

Quality changes of selected vegetable oils during frying of doughnuts

CAMBIAMENTI CHE AVVENGONO IN DETERMINATI OLI VEGETALI DURANTE LA FRITTURA DI KRAPPEN

Olio di cotone, Friol (nome commerciale di una miscela al 75% di olio di girasole, 25% olio di palma e 5% olio di arachide), olio di sansa raffinato con il 5% di olio vergine di oliva e olio extra vergine di oliva sono stati usati per friggere krapfen ininterrottamente per 2 ore al giorno, per 5 giorni consecutivi, a 170 ± 5°C. Gli oli sono stati sottoposti a ripetuti processi di frittura simulando l'operazione che viene eseguita in ambito domestico. In queste condizioni si verifica negli oli una degradazione termica ed ossidativa. La viscosità, l'intensità di colore, i componenti polari e gli acidi grassi liberi degli oli aumentano mentre il punto di fumo, l'indice di iodio, il periodo di induzione Rancimat, il contenuto di acidi grassi polinsaturi e la concentrazione di tocoferoli diminuiscono. I risultati della sperimentazione indicano chiaramente che l'olio di oliva è il più stabile con una stabilità termica ossidativa più alta rispetto agli altri oli.

Cottonseed oil, Friol oil (commercial name of a blend of 75% sunflower oil, 25% palm oil and 5% peanut oil), refined residue oil with 5% virgin olive oil and extra virgin olive oil were used for intermittently frying of doughnuts for 2 hours per day at a temperature of 170 ± 5°C for 5 consecutive days. The oils were subjected to repeated frying processes designed to simulate those which might be carried out in domestic situations. Under these conditions thermal and oxidative degradation of the oils occurred. Afterwards the quality changes of the frying oils were evaluated. Viscosity, colour, polar compounds, and free fatty acids of oils increased whereas smoke point, iodine value, Rancimat induction period polyunsaturated fatty acids content and tocopherols concentration decreased. The results of the above tests clearly suggested that the olive oil was in comparison with all the other oils more stable with increased thermal oxidation stability.

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INTRODUCTION

Deep-fried foods and especially fried potatoes and cod are becoming more and more popular in Greece. Deep frying is a very important method of cooking in the food services industry. It is estimated that nearly one-half of all lunch and dinner food orders in commercial restaurants include one or more deep-frying items [1].

Deep fat frying enhances the sensory properties of food. However, repeated use of frying oils produces undesirable constituents that may pose health hazards [2].

During deep-frying the oil is exposed to elevated temperatures in the presence of air and moisture. A number of chemical reactions including oxidation and hydrolysis, occur during this time as do changes due to thermal decomposition [3].

Chang et al. [4] and Landers et al. [5] have reported that the chemical reactions taking place during deep oil frying differ from those which occur when the oil is heated continuously, thus reactions occurring in studies conducted with oils heated in the presence of air, with or without agitation, may not be representative of those of the same oils used under normal intermittent frying conditions. The decomposition products formed during frying can be divided into two broad classes: volatile and non-volatile products. Volatile decomposition products have been shown to be retained in the fried food and also inhaled by the deep-frying operator and could thus have an effect on the health of these individuals [4].

The formation of non-volatile decomposition products is due largely to the thermal oxidation and polymerisation of the unsaturated fatty acids present in the frying medium and is of concern since these products not only remain in the frying oil to prevent further degradation but are also absorbed by the fried food and hence consumed [3].

There is some evidence that highly oxidised and heated fats may have carcinogenic properties because of potentially toxic substances [6, 7, 8]. On the other hand, investigations of commercial frying have generally indicated that these oils have no deleterious effects upon human health [9, 10, 11, 12]. Apart from this, the nutritional value of frying fats is affected by loss of polyunsaturated fatty acids (PUFA), which supplement the essential fatty acids' requirement human metabolism [13, 14].

MATERIAL AND METHODS

Vegetable oils

- Extra virgin olive oil Xenia (acidity 0-1%) was obtained from Olympia Agroindustrial S.A.
- Refined residue oil with 5% virgin olive oil was obtained from Aspis Olive Industries, D. P. Georgacopoulos A.E.8.E.
- Friol, which is the commercial name of a blend of 75% sunflower oil, 25% palm oil and 5% peanut oil, special made for frying was obtained from Elais Olive Industries
- Refined cottonseed oil was obtained from Olive Industries, D. P. Georgacopoulos A.E.B.E.

Doughnuts

Doughnuts were made according to the following recipe: 100 g of fresh yeast was mixed with 430 g of milk and a 100 g of bread flour and the mixture was left to rest for 20-30 min so as a sponge dough was prepared.

100 g of shortening, 100 g of sugar, 150 g of whole egg, 35 g egg yolk, 12 g of salt, 900 g of bread flour and the prepared sponge dough were mixed in a Kenwood mixer until a smooth dough was prepared.

The prepared dough was given a 20 min rest before make-up and then rolled out by hand and spread with a sheeter to reduce the sheet thickness.

The doughnuts were cut out by hand into a round shape with a hole in the middle and left to proof for 20 min. 200 mg/kg of lemon citrus oil was added in order to improve flavour, as well as preservative [15].

Methods

The method used for the frying procedure was adapted from that developed by Tsaknis [16]. Doughnuts were deep-fried in 2 litres of oil. When the temperature of the oil reached 175 °C dough pieces of about 43 grams weight were fried. Repeat frying were carried out at half hour intervals for 2 h. The frying time was 2 min (one minute on each side). A total of five frying were done per day for five consecutive days. At the end of each day 50 g sample of oil was removed from each fryer and stored at 0 °C. The lid of the fryer was replaced and the

frying was continued the following day. Fresh oil was not added to the frying pans.

Colour was measured with a Lovibond tintometer (The Tintometer Ltd., Salisbury, England).

Free fatty acid content was measured according to the method described by IUPAC [17].

Smoke point was measured according to the method described by British Standards Methods of Analysis (BS 684: Section 1.8).

Iodine value was measured according to the Wijs method as described by Pearsons [18].

The polar compounds were determined using the IUPAC [17] method. The determination of the fatty acids composition was done by gas-liquid chromatography according to the method described by Tsaknis [19]. The FAMES preparation was done using the following procedure: about 25 mg of oil were accurately weighed into a screw cap tube, and 1.5 cm³ methanolic sodium hydroxide was added, mixed and heated at 100 °C for 7 minutes. After cooling, 2 cm³ of boron trifluoride were added and heated at 100 °C for 5 minutes. The tube was cooled to 30-40 °C and 1 cm³ of iso-octane was added, capped and shaken using whirli mix for 30 seconds. 5 cm³ of saturated sodium chloride solution was immediately added and the tube was shaken again. The tube contents were allowed to separate and the top (iso-octane containing fatty acid methyl esters) layer was removed and the lower layer was extracted again with an addition of 1 cm³ iso-octane. The two iso-octane extracts were combined (dried over anhydrous sodium sulfate) and concentrated to approximately 1 cm³ with a stream of nitrogen.

Analysis of fatty acid methylesters was performed on a Varian 3600 Gas chromatograph (Varian, Palo Alto, California, USA) equipped with a Carbowax 20M (Supelco, INC. Supelco Park, Bellefonte, PA 16823-0048) 10' x 1/8" (5% on Chromosorb W 80/100 mesh) column. The temperature program was 60 °C for 10 min and then 2 °C min⁻¹ up to 220 °C. Injector and FID temperatures were set at 160 °C and 280 °C respectively, sample volume was 0.2 µl, the carrier gas was N₂ at a flow of 30 ml min⁻¹, chart speed was set at 0.5 cm min⁻¹ and the attenuation at 10⁻¹⁰x32. In total three samples were prepared and measured separately.

The method used for the determination of tocopherols was a modification of that reported by Carpenter's [20]:

(a) 1 g of oil was accurately weighed into a 3 dram sample vial wrapped in foil paper to prevent oxidation. The oil was dissolved in a 5 cm³ n-hexane before injection.

(b) A 20 µl sample was injected into the Waters 600E HPLC pump (Millipore Corporation, Waters Chromatography Division, Massachusetts, MA 01757, USA) fitted with a Waters µ-Polarsil, 125 A, 10 µm, 3.9x300 mm column.

Detection was performed with a Waters 486 Tunable Absorbance Detector set at 295 nm. Iso-propanol: n-hexane: absolute ethanol (2: 97.5: 0.5) at 1 cm³/min was used as the mobile phase. A total of 5 min was necessary to assay the tocopherols. In total three samples were prepared and measured separately.

The determination of peroxide value was done using the method adapted from Lea [21].

The determination of the induction period was done as follows: two and a half grams (2.5 g) of oil were accurately weighed into each of the six reaction vessels and the following procedure was carried out. The "Metrohm Rancimat 679" (Metrohm Ltd., CH-9101, Herisau, Switzerland) was switched on until the temperature of the oil batch reached the temperature of 120 °C. Then 50 cm³ of distilled water was placed into each of the six conductivity cells and the air flow rate was set at 20 L h⁻¹.

The temperature was checked to ensure it had a constant value. The air supply was connected to the tubes containing the oil samples and the chart recorder was started. The determination continued automatically until the conductivity reached the maximum value and the induction period was read.

RESULTS AND DISCUSSION

► *Viscosity* - Changes in viscosity of frying oils during frying are shown in Figure 1. As the oxidation is accelerated by heat proceeded, the values of viscosity progressively increased [22]. Olive oil and olive-residue oil showed the lowest change in viscosity after 10 h of frying, while Friol and cottonseed oil showed much higher changes. These results clearly indicated the higher deteriorative effect of oxidation and polymerisation of Friol and cottonseed oil compared to olive oil and olive-residue oil because the former contained larger quantities of polyunsaturated acids. The increase in viscosity of frying oils was due to polymerisation which resulted in formation of higher molecular weight compounds (carbon to carbon and/or carbon to oxygen-to carbon bridges between fatty acids [23]).

► *Colour* - Table I shows the changes in colour of the frying oils. Darkening is attributed to the presence of unsaturated car-

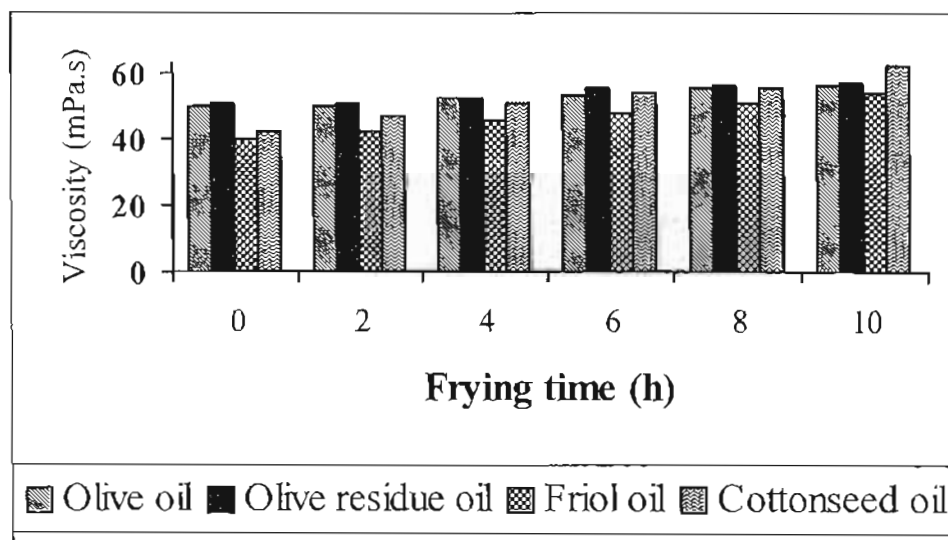


Fig. 1 - Changes in viscosity during frying of oils

TABLE I - Changes of colour during frying of oils

Frying Time (h)	COLOUR			
	Olive oil	Olive residue oil	Friol oil	Cottonseed oil
0	36Y (0.141), 2.5R (0.090)	40Y (0.061), 2.0R (0.101)	15Y (0.083), 5.0R (0.361)	20Y (0.234), 4.1R (0.264)
2	36Y (0.195), 3.0R (0.212)	40Y (0.253), 2.5R (0.058)	15Y (0.150), 6.4R (0.100)	20Y (0.048), 6.1R (0.252)
4	36Y (0.301), 3.5R (0.058)	40Y (0.423), 2.5R (0.100)	20Y (0.055), 7.4R (0.208)	20Y (0.203), 7.1R (0.058)
6	36Y (0.198), 3.5R (0.100)	40Y (0.325), 2.5R (0.153)	20Y (0.036), 7.9R (0.058)	20Y (0.280), 7.6R (0.115)
8	35Y (0.063), 3.6R (0.058)	40Y (0.075), 3.0R (0.173)	20Y (0.048), 8.5R (0.321)	20Y (0.106), 8.0R (0.058)
10	35Y (0.203), 3.6R (0.152)	40Y (0.139), 3.5R (0.200)	20Y (0.263), 9.0R (0.115)	20Y (0.094), 9.0R (0.173)

Y: yellow units, R: red units. # Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

bonyl compounds or to non-polar compounds of foodstuff solubilised in the oil [24]. The colour of frying oils changed from light yellow or green of fresh oils to amber and reddish brown, as a result of the diffusion of pigments into the oil during frying. Cottonseed oil showed the highest increase in colour while olive oil showed the lowest. The results confirm that olive oil and olive-residue oil were more stable in thermal abuse than Friol and cottonseed oil. Palm oil is known to darken more quickly than other oils, but this does not necessarily mean a reduction in quality [23].

► *Free fatty acid (FFA) content* - Table II illustrates the changes in free fatty acids in oil used for frying doughnuts. No significant increases were observed after 5 days of frying in all the oils at the 95% level of significance (student's t-test). The olive oil showed the lowest increase and the cottonseed oil the highest. The steady rise in the formation of FFA can be attributed partly to the hydrolysis and partly to the component

TABLE II - Changes in free fatty acid content during frying of oils

Frying Time (h)	FREE FATTY ACIDS (% as oleic)			
	Olive oil	Olive residue oil	Friol oil	Cottonseed oil
0	0.644 (0.002)	0.203 (0.006)	0.056 (0.001)	0.078 (0.007)
2	0.665 (0.011)	0.219 (0.001)	0.084 (0.003)	0.134 (0.003)
4	0.704 (0.001)	0.266 (0.002)	0.111 (0.004)	0.183 (0.006)
6	0.744 (0.019)	0.312 (0.006)	0.139 (0.011)	0.235 (0.003)
8	0.754 (0.032)	0.350 (0.018)	0.191 (0.009)	0.282 (0.018)
10	0.792 (0.014)	0.392 (0.001)	0.226 (0.014)	0.309 (0.011)

Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

carboxylic groups present in polymeric products of frying [21]. The acidity was mainly formed by hydrolysis of triglycerides, which was promoted by the presence of food moisture, and by oxidation or by the reaction of oil with moisture formed during other deterioration reactions [23].

► *Smoke point* - Results are shown in Figure 2. As expected a decrease of smoke point of the oils was observed. The Friol and cottonseed oil showed a significant decrease in smoke point after 4 days of frying, while the olive oil and olive residue oil showed no significant increase after 5 days of frying. Morton and Chidley [25] reported that the amount of smoke emanating from a cup is directly proportional to the concentration of low molecular weight decomposition products in the oil. The free fatty acids and other volatile substances leaving the fat as gases, will not appear as smoke until their concentration is great enough to permit aggregation to colloidal sized particles.

► *Peroxide value* - Changes in peroxide value are illustrated in Figure 3. Friol showed an increase at the initial stages of

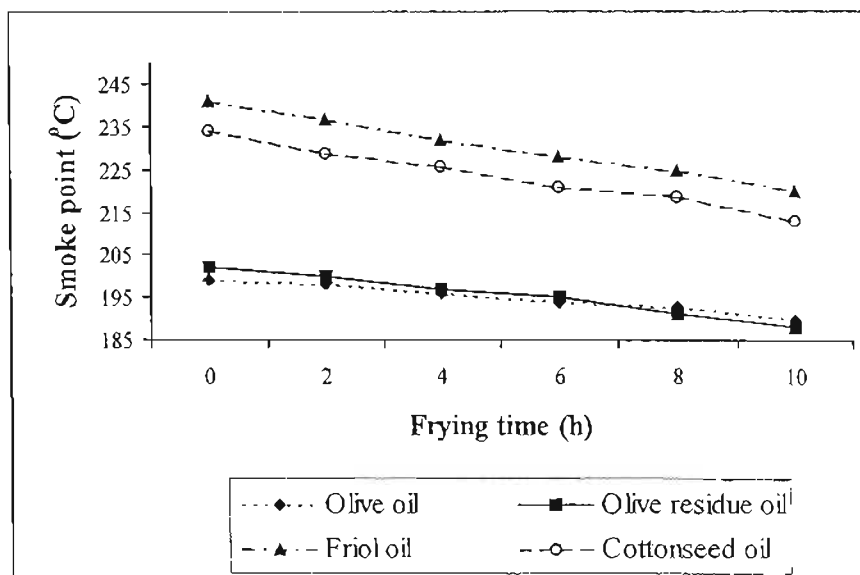


Fig. 2 - Changes in smoke point during frying of oils.

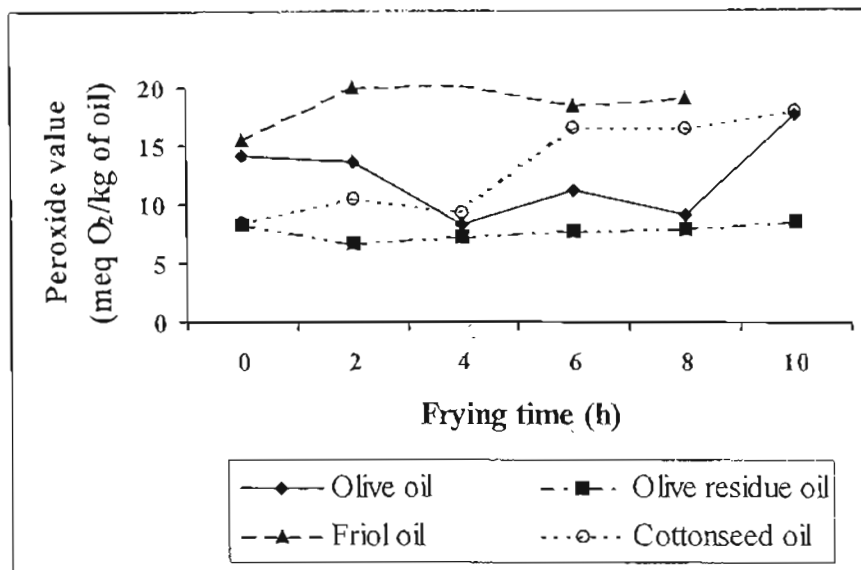


Fig. 3 - Changes in peroxide value during frying of oils.

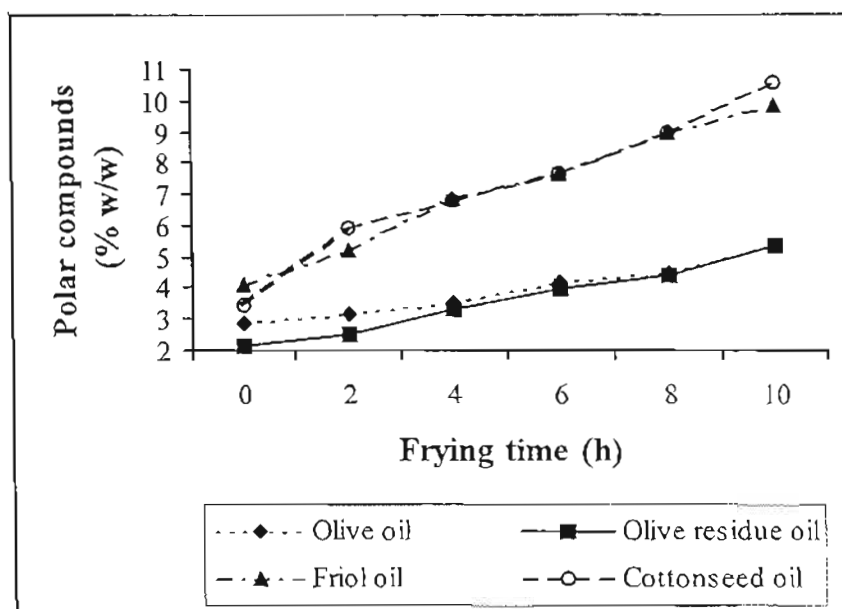


Fig. 4 - Changes in polar compounds during frying of oils.

frying (until 6 h of frying) followed by a decrease in PV with further frying. The picture was entirely different for the other three oils (olive oil, olive-residue oil, cottonseed oil) which did not exhibit the expected behaviour. Peroxides under the heating conditions used are unstable, and react to form secondary oxidation products. An increase in the initial stage of frying would be expected to be followed by a decrease with further frying, because the hydroperoxides tend to decompose at 180°C to form secondary oxidation products [26]. The overall increase in peroxide value is connected with the cooling period of the oil. The length of time required to cool the oils at room temperature (28°C) was more than 4 h. During the cooling period the oils were exposed to air at high temperature and hydroperoxides were formed again [27].

In view of these factors, peroxide value is not to be recommended for measuring heating oil deterioration. The method suggested by Tsaknis et al. [28] would be more suitable for measuring frying oil deterioration, because it determines malonaldehyde, which is a stable secondary oxidation product.

► *Iodine value* - Table III shows the changes of iodine value

in frying oils. The results showed that there were not significant changes between the fresh and used oils after 5 days of frying. The decrease of iodine value correlated well with the decrease of unsaturated fatty acids ($r = 0.992$), and more over this analysis confirmed that less oxidation of unsaturated fatty acids has taken place in olive oil.

► *Polar compounds* - Results are shown in figure 4. The results demonstrated that olive oil exhibited a significant increase in polar compounds after 4 days of frying, while all the other oils showed this change after 3 days of frying. Fritch [29], reported that the analysis of percentage polar compounds is considered to be one of the more reliable indicators of the state of the oil deterioration. This latter statement is supported by those of other researchers [30].

► *Fame analysis by gas-liquid chromatography* - Tables IV, V, VI, VII show the fatty acid composition of the fresh and the frying oils. It was observed that there was a decrease in polyunsaturated fatty acids and a resulting increase in the saturated acids content. However, the changes in polyunsaturated fatty acids were not statistically significant. Changes in fatty

TABLE III - Changes in iodine value during frying of oils

Frying Time (h)	IODINE VALUE (mg of I ₂ /kg of oil)			
	Olive oil	Olive residue oil	Friol oil	Cottonseed oil
0	85.65 (0.411)	88.29 (0.625)	120.17 (0.502)	107.25 (0.278)
2	85.39 (0.218)	88.14 (0.118)	119.90 (0.301)	106.83 (0.403)
4	85.26 (0.501)	87.85 (0.361)	119.66 (0.207)	106.49 (0.278)
6	85.07 (0.173)	87.50 (0.219)	119.24 (0.635)	105.91 (0.516)
8	84.91 (0.403)	87.03 (0.101)	118.72 (0.713)	105.57 (0.463)
10	84.59 (0.568)	86.47 (0.363)	118.14 (0.180)	104.99 (0.213)

Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

TABLE IV - Fatty acid composition of fried olive oil

Fatty acids	FRYING TIME (h)					
	0 (fresh)	2	4	6	8	10
C16:0	13.07 (0.015)	13.14 (0.012)	13.20 (0.028)	13.27 (0.036)	13.35 (0.022)	13.44 (0.017)
C16:1	0.66 (0.002)	0.68 (0.001)	0.64 (0.019)	0.59 (0.054)	0.60 (0.034)	0.61 (0.016)
C18:0	0.41 (0.023)	0.45 (0.029)	0.56 (0.075)	0.74 (0.013)	0.97 (0.062)	1.07 (0.013)
C18:1	76.12 (0.052)	76.89 (0.064)	76.84 (0.034)	76.79 (0.024)	76.75 (0.021)	76.73 (0.004)
C18:2	7.92 (0.044)	7.29 (0.038)	7.18 (0.067)	6.93 (0.018)	6.69 (0.049)	6.55 (0.033)
C18:3	0.74 (0.027)	0.58 (0.036)	0.54 (0.005)	0.50 (0.008)	0.48 (0.014)	0.43 (0.025)
C20:0	0.37 (0.013)	0.27 (0.009)	0.29 (0.016)	0.32 (0.026)	0.28 (0.011)	0.24 (0.046)
Unknown	0.71	0.70	0.62	0.86	0.88	0.93

Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

acid profile of all oils during frying are basically among the unsaturated fatty acids, whereas the saturated fatty acids (myristic, palmitic, and stearic) were slightly increased [22].

► **HPLC of tocopherols** - Table VIII shows the changes in tocopherols during frying. The relative decomposition rates after 5 days of frying were $\delta > \gamma > \alpha$. The results are in agreement with those of Sonntag [31], who reported that the decomposition rates of tocopherols, after 10 hours frying, were $\gamma > \alpha$. Lea [32] showed that the order of antioxidant activity changed with the oil used for the experiment. In contrast Miyagawa et al. [33], in their experiments, using

TABLE V - Fatty acid composition of fried olive residue oil

Fatty acids	FRYING TIME (h)					
	0 (fresh)	2	4	6	8	10
C16:0	11.72 (0.035)	11.82 (0.016)	11.99 (0.003)	12.22 (0.024)	12.54 (0.017)	12.70 (0.029)
C16:1	0.61 (0.012)	0.62 (0.008)	0.62 (0.001)	0.64 (0.016)	0.64 (0.021)	0.62 (0.003)
C18:0	2.64 (0.007)	2.69 (0.013)	2.97 (0.062)	3.14 (0.056)	3.31 (0.019)	3.42 (0.036)
C18:1	70.74 (0.028)	70.22 (0.015)	69.98 (0.042)	70.14 (0.038)	70.35 (0.024)	70.81 (0.047)
C18:2	12.59 (0.031)	12.50 (0.040)	12.21 (0.027)	11.92 (0.023)	11.63 (0.033)	11.05 (0.051)
C18:3	0.75 (0.006)	0.73 (0.002)	0.68 (0.010)	0.66 (0.003)	0.63 (0.011)	0.57 (0.008)
C20:0	0.30 (0.011)	0.35 (0.009)	0.41 (0.013)	0.38 (0.007)	0.37 (0.015)	0.32 (0.030)
Unknown	0.65	1.08	1.14	0.90	0.52	0.51

Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

TABLE VI - Fatty acid composition of fried Friol oil

Fatty acids	FRYING TIME (h)					
	0 (fresh)	2	4	6	8	10
C14:0	0.33 (0.035)	0.34 (0.042)	0.38 (0.015)	0.39 (0.048)	0.38 (0.013)	0.40 (0.011)
C16:0	12.19 (0.052)	12.47 (0.033)	12.80 (0.028)	13.06 (0.018)	13.32 (0.027)	13.50 (0.016)
C16:1	0.10 (0.002)	0.10 (0.010)	0.11 (0.007)	0.12 (0.016)	0.09 (0.002)	0.09 (0.004)
C18:0	3.88 (0.014)	3.97 (0.017)	4.03 (0.046)	4.09 (0.001)	4.29 (0.015)	4.29 (0.006)
C18:1	28.47 (0.026)	28.83 (0.068)	29.15 (0.052)	29.22 (0.055)	29.31 (0.027)	29.36 (0.012)
C18:2	52.87 (0.037)	52.21 (0.055)	51.42 (0.061)	50.89 (0.070)	50.52 (0.042)	50.20 (0.041)
C18:3	0.29 (0.013)	0.28 (0.044)	0.27 (0.009)	0.25 (0.017)	0.24 (0.014)	0.20 (0.006)
C20:0	0.17 (0.021)	0.16 (0.001)	0.17 (0.001)	0.17 (0.004)	0.16 (0.003)	0.18 (0.005)
C22:0	0.54 (0.003)	0.58 (0.016)	0.59 (0.002)	0.61 (0.019)	0.63 (0.010)	0.64 (0.011)
C22:1	0.18 (0.014)	0.18 (0.005)	0.17 (0.007)	0.16 (0.011)	0.16 (0.021)	0.15 (0.018)
Unknown	0.98	0.88	0.91	1.04	0.97	0.99

Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

TABLE VII - Fatty acid composition of fried cottonseed oil

Fatty acids	FRYING TIME (h)					
	0 (fresh)	2	4	6	8	10
C14:0	0.92 (0.008)	0.94 (0.015)	0.90 (0.017)	0.89 (0.013)	0.86 (0.028)	0.90 (0.020)
C16:0	23.58 (0.012)	23.67 (0.045)	23.71 (0.054)	23.74 (0.025)	23.80 (0.039)	23.95 (0.051)
C16:1	0.50 (0.034)	0.52 (0.018)	0.49 (0.027)	0.51 (0.021)	0.48 (0.022)	0.49 (0.042)
C18:0	2.01 (0.042)	2.11 (0.051)	2.18 (0.033)	2.25 (0.008)	2.29 (0.046)	2.38 (0.064)
C18:1	15.01 (0.029)	15.37 (0.036)	15.54 (0.021)	15.88 (0.056)	16.03 (0.067)	16.49 (0.058)
C18:2	56.86 (0.014)	56.10 (0.071)	55.74 (0.063)	55.28 (0.057)	54.91 (0.050)	54.08 (0.068)
C18:3	0.27 (0.003)	0.24 (0.019)	0.22 (0.021)	0.20 (0.012)	0.21 (0.011)	0.17 (0.016)
C20:0	0.05 (0.001)	0.05 (0.002)	0.06 (0.004)	0.06 (0.003)	0.07 (0.010)	0.08 (0.005)
C22:0	0.10 (0.017)	0.13 (0.012)	0.14 (0.007)	0.14 (0.003)	0.15 (0.002)	0.17 (0.006)
C22:1	0.06 (0.001)	0.06 (0.003)	0.05 (0.001)	0.05 (0.003)	0.05 (0.004)	0.05 (0.002)
C24:0	0.12 (0.011)	0.12 (0.009)	0.12 (0.006)	0.11 (0.001)	0.11 (0.008)	0.10 (0.003)
Unknown	0.54	0.69	0.85	0.89	1.02	1.14

Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

a mixture of soybean and rapeseed oils to fry potatoes, found that the decomposition rates of tocopherols were gamma > delta > alpha after 32 batches of frying. Also Carlson and Tabach [34], reported that the decomposition rates of tocopherols in fried soybean oil with french fries were gamma > delta > alpha.

► *Induction period* - Table IX illustrates the induction period of the oils during frying. The results showed that extra virgin olive oil had the longest induction period followed by olive residue, Friol and cottonseed oil. Induction period measurements were carried out on frying oils in order to provide a quick indication of the trends in resistance to oxidative rancidity of the heated oils. The induction period determined via accelerated oxidation methods on the original oil cannot guarantee or predict the actual frying performance of the oil as other factors will be introduced once frying commences (e.g. badly operated fryer or heat exchanger will ruin even the best quality oil). Nevertheless, it is considered that the 'Rancimat' induction period can be useful to act as a screening test and eliminate the possibility of introducing lower stability oils into the production area with all the attendant consequences [25].

► *Sensory evaluation* - A number of panellists were chosen to taste the doughnuts for the overall characterisation of the organoleptic properties (appearance, colour, flavour and texture) after each batch had been fried. A taste panel score sheet with a numerical scale of rating was developed, using descrip-

TABLE VIII - Changes of tocopherols during frying of oils

Oil	α -TOCOPHEROL (mg/kg)					
	Frying Time (h)					
	0	2	4	6	8	10
Olive oil	210 (0.040)	201 (0.031)	193 (0.024)	176 (0.091)	165 (0.020)	160 (0.013)
Olive residue oil	125 (0.018)	112 (0.009)	100 (0.027)	92 (0.030)	81 (0.073)	72 (0.011)
Friol oil	166 (0.054)	154 (0.060)	139 (0.017)	120 (0.034)	102 (0.008)	94 (0.016)
Cottonseed oil	28 (0.007)	25 (0.010)	24 (0.005)	19 (0.003)	15 (0.008)	13 (0.004)

Oil	γ -TOCOPHEROL (mg/kg)					
	Frying Time (h)					
	0	2	4	6	8	10
Friol oil	22 (0.004)	16 (0.007)	13 (0.002)	12 (0.004)	9 (0.001)	6 (0.003)
Cottonseed oil	42 (0.011)	39 (0.009)	32 (0.008)	24 (0.012)	18 (0.003)	13 (0.001)

Oil	δ -TOCOPHEROL (mg/kg)					
	Frying Time (h)					
	0	2	4	6	8	10
Olive residue oil	13 (0.004)	11 (0.007)	7 (0.002)	5 (0.003)	5 (0.001)	3 (0.005)
Friol oil	9 (0.002)	9 (0.004)	7 (0.002)	7 (0.006)	5 (0.007)	2 (0.001)

Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

TABLE IX - Changes of induction period during frying of oils

Frying time (h)	INDUCTION PERIOD (h)			
	Olive oil	Olive residue oil	Friol oil	Cottonseed oil
0	32.16 (0.756)	26.90 (0.106)	12.32 (0.204)	11.93 (0.237)
2	30.24 (0.209)	25.06 (0.313)	9.00 (0.358)	8.46 (0.312)
4	27.16 (0.183)	21.49 (0.434)	6.27 (0.307)	5.79 (0.072)
6	23.13 (0.523)	18.15 (0.227)	4.08 (0.216)	3.58 (0.109)
8	20.75 (0.124)	14.41 (0.164)	2.63 (0.247)	1.96 (0.155)
10	19.70 (0.257)	9.59 (0.117)	1.61 (0.047)	1.06 (0.062)

Values are means of triplicate determinations and the percentage coefficient of variations is given in parenthesis.

tive terms against each numerical score for each quality parameter. The scores showed that there was a significant in-

crease in the overall acceptance of fried doughnuts with olive oil and olive residue oil, at a level of 95% after 5 days (25 batches) of frying, while the fried doughnuts with Friol oil and cottonseed oil demonstrated a significant increase after 4 days (20 batch) of frying.

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