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Optimization of the Deep-fat Frying Process of Sweet Potato Chips in Palm Olein or Stearin

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ABSTRACT

The aim this study was to optimize the deep-fat frying process in order to minimize the oil content incorporated into the food and the moisture in sweet potato chips fried in palm olein and stearin in light of the global trend to consume healthy products with low calories and oil. The process of deep-fat frying results in sensorial characteristics such as smell, flavour, colour and texture which are much appreciated by all ages and social classes, as the oil is incorporated into the food, occupying part of the space left by the water and thus increasing its palatability. Samples of sweet potatoes were washed, peeled, sliced into 3 mm thickness chips and fried in a deep-fat fryer with palm olein and stearin at a proportion of 1:30. The sweet potato chip frying process was evaluated according to the rotational central composite design with 2 independent variables: (1) temperature and (2) frying time. The moisture content, colour and incorporated oil content were considered as process-dependent variables. The optimum conditions for deep-fat frying sweet potato chips in palm olein were found to be: temperature of 160°C and a frying time of 3 min and 30 sec. The chips presented a moisture content of 7.43% and oil content of 14.46%. For palm stearin, the optimum frying time was the same as that found for palm olein, however the optimum temperature was 180°C. The chips presented a moisture content of 3.47% and oil content of 13.1%.

Key words: Frying process, optimization, palm olein, palm stearin, sweet potato chips, optimum conditions, oil content

INTRODUCTION

The acceptance of food subjected to deep-fat frying is universal, with such products being appreciated by all ages and social classes. The deep-fat frying process can be defined as a drying, cooking or fast dehydration process, in which the water is removed from the food by means of immersion into oil at a temperature of 120 to 180°C (Vitrac *et al.*, 2000; Torezan, 2005).

The oil has a dual function in deep-fat frying: (1) it acts as a means of transmitting heat and (2) it constitutes a new ingredient in the fried food upon being absorbed by that product (Cella *et al.*, 2002). The absorption of the oil by the food ranges from 10 to 60% and may be influenced by a series of parameters which act on the speeds of mass and energy transfer between the oil and the food and which depend on the food, the oil and the frying conditions (Smith *et al.*, 1985).

Deep-fat frying is a complex operation that involves several dependent parameters: (1) the food itself, (2) the frying oil and (3) the process.

The characteristics of the food, such as the chemical composition, type of vegetable or animal cell tissue (Moreira *et al*., 1999) and the variety, in the case of vegetables (Vitrac *et al*., 2000), are all important parameters in the deep-fat frying process. The initial moisture content of the food is a critical factor for the final quality, as it determines for the same moisture content in the final product, different levels of oil absorption and process times (Vitrac *et al*., 1997). The surface/volume ratio of the food in contact with the means of frying is highly important in relation to oil absorption. Each kind of fried food tends to have a characteristic level of oil absorption, which depends, above all, on the distance between the interior and the surface of the food. The lipid content in food with a high surface/volume ratio is much higher than in those with a lower ration, such as potato chips and stick potato chips (Paul and Mittal, 1997).

The oil properties that influence the deep-fat frying process are: (1) the chemical composition (in unsaturated, polyunsaturated and saturated fatty acids); (2) the physical-chemical characteristics (free fatty acids, peroxide value, iodine value, moisture content and colour); (3) the melting point and (4) the presence of contaminants and additives, which may have an effect on the palatability, digestibility and metabolic utilization of the fried food (Torezan, 2005; Querido, 2005). The type of oil represents the most critical component in the deep-fat frying system, as it should present characteristics such as: (1) high resistance to oxidation, polymerization and gum formation; (2) low rate of foam formation; (3) low melting point; (4) minimal darkening; (5) lack of odours and (6) accessible cost (Torezan, 2005).

Palm oil is extracted from the fruit pulp and presents amounts that are approximately equal to those of saturated and unsaturated fatty acids: unsaturated fats contain 39% oleic acid (18:1n-9) and 10% linoleic acid (18: 2n-6); saturated fats contain 44% palmitic acid (16:0) and 5% stearic acid (18:0). By comparison, palm oil is 54-70% saturated, including a high quantity of lauric acid (12:0), similar to coconut oil. However, neither of these oils contain a large quantity of highly saturated fatty acids, such as linolenic acid and, therefore, they are not subject to many flavour reversal problems (Giese, 1996).

Palm olein is acquired through the natural fractionation of refined palm oil, which consists of cooling and filtering operations without the use of chemical additives. At room temperature palm olein is liquid; it may present precipitation of triacilglycerols of a higher melting point, if the product is stored in cold environments. Due to the low alpha-linolenic acid content (18:3n-3), this product is highly resistant to oxidation and, as it is not subjected to hydrogenation processes, it is trans fat free (Agropalma, 2008).

Palm stearin is also acquired by natural fractionation of refined palm oil, involving cooling and filtering operations without the use of chemical additives. Due to its high content of saturated triacilglycerols with a high melting point, this product is solid at room temperature and as it has not been subjected to any artificial hydrogenation processes it is also trans fat free. Due to its particular physical characteristics, this product can be used as an advantageous substitute for various hydrogenated fats in the food industry (Agropalma, 2008).

The main parameters of the deep-fat frying process include the oil temperature, the time the product remains in the fryer and the kind of equipment used (Torezan, 2005).

The oil temperature and frying time are the main variables in the mechanism of mass transfer (loss of water and incorporation of oil), as well as transformations and reactions in the product (Vitrac *et al*., 2002). At a low temperature, oil stability is greater, however excessive oil absorption occurs. On the other hand, a high temperature will cause over cooking of the food on the outside and the inside remaining raw, as well as resulting in greater alterations in the frying oil (Kupranycs *et al*., 1986). As well as the temperature, the oil absorption is related to micro structural changes during frying, such as wrinkling of the surface, pore porosity and distribution (Torezan, 2005).

Thus, transformations in the physical-chemical and sensorial properties of the product are verified as a result of the deep-fat frying. The products become crisp, with a more agreeable texture. The deep-fat frying process also gives the food a shiny and uniform golden colour, improving its presentation and enhancing flavours and aromas due to the oil itself or the development of new compounds. Conservation of the product is prolonged due to the destruction of microorganisms and enzymes present in food and its palatability is enhanced as a consequence of the moisture loss and oil incorporation (Pigott, 1996).

In order to obtain high quality sweet potato chips with controlled development of the characteristic taste, aroma, colour and texture, as well as low oil incorporation and maximum water loss, the parameters of the deep-fat frying process, particularly the time and temperature, must be optimized (Tfouni *et al*., 2003).

The objective of this study was to optimize the deep-fat frying process in order to minimize the oil content incorporated into the food and the moisture in sweet potato chips fried in palm olein and stearin in light of the global trend to consume healthy products with low calories and oil.

MATERIALS AND METHODS

Preparation of the samples: Sweet potatoes (*Ipomoea batatas*) of the yellow Monalisa variety were acquired from a single producer at the Campinas/SP CEASA (Wholesale Distribution Centre) in the latter half of 2008 purchased from different batches according to the need for the raw material for processing. The tubers were washed in running water to remove dust from the field. They were then peeled, using a manual, stainless steel potato peeler and sliced into 3 mm-thickness slices in a Food Processor (brand: SKYMSEN; model: PAIE, Brazil). The sweet potatoes were fried in a SIRE 3000W deep-fat fryer (Indústria e Comércio Sire Ltda, Santo Amaro, SP) with 5 L in each compartment.

The PN-6 refined palm olein and palm stearin were donated by the Agropalma group. The two samples were characterized in accordance with analyses of: (1) fatty acid composition; (2) free fatty acids; (3) peroxide value; (4) iodine value; (5) colour and (6) moisture content.

Fatty acid composition: Gas chromatographic analysis of the fatty acid composition was performed with a CGC AGILENT 6850 SERIES GC SYSTEM, after transesterification using BF_3 as a reagent, in line with the AOCS (2004), method Ce 1-62. The fatty acid methyl esters were separated according to the AOCS (2004), method Ca 2-66, in a DB-23 AGILENT capillary column (50% cyanopropyl-methylpolysiloxane) measuring 60 m long, with an internal diameter of 0.25 mm and 0.25 μm film thickness. The oven temperature was initially 110°C for 5 min and subsequently increased by 5°C each minute, within the temperature range of 110 to 215°C, ending with a temperature of 215°C for 24 min; detector temperature: 280°C; injector temperature: 250°C; carrier gas: helium; split ratio: 1:50; volume inject: 1.0 μL. The qualitative composition was determined by comparing the peak retention times to the respective fatty acid standards. The quantitative composition was carried out by area normalization, expressed as a percentage in mass.

Table 1: Independent variable levels in the experimental plan for frying sweet potato slices in palm olein and stearin.

	Levels				
Independent variables	-1.41	-1	0	+1	+1.41
Temperature (°C)	140	145	160	175	180
Time	3 min	3 min 15 sec	3 min 30 sec	3 min 45 sec	4 min

Free fatty acids: The free fatty acids content was determined according to AOCS (2004), method Ca 5a-40.

Peroxide value: The peroxide value was determined according to AOCS (2004), method Cd 8b-90.

Iodine value: The iodine value was calculated based on the fatty acid composition, according to AOCS (2004), method Cd 1c-85.

Colour: The Lovibond colour was determined using AOCS (2004), method Cc 13b-45.

Moisture content: The moisture content was measured following AOCS (2004), method Ca 2c-25.

Experimental plan for optimizing the deep-fat frying process of sweet potato chips in palm olein or stearin: The process of deep-fat frying sweet potato was assessed in accordance with rotational central composite design with 2 independent variables (2^2 = 4 tests + 4 axial points + 3 central points = total of 11 tests) applicable to response surface methodology in order to optimize the frying process (Rodrigues and Iemma, 2005). Each variable was studied at 5 different levels, as presented in Table 1.

The process-dependent variables to be evaluated were: (1) moisture content in accordance with method 44-40 (AACC, 1995); (2) colour (Macdougall, 2002) and (3) incorporated oil content, according to the Soxhlet 02-01 method (AACC, 1995). All the analyses were performed in triplicate.

The colour of the sweet potato chips was determined with a Hunter Lab spectrophotometer, using the CIELAB colour system and RSEX calibration, D_{65} illuminant and a 10° viewing angle expressed through the hue angle. The samples were triturated and placed in a 25 mm cuvette and the readings were performed four times.

The hue angle represents, in this study, how close to the natural colour (yellow) the product is. For the sweet potato chips in this study, the hue angle cannot be 90°, as that would represent the *in natura* (raw) product, nor can it be less than 45°, which would represent an extremely burned colouration. The hue angle is calculated using Eq. 1, in accordance with Macdougall (2002).

$$h^* = \tan^{-1} (b^*/a^*) \quad (1)$$

The objective of the experimental planning was to minimize the levels of incorporated oil content and moisture. Therefore a joint analysis was conducted on the surfaces obtained with the analysed responses, in order to identify the region which best served the objective of this study.

Deep-fat frying process: The sweet potatoes were washed, peeled, sliced to a thickness of 3 mm and fried in a deep-fat fryer with palm olein or stearin with a potato to oil proportion of 1:30, that is, for every 3 L of oil in each cookpot, 100 g of sweet potato were fried in each process. The temperature variation used was from 140 to 180°C and the time ranged from 3 to 4 min. Once removed from the fryer, the potatoes were placed on paper towel in order to drain the excess oil.

RESULTS

Characterization of palm olein and stearin: Palm olein contains a high level of unsaturated fatty acids (57.38%), of which oleic acid accounts for 45.98%. The percentage of saturated fatty acids is 42.62%, with 36.30% palmitic acid (Table 2). Palm stearin contains a high level of saturated

Table 2: Fatty acid composition of palm olein

Fatty acid		PO (%)	A (%)	Opa (%)
8:0	Caprylic	0.03	-	-
10:0	Capric	0.04	-	-
12:0	Lauric	0.46	0.30	-
14:0	Myristic	0.93	1.00	0.90
16:0	Palmitic	36.30	37.00	42.90
16:1n-7	Palmitoleic	0.17	0.30	0.10
17:0	Margaric	0.09	-	-
17:1n-7	Margaroleic	0.03	-	-
18:0	Stearic	4.30	4.00	5.00
18:1n-9	Oleic	45.98	46.00	41.00
t,t-18:2n-6	Linolelaidic	0.12	-	-
18:2n-6	Linoleic	10.53	10.80	9.30
18:3n-3	Alpha-linolenic	0.26	-	0.20
20:0	Arachidic	0.40	0.30	0.40
20:1n-11	Gadoleic	0.18	-	0.10
22:0	Behenic	0.07	-	-
24:0	Lignoceric	0.11	-	-
Σ saturated (%)	-	42.62	42.5	49.2
Σ unsaturated (%)	-	57.38	57.5	50.8

PO: Palm olein; A: Agropalma (Agropalma, 2008), Opa: Palm oil (Wada, 2007). Results are expressed in relative area percentage

Table 3: Fatty acid composition of palm stearin

Fatty acid		PS	A (%)	SPa (%)
8:0	Caprylic	0.04	-	-
10:0	Capric	0.04	-	-
12:0	Lauric	0.56	0.20	0.40
14:0	Myristic	1.27	0.70	1.20
16:0	Palmitic	55.50	54.20	54.50
16:1n-7	Palmitoleic	0.10	0.20	0.10
17:0	Margaric	0.13	-	-
17:1n-7	Margaroleic	0.03	-	-
18:0	Stearic	5.25	6.00	5.50
18:1n-9	Oleic	30.46	32.30	31.30
t,t-18:2n-6	Linolelaidic	0.28	-	-
18:2n-6	Linoleic	5.59	6.00	6.40
18:3n-3	Alpha-linolenic	0.08	-	0.10
20:0	Arachidic	0.39	0.40	0.50
20:1n-11	Gadoleic	0.11	-	-
22:0	Behenic	0.08	-	-
24:0	Lignoceric	0.09	-	-
Σ saturated (%)	-	63.26	61.5	62.0
Σ unsaturated (%)	-	36.74	38.5	38.0

PS: Palm stearin; A: Agropalma (Agropalma, 2008), Spa: Palm stearin (Wada, 2007). Results are expressed in relative area percentage fatty acids (63.26%), of which palmitic acid accounts for 55.50%. The percentage of unsaturated fatty acids is 36.74%, with 30.46% oleic acid (Table 3). Physical-chemical characteristics of palm olein and stearin shown in Table 4.

Optimization of the deep-fat frying process with palm olein or stearin: The lowest temperature values in the frying process in palm olein (Table 5) or palm stearin (Table 6) resulted in greater moisture content and greater hue angles, in other words, the colour of these sweet potato chips was closer to that of sweet potato *in natura* (yellow) and the chips were raw, as identified upon tasting of the samples by the authors.

Test number 8 presented the highest incorporated oil content both in palm olein and stearin, due to the fact that this test involved the longest time for which the sweet potato chips were immersed in the oil (Table 5, 6).

Moisture content: For palm olein, the significant factors were: the mean, temperature (L), temperature (Q) and time (L) (Table 7). For frying with palm stearin, the significant factors were: the mean and temperature (L) (Table 8), with a 95% confidence interval, in other words, a 5% level of significance for analysis through standard error (residual MS). The estimated effect of a variable indicates the extent to which that variable influences the response. Therefore, the greater the value, the greater the influence it will have on the response. A positive effect on the response indicates that, as the variable increases from a minimum to a maximum value, the response value

Table 4: Physical-chemical characteristics of palm olein and stearin

	Palm olein		Palm stearin	
Characteristics	Values*	Agropalma (2008)	Values*	Agropalma (2008)
FFA	0.10	0.05	0.06	0.05
PV	7.4	1.0	36.9	1.0
Iodine value (%)	58.8	59.0	36.3	36.9
Lovibond Colour	20.0Y/1.0R	n.d.	6.9Y/0.9R	n.d.
Moisture (%)	0.06	n.d.	0.04	n.d.

FFA: Free fatty acids = % oleic acid; PV: Peroxide value = meq O_2 kg^{-1}. *Values obtained by analyses performed in this study

Table 5: Experiment design for sweet potato chips fried in palm olein

	Independent variables		Dependent variables		
Tests	Temperature (°C)	Time	Moisture (%)	Colour (hue)	Oil content (%)
1	145 (-1)	3 min 15 sec (-1)	31.21	85.70	13.7
2	175 (+1)	3 min 15 sec (-1)	7.13	73.56	12.9
3	145 (-1)	3 min 45 sec (+1)	20.01	84.37	15.3
4	175 (+1)	3 min 45 sec (+1)	3.03	68.51	14.6
5	140 (-1,41)	3 min 30 sec (0)	34.17	86.10	14.0
6	180 (+1,41)	3 min 30 sex (0)	4.78	64.21	13.3
7	160 (0)	3 min (-1,41)	10.06	80.61	16.4
8	160 (0)	4 min (+1,41)	4.48	70.41	19.1
9	160 (0)	3 min 30 sec (0)	6.78	77.98	13.9
10	160 (0)	3 min 30 sec (0)	7.44	76.66	15.1
11	160 (0)	3 min 30 sec (0)	8.07	79.03	14.4

The numbers between parentheses are the codified values of the independent variables

Table 6: Experiment design for sweet potato chips fried in palm stearin

	Independent variables		Dependent variables		
Tests	Temperature (°C)	Time	Moisture (%)	Colour (hue)	Oil content (%)
1	145 (-1)	3 min 15 sec (-1)	19.44	86.53	13.4
2	175 (+1)	3 min 15 sec (-1)	3.21	71.39	15.0
3	145 (-1)	3 min 45 sec (+1)	26.67	85.10	15.5
4	175 (+1)	3 min 45 sec (+1)	1.08	66.03	15.7
5	140 (-1,41)	3 min 30 sec (0)	28.81	85.34	13.8
6	180 (+1,41)	3 min 30 sec (0)	3.47	66.13	13.1
7	160 (0)	3 min (-1,41)	17.61	79.23	15.9
8	160 (0)	4 min (+1,41)	13.47	71.95	19.1
9	160 (0)	3 min 30 sec (0)	11.12	77.41	16.3
10	160 (0)	3 min 30 sec (0)	12.73	78.62	15.8
11	160 (0)	3 min 30 sec (0)	14.21	76.54	16.4

The numbers between parentheses are the codified values of the independent variables

Table 7: Effects of the independent variables on the moisture content of the sweet potato chips fried in palm olein (R^2 = 0.98)

Factor	Effect	Standard error	p-value
Mean	7.4223	1.0045	0.0007
Temperature (L)	-20.6865	1.2321	0.0000
Temperature (Q)	13.0990	1.4702	0.0002
Time (L)	-5.8092	1.2321	0.0052
Time (Q)	0.8210	1.4702	0.6006
Temperature×time	3.5500	1.7399	0.0968

L: Linear term, Q: Quadratic term

Table 8: Effects of the independent variables on the moisture content of the sweet potato chips fried in palm stearin (R^2 = 0.94)

Factor	Effect	Standard error	p-value
Mean	12.6996	1.7358	0.0007
Temperature (L)	-19.4452	2.1291	0.0002
Temperature (Q)	1.8219	2.5406	0.5054
Time (L)	-0.1849	2.1291	0.9341
Time (Q)	1.2183	2.5406	0.6518
Temperature×time	-4.6800	3.0066	0.1803

L: Linear term, Q: Quadratic term

Table 9: Analysis of variance for the moisture content sweet potato chips fried in palm olein and stearin

	Moisture in palm olein	Moisture in palm stearin
Calculated F-value	95.48	93.54
Table F value	4.35	5.12
R^2	0.97	0.91
Equation	$7.42-10.34*T + 6.54*T^2-2.90*TI$	$12.69-9.72*T$

T: Temperature; TI: Time

increases. In the event of a negative effect, this will indicate a reduction in the response. The parameter that exerted the greatest influence was the temperature (L), both for the chips fried in palm olein and the chips fried in palm stearin (Table 7, 8). After eliminating the insignificant parameters, Analysis of Variance (ANOVA) demonstrated the significance of the regression and of the residual to a 95% confidence level, using the F test, for the studied plan, as per Table 9. By means of analysis of variance, it was found that the model presented significant regression

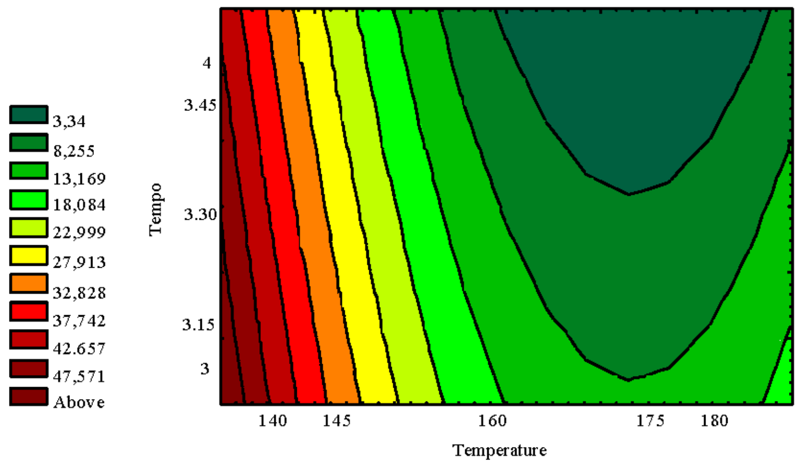

Fig. 1: Contour curve of the moisture content in relation to the temperature and the frying time for sweet potato chips fried in palm olein

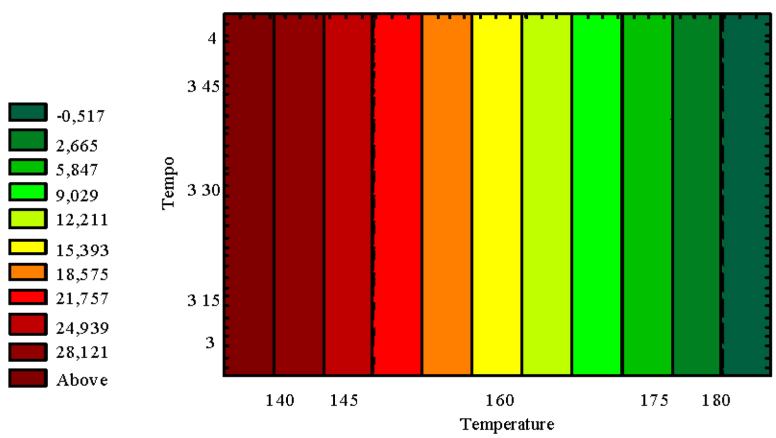

Fig. 2: Contour curve of the moisture content in relation to the temperature and the frying time for sweet potato chips fried in palm stearin

(calculated F-value greater than the table F-value) and the coefficient of determination (R^2) obtained for the adjusted model was 0.97 for palm olein and 0.91 for palm stearin, indicating that the model explains 97 and 91% of the observed data variance, respectively (Table 9). The proposed codified models to represent the moisture content of the sweet potato chips fried in palm olein and stearin are presented by the equations in Table 9.

The frying time did not influence the moisture content of the sweet potato chips fried in palm olein and stearin (Fig. 1, 2). To obtain sweet potato chips with a moisture content less than 9%, the frying temperature used should be above 160°C for palm olein and above 170°C for palm stearin.

Colour: The parameter which exerted the greatest influence was the mean, followed by temperature (L) and time (L) both for palm olein and stearin (Table 10, 11). An increased

Table 10: Effects of the independent variables on the colour of the sweet potato chips fried in palm olein (R^2 = 0.94)

Factor	Effect	Standard error	p-value
Mean	77.8792	1.3370	0.0000
Temperature (L)	-14.7601	1.6400	0.0002
Temperature (Q)	-1.3735	1.9569	0.5140
Time (L)	-5.2060	1.6400	0.0246
Time (Q)	-1.0164	1.9569	0.6256
Temperature×time	-1.8600	2.3158	0.4583

L: Linear term, Q: Quadratic term

Table 11: Effects of the independent variables on the colour of the sweet potato chips fried in palm stearin (R^2 = 0.97)

Factor	Effect	Standard error	p-value
Mean	77.5169	0.9980	0.0000
Temperature (L)	-15.3698	1.2241	0.0000
Temperature (Q)	-0.9823	1.4607	0.5311
Time (L)	-4.2764	1.2241	0.0174
Time (Q)	-1.1281	1.4607	0.4748
Temperature×time	-1.9650	1.7286	0.3071

L: Linear term, Q: Quadratic term

Table 12: Analysis of variance for the colour of sweet potato chips fried in palm olein and stearin

Analysis	Colour in palm olein	Colour in palm stearin
Calculated F-value	58.32	95.58
Table F value	4.46	4.46
R^2	0.93	0.95
Equation	77.87-7.38*T-2.60*TI	77.51-7.68*T-2.13*TI

T: Temperature; TI: Time

temperature value in the deep-fat frying process in palm olein and stearin promotes a reduced hue angle, in other words, the sweet potato chips present a different colouration from the natural colour (yellow), tending towards the orange quadrant.

After eliminating the insignificant parameters, Analysis of Variance (ANOVA) demonstrated the significance of the regression and of the residual to a 95% confidence level, using the F test, for the studied plan, as per Table 12. By means of analysis of variance, it was found that the model presented significant regression (calculated F-value greater than the table F-value) and the coefficient of determination (R^2) obtained for the adjusted model was 0.93 for palm olein and 0.95 for palm stearin, indicating that the model explains 93% and 95% of the observed data variance, respectively. The proposed codified models to represent the colour of the sweet potato chips fried in palm olein and stearin are presented by the equations in Table 12.

The ideal and accepted colouration for the sweet potato chips would be when the hue angle is between 74 and 80, so that the chips look neither burned nor raw (Fig. 3, 4). Therefore, the temperature should be within the range of 160 to 175°C, whereas the time was indifferent in the process of deep-fat frying sweet potato chips in palm olein and stearin

Incorporated oil content: The parameter which exerted the greatest influence on the sweet potato chips fried in palm olein was the mean, followed by time (Q) and time (L). For palm stearin, the parameter which exerted the greatest influence was the mean, followed by temperature (Q) and time (L) (Table 13, 14).

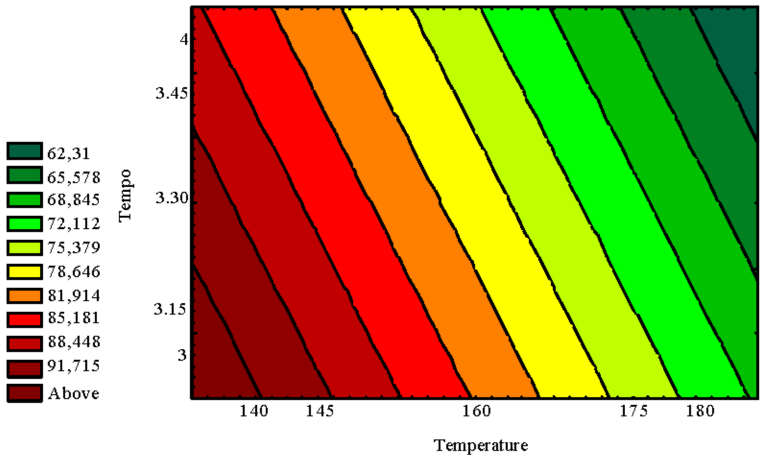

Fig. 3: Contour curve of the colour in relation to the temperature and frying time for sweet potato chips fried in palm olein

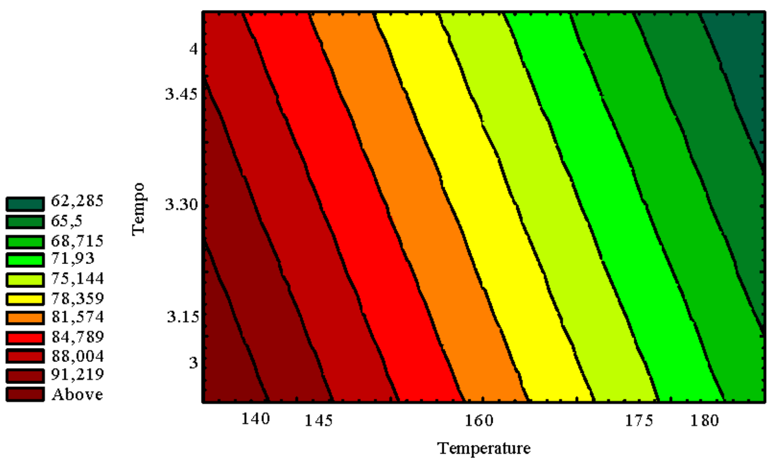

Fig. 4: Contour curve of the colour in relation to the temperature and frying time for sweet potato chips fried in palm stearin

Table 13: Effects of the independent variables on the incorporated oil content of sweet potato chips fried in palm olein ($R^2 = 0.80$)

Factor	Effect	Standard error	p-value
Mean	14.4729	0.6202	0.0000
Temperature (L)	-0.6231	0.7608	0.4497
Temperature (Q)	-1.6237	0.9078	0.1337
Time (L)	1.7820	0.7608	0.0661
Time (Q)	2.5007	0.9078	0.0400
Temperature×time	0.050	1.0743	0.9646

L: Linear term, Q: Quadratic term

After eliminating the insignificant parameters, Analysis of Variance (ANOVA) demonstrated the significance of the regression and of the residual to a 95% confidence level, using the F test, for the studied plan, as per Table 15.

Table 14: Effects of the independent variables on the incorporated oil content of sweet potato chips fried in palm stearin (R^2 = 0.92)

Factor	Effect	Standard error	p-vlaue
Mean	16.1689	0.3832	0.0000
Temperature (L)	0.2038	0.4701	0.6826
Temperature (Q)	-3.0223	0.5609	0.0029
Time (L)	1.8334	0.4701	0.0114
Time (Q)	1.0519	0.5609	0.1196
Temperature×time	-0.7000	0.6638	0.3399

L: Linear term, Q: Quadratic term

Table 15: Analysis of variance for oil incorporation in sweet potato chips fried in palm olein and stearin

	Oil incorporation in PO	Oil incorporation in PS
Calculated F-value	7.75	21.88
Table F value	4.46	4.46
R^2	0.65	0.84
Equation	$14.47 + 0.89*T + 1.25*TI^2$	$16.16-1.51*T^2 + 0.91*TI$

PO: Palm olein; PS: Palm stearin; T: Temperature; TI: Time

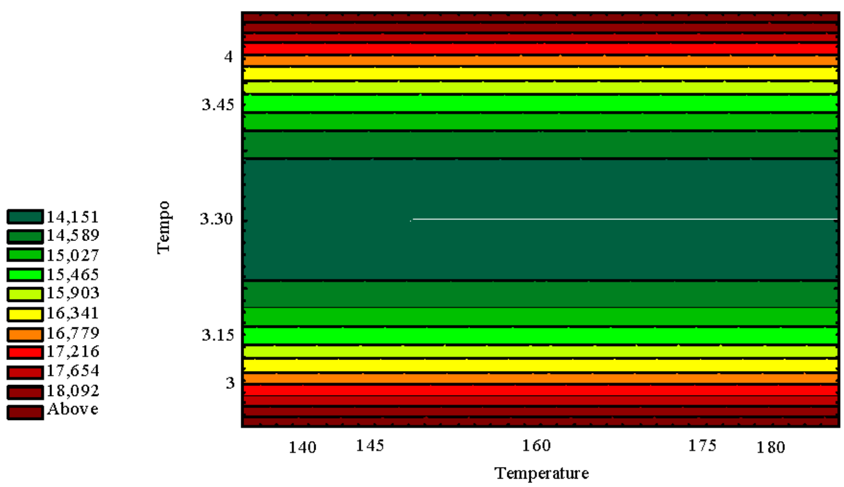

Fig. 5: Contour curve of the oil incorporation in relation to the temperature and frying time for sweet potato chips fried in palm olein

By means of analysis of variance, it was found that the model presented significant regression (calculated F-value greater than the table F-value) and the coefficient of determination (R^2) obtained for the adjusted model was 0.65 for palm olein and 0.84 for palm stearin, indicating that the model explains 65 and 84% of the observed data variance, respectively.

The lowest oil incorporation level for sweet potato chips fried in palm olein and stearin was obtained when the frying time was 3 min and 30 sec. The temperature did not influence the oil incorporation in the sweet potato chips fried in palm olein, however for the chips fried in palm stearin the temperature should be below 140°C or above 180°C (Fig. 5, 6).

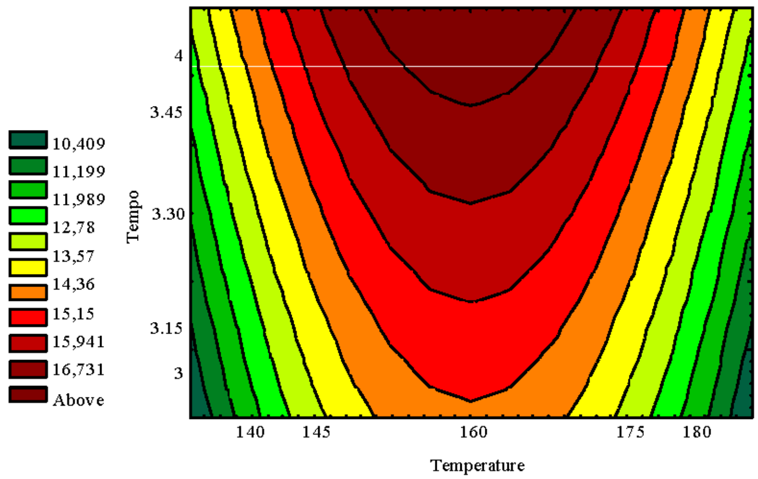

Fig. 6: Contour curve of the oil incorporation in relation to the temperature and frying time for sweet potato chips fried in palm stearin

DISCUSSION

Characterization of palm olein and stearin: The values presented in Table 2 are very similar to the report provided by the Agropalma group (Agropalma, 2008), however, for the palm oil studied by Wada (2007) the palmitic acid level observed was 18.3% higher (42.90%) and the oleic acid level 12% lower (41%).

The values presented in Table 3 are very similar to those found in the Wada (2007) with palm stearin and to the report provided by the Agropalma group (Agropalma, 2008), with lower values only being verified for lauric acid (0.56%) and myristic acid (1.27%).

The free fatty acid contents in palm olein and stearin found were low and similar to those reported in the Agropalma findings (Table 4), however, the peroxide values, which represent lipidic oxidation of the palm olein and stearin were significantly higher than the values provided by the company. In countries like France, Switzerland, the United States and Chile, laws and regulations have been created to control the disposal of oil for values of over 1.0% free fatty acids (Monferrer and Villalta, 1993). The standards that regulate the fitness of oil for consumption in Brazil (Resolution 482/99-ANVISA), establish a peroxide value of 10 meq kg^{-1} for refined cottonseed, sunflower and palm oils (Brazil, 1999), which would deem the palm stearin inadequate for use with a value of 36.9 meq kg^{-1}.

The iodine value, which evaluates the degree of unsaturation of the fatty acids, is in accordance with the Agropalma report. Analysis of the colour and moisture were not provided in the Agropalma report; however, these evaluations were performed for the purpose of characterization of the palm olein and stearin.

Optimization of the deep-fat frying process with palm olein or stearin: In the optimization of the deep-fat frying process for apples in special Cukin Fry fat (Bunge) it was also concluded that closer the colour is to its natural colour, the greater the moisture content of the apples (Querido, 2005).

Studies to determine the oil content of potatoes during intermittent frying with varying frying times and different temperatures have reported that the oil absorption in the potatoes increased with frying time at all temperatures (Sahin *et al*., 2000).

The average oil content absorbed by sweet potato chips fried in palm olein was 14.79%, which is 81.8% below that found by Querido (2005) for the incorporation of oil in sliced apple, which was 26.88%. In the sweet potato chips fried in palm stearin, the average incorporated oil content was 15.45%, superior, therefore, to the result for sweet potato chips fried in palm olein. The higher oil incorporation in sweet potato chips fried in palm stearin may be explained by the greater quantity of saturated fatty acid in its composition, as also found in a study with potatoes fried in soybean oil and hydrogenated fat. After the deep-fat frying process, hydrogenated fat, as well as being incorporated into the interior of the vegetable, also remains on the surface of the product, thus increasing the total oil content in the final product (Damy, 2001).

Moisture content: Temperature increase resulted in reduced moisture content in the sweet potato chips, as also verified by Torezan (2005) in optimizing the deep-fat frying process for mango chips. Barros *et al.* (2003), suggested that for a regression to be not only statistically significant, but also useful for predictive purposes, the F value calculated for the regression should be at least four times the F value in the table. This condition is fully satisfied in this study.

The moisture content should be less than 7% (upper limit for acquiring crispness), according to Querido (2005) in his study involving 3 mm-thick apple chips. In a study involving 3 mm-thick potato chips, the ideal moisture content was found to be roughly 9.13% (Jorge and Lunardi, 2005).

Colour: The ideal and accepted colouration for the sweet potato chips would be when the hue angle is between 74 and 80. Therefore, the temperature should be within the range of 160 to 175°C, whereas the time was indifferent in the process of deep-fat frying sweet potato chips in palm olein and stearin.

Incorporated oil content: By joint analysis of the contact surfaces and contour areas of the dependent variables (moisture content, colour and incorporated oil content) the optimal point for the process of deep-fat frying sweet potato chips in palm olein was found to be: (1) temperature of 160°C and (2) time of 3 min and 30 sec, that is, the centre point of the rotational central composite design. The sweet potato chips fried in palm olein presented a moisture content of 7.43% and final oil content in the product of 14.46%. For palm stearin, the optimal point was found to be: (1) temperature of 180°C and (2) a frying time of 3 min and 30 sec. The sweet potato chips fried in palm stearin presented a moisture content of 3.47% and final oil content in the product of 13.1%.

CONCLUSION

The best operational conditions for the process of deep-fat frying sweet potato chips in palm olein with the aim of minimizing the incorporated oil content and moisture content were: (1) temperature of 160°C and (2) a frying time of 3 min and 30 sec. For optimization of the deep-fat frying process in palm stearin, the optimal time was the same as that found for palm olein, however, the optimal temperature was 180°C.

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