.60	16.06	8.89
K_{270}	Minimize	3.27	6.02	3.20
p-anisidine	Minimize	58.32	144.5	60.16
Polymer triglycerides (%)	Minimize	3.97	10.89	4.08

Desirability value: 0.950

triglyceride contents was not significant ($p > 0.05$) (Tab. III). The highest polymer triglyceride contents were found at high temperatures and prolonged frying where the dough salt content was kept constant (Fig. 4). Whilst the polymer triglyceride content of oils of 1% salted doughs fried at 180°C was 5.30% when fried for 1 min (Run 18), it increased to 8.46% when fried for 5 min (Run 15). On the other hand, the polymer triglyceride contents of oils of 1% salted doughs increased from 5.03% (Run 2) to 7.88% (Run 11), when the frying temperature was increased from 160°C to 200°C. Soriano et al. [33] reported that higher temperatures accelerate thermal and oxidative changes and raise the rate of decomposition products formation. They recommended a temperature range of 160-180°C for frying operations in the case of using sunflower oil for frying medium.

3.5 OPTIMISATION

Optimisation of frying conditions and monitoring the oxidation products during frying can help to minimize the formation of decomposition products [34]. The optimum frying conditions to minimize the oxidation products in FDOs were determined and shown in Table IV. Chemo-metric design allows us to determine the conditions that lead to the minimum formation of oxidation products during frying of leavened doughs in shortest time with the least number of experiments. During deep-frying, an increase in primary and secondary products, was observed as frying temperature and time increased. Optimum conditions were defined as the conditions that would reduce the K_{232}, K_{270}, p-anisidine and polymer triglyceride values. The desirability was found as 0.950 and the optimum conditions by numeric optimisation were: frying temperature of 160°C, frying time of 1 min and dough salt content of 2%. The calculated values at the optimum conditions for K_{232} value, K_{270} value, *p*-anisidine value and polymer triglyceride content were 8.89, 3.20, 60.16 and 4.08%, respectively. It was concluded that the R^2 value obtained with the quadratic equations (Tab. IV) represented at least more than 90% of the total regression model created, so the measured experimental parameters could be largely explained by the obtained data.

High temperature causes oxidative degradation, thermal decomposition and polymerisation of the oil, while the prolonged frying time triggers degradation caused by food-borne moisture such as hydrolysis in addition to these degradations. Volatile products and non-volatile monomeric and polymeric compounds are formed owing to the deep-frying. With continued heating and frying, these compounds form further breakdown products with potentially toxic effects and undesirable flavour making the oil unsuitable for frying [35]. The optimum conditions for frying depend on the oil type, the composition of the food (moisture, sugar, etc.), frying conditions (time, cycle and temperature). Optimisation of the food-specific frying conditions is of great importance.

In order to determine optimum operating conditions, in traditional products such as plantain chips [36, 37], kokoro [38], Chinese deep-fried dough [39], puri [11], or in fried potatoes such as orange-fleshed sweet potato [40], yam [12], pre-fry microwave dried French fries [13], the response surface method was used in the literature. Similar to our study, it was determined that frying temperature and frying time had significantly affected the quality parameters (moisture content, oil content, breaking force and colour) of plantain chips. Furthermore, the effects of the composition of fried food had also been studied [36].

When the food is fried, it absorbs oil from its environment. For this reason, changes in fried oil were also observed in fried food [41]. Kim et al. [42] stated that the free fatty acid content of potato chips obtained after 80th frying trial (each 4 minutes at 180°C) was like the oil used. Lee et al. [29] reported that the lipid oxidation taken place in the fried dough was very similar to that in the frying oil. They claimed that the extent of lipid oxidation in the fried dough can be calculated from oxidation rate of the frying oil.

4. CONCLUSION

Changes in oil and fried foods during the deep-frying process can be determined by different analysis methods. Fried foods and absorbed oil consumed after frying. Hence, the quality of the oil that penetrates the fried food is very important. Optimum conditions that can minimise the formation of undesirable compounds can be identified by the response surface methodology. In this study, the effects of frying time, frying temperature and dough salt content on the oxidation products of FDOs were investigated. Based on the results, it was observed that both frying temperature and frying time had significant effects ($p < 0.05$) on the K_{232} and K_{270} values, *p*-anisidine value and polymer triglyceride content of fried dough samples while dough salt content was not significant effect ($p > 0.05$) on these parameters.

During deep frying, it was observed that oxidation products turned into dough from frying oil with increasing temperature and duration.

Optimum frying conditions to minimise the oxidation products in fried doughs were found as a frying temperature of 160°C, the frying duration of 1 min and the salinity of 2% by using desirability function.

In the later stages of the study, experiments will be conducted to determine the effects of other dough ingredients such as moisture, protein and starch content on the amount of absorbed oil oxidation products.

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Conflict of interest

Authors declare no conflict of interest.

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