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Effect of rosemary and sage extracts on frying performance of refined, bleached and deodorized (RBD) palm olein during deep-fat frying

Yaakob B. Che Man *, Irwandi Jaswir

Department of Food Technology, Universiti Putra Malaysia, 43400 UPM Serdang Selangor DE, Malaysia

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Abstract

The effects of two natural antioxidants, rosemary and sage extracts, on physico-chemical changes of refined, bleached and deodorized (RBD) palm during deep-fat frying and on sensory acceptability of potato crisps were studied. Results showed that the two antioxidants significantly ($P < 0.05$) retarded the oil deterioration during 6-day frying. The two antioxidants were proven to lower the rate of oxidation of oils during frying. It was also shown that, during frying, the quality of oils gradually decreased. Sensory evaluation indicated that, except for crispiness scores, both rosemary and sage extracts could improve acceptability of fried potato crisps. However, no sample was unacceptable by panellists even up to day 6. In general, sage extract was as effective as rosemary extract in maintaining the quality of oils during frying.

1. Introduction

Deep-fat frying is extensively used both at home and on a commercial scale to enhance the organoleptic properties of foods. A number of chemical changes occur both in the frying medium and the product fried. These affect the quality of the oil and the fried food product (Varela, 1988). Repeated use of frying oils results in the development of undesirable chemicals that have been believed to pose a health hazard. Also, the repeated use of oils could cause fried foods to have a rather limited shelf life due to the development of rancidity in the frying oil taken-up by the products. In some countries, such as China and USA, oils and fats manufacturers normally treat the refined oils with antioxidants to retard the undesirable changes during storage and frying operations and, in eventuality, to prolong the shelf-life of the fried products. It is believed that the antioxidants protect the fat from oxidation during the time that the oil is exposed to high temperature (Augustin & Berry, 1983a). To avoid or delay the lipidic oxidation in food processing, antioxidants have been used for over 50 years (Cuvelier, Berset & Richard, 1994). They play an important role in the manufacturing, packaging and storage of fats and fatty foods and have been proven to retard oxidation (Lin, Warner & Fazio, 1981)

Currently, synthetic antioxidants are often used to improve the storage behaviour. The most commonly used antioxidants at the present time are butylated hydroxyianisole (BHA), butylated hydroxytoluene (BHT) and tertiary butylated hydroquinone (TBHQ).They are added to a wide variety of foods in the market (Chang, Ostric-Matijasevic, Hsieh & Cheng, 1977). However, their use is increasingly contested or even banned in certain countries. The recent consumer interest in ''natural'' products also requires natural antioxidative substances to replace the conventional antioxidants (Cuvelier et al., 1994). BHA and BHT are quite volatile and easily decomposed at high temperatures. Consequently, they are only effective for certain products. They are not effective for such common food products as french fries and potato chips. Furthermore, it has been stated that they are not effective in vegetable oils at preventing the development of initial off-flavour (Chang et al., 1977). The use of natural antioxidants for frying purposes has increased during the last few years (Bracco, Loliger, & Viret, 1981). Plant extracts, especially antioxidants obtained from herbs and spices, have been proposed for stabilizing frying oils.

* Corresponding author. Tel.: +603-9486101; fax: +60-3-9423552.
E-mail address: yaakub@fsb.upm.edu.my (Y.B. Che Man).

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Rosemary and sage extracts are two new antioxidants with very good thermal resistance that have recently been developed. The two natural antioxidants have been reported to have strong antioxidative characteristics (Houlihan & Ho, 1985; Saito, Kimura & Sakamoto, 1976; Watanabe & Ayano, 1974). Chipault, Mizuno and Lundberg (1956) reported a study of 32 common spices used as antioxidants in lard, and showed that only rosemary and sage are effective as antioxidants. The use of rosemary and sage extracts as antioxidants in foods has been also reported by Berner and Jacobson (1973); Chang et al. (1977) and Nakatani (1989).

However, there appears to be limited information on the effectiveness of rosemary and sage extracts in retarding the deterioration of oils during frying. Refined, bleached and deodorized (RBD) palm olein was used in this because of its major commercial role in deep-fat frying. Therefore, this study was carried out to determine effects on the quality of the oil of rosemary and sage extracts added during deep-fat frying of potato crisps, and sensory characteristics of the fried product.

4 kg oil put into fryer
⇓
0.4% antioxidants (depending on treatment) added
⇓
Oil heated up to 60°C
⇓
120 g sample (sample day 0) collected, flushed with nitrogen
⇓
Heating continued up to 180±5°C
⇓
* 100 g fresh sliced potato added into fryer
⇓
Frying for 2.5 min
⇓
Potato crisps drained and transfer into labelled container
⇓
Temperature of oil let rise to 180°C within 30 min.
⇓
Step * repeated (for the second frying) until 10 batches
⇓
Fryer switched off and temperature of oil let drop to 60°C
⇓
Oil filtered with cotton filter
⇓
120 g sample collected, flushed with nitrogen and kept in cold room for further analysis
⇓
Fryer covered and left overnight for next frying
⇓
Next day, the oil heated until 60°C
⇓
Step * repeated
⇓
Fryings repeated for 6 days

Fig. 1. Flow-chart for frying procedure.

2. Materials and methods

2.1. Materials

Refined, bleached and deodorized (RBD) palm olein was supplied by a local refinery. Oleoresin rosemary (Herbalox Brand, Type O) and sage (Herbalox seasoning, Type S-0) extracts, both in liquid form, were kindly donated by Kalsec Inc., USA (Gulf Chemical St. Bhd., Selangor, Malaysia). Fresh potatoes and salt (sodium chloride) were purchased from a local supermarket. All reagents were of analytical grade and obtained from local suppliers.

2.2. Frying experiment

Fresh potatoes to be fried were peeled and sliced around 1.5 mm thick manually. The sliced potatoes were then soaked in 2.5% salt (NaC1) solution for 5 min and dried before frying. Oleoresin rosemary extract (0.4%) and sage extract (0.4%) were added into RBD olein just before frying. The performance of frying using the antioxidant-treated oils was then compared to untreated oil (control) during the frying experiment.

The lay-out of the frying experiments is shown in Fig. 1. Fryings were conducted in batch fryers (Berto's, Model ELT 8B, Germany). Four kilogrammes of oil were heated up to 60°C and 120 g of oil was collected to present sample for day 0. The remaining oil was then heated up to 180 ± 5°C in 10 min. Frying was started half an hour after the temperature of the oil reached 180°C. One hundred grams of potato crisps were fried for 2.5 min. Afterwards, the oil temperature was allowed to rise up to 180°C again within 30 min. There were 10 fryings conducted every day for 6 consecutive days. This was equivalent to a total of 60 fryings. The fryers were left uncovered during the frying operations. At the end of each day, 200 g of oil at temperature 60°C were removed from the fryer, flushed with nitrogen gas, and kept in a cold room at 5°C until the day of analysis. The lid of the fryer was then put on and the fryer was left overnight for the following day's frying.

After frying, the potato crisps were removed from the fryer and toasted. The tenth batch of potato crisps each day was taken and labelled and packed in low-density polyethylene (LDPE) plastic bags for sensory evaluation. The evaluation was conducted on the same day that the frying was carried out.

2.3. Physico-chemical analysis of oil

Peroxide value (PV), free fatty acid (FFA), iodine value, polymer content and viscosity were determined using The American Oil Chemists' Society Official methods (AOCS, 1974). The absorbances at 232 and 268 nm and anisidine value were obtained using IUPAC (1979) methods. The C 18:2/C 16:0 ratio of the oil was determined by gas chromatography as reported by Berry (1980). The oil samples were analyzed on a Hewlett–Packard gas chromatograph Type 5890 A using a 15 m × 0.53 mm capillary column. The chromatograph was equipped with flame ionization detectors. The temperature of the column was 140°C and then increased at 4°C/min up to 200°C, while temperatures of injector and detector were 250°C. The flow rates were 65, 44 and

440 ml min^{-1} for carrier gas nitrogen, hydrogen and air, respectively.

2.4. Sensory evaluation

Sensory attributes of fried potato crisps including appearance, crispiness, taste, odour and overall acceptability were evaluated using a 7-point hedonic scale (1 dislike extremely, 4 = moderate, 7 = like extremely) by 18 semi-trained panellists selected from students and staff of the Faculty of Food Science and Biotechnology, Universiti Putra Malaysia (Larmond, 1977). All panelists regularly participated in sensory evaluation and are also regular consumers of potato crisps. The procedure for the sensory evaluation was explained to the panellists before testing commenced.

2.5. Statistical analysis

The statistical analysis system (SAS) program was used to analyze data for determining analysis of variance (ANOVA), standard deviation and Duncan's multiple range test (Steel & Torrie, 1980).

3. Results and discussion

3.1. Physico-chemical changes during deep-fat frying

The changes in quality characteristics of RBD palm olein during deep-fat frying are given in Table 1. Results showed that for almost all quality parameters examined, the addition of either rosemary or sage extracts to RBD palm olein during frying could retard the deterioration of the oil.

3.2. Peroxide, anisidine and iodine values

Peroxide value is a measure of the amount of peroxides formed in fats and oils through autoxidation and oxidation processes. Indirectly, it is a measure of the degree of initial oxidation of fats and oils. Table 1 shows that rosemary and sage could significantly ($P < 0.05$) reduce the oil oxidation process during frying. At day 1, peroxide values for rosemary- and sage-treated oils were 2.18 and 1.98 meq oxygen/kg, respectively, while that of control, was 6.55 meq oxygen /kg. At day 6, the values were 7.22, 6.95 and 11 .5 for rosemary, sage and control, respectively. The lower peroxide values of samples treated with either rosemary or sage was due to the antioxidative activity of both materials. Chang et al. (1977) reported that rosemary extract had been proven to be effective when applied to prime steam lard, chicken fat, sun-flower oil or corn oil where the addition of 0.02% rosemary extract to the fats or oils could reduce the peroxide values by 50%. It also

Table 1
Quality changes in RBD palm olein during frying[a]

Characteristic	Day	Frying system		
		Control[c]	Rosemary	Sage
Peroxide value[b] (meq oxygen/kg)	0	0.91 ± 0.06aD	0.71 ± 0.04aE	0.69 ± 0.04aE
	1	6.55 ± 0.29aC	2.18 ± 0.35bD	1.98 ± 0.19bD
	2	7.80 ± 0.33aB	2.27 ± 0.34bD	2.24 ± 0.25bCD
	3	8.06 ± 0.35aB	3.37 ± 0.41bC	2.88 ± 0.30bC
	4	8.47 ± 0.27aB	4.74 ± 0.26bB	4.26 ± 0.26bB
	5	11.7 ± 0.41aA	6.36 ± 0.31bA	6.27 ± 0.34bA
	6	11.5 ± 0.42aA	7.22 ± 0.27bA	6.95 ± 0.30bA
Anisidine value	0	0.96 ± 0.08aE	0.95 ± 0.05aF	0.96 ± 0.04aE
	1	31.5 ± 0.41aD	25.6 ± 0.38bE	26.2 ± 0.40bD
	2	36.0 ± 0.66aCD	30.6 ± 0.42bD	29.3 ± 0.39bD
	3	40.2 ± 0.61aC	35.3 ± 0.51bC	36.5 ± 0.43bC
	4	51.4 ± 0.70aB	42.1 ± 0.66bB	42.0 ± 0.55bB
	5	55.0 ± 0.76aB	47.6 ± 0.70bA	46.0 ± 0.60bB
	6	62.0 ± 0.63aA	50.2 ± 0.75bA	50.8 ± 0.71bA
Iodine value (g I_2/100 g oil)	0	56.1 ± 0.28aA	55.8 ± 0.22aA	55.6 ± 0.34aA
	1	52.0 ± 0.56bB	53.7 ± 0.42aB	54.3 ± 0.49aA
	2	48.8 ± 0.55bC	51.2 ± 0.69aC	50.3 ± 0.44aB
	3	45.3 ± 0.72bD	46.7 ± 0.75abD	47.7 ± 0.54aC
	4	43.4 ± 0.50cE	45.0 ± 0.49aE	44.0 ± 0.56bD
	5	41.9 ± 0.63bF	43.4 ± 0.61aF	43.8 ± 0.61aD
	6	41.0 ± 0.62bF	43.2 ± 0.55aF	42.4 ± 0.51aE
Free fatty acid content (%)	0	0.05 ± 0.01aE	0.05 ± 0.01aF	0.05 ± 0.01aF
	1	0.14 ± 0.01aD	0.12 ± 0.01bEF	0.12 ± 0.01bE
	2	0.19 ± 0.01aD	0.15 ± 0.01bDE	0.16 ± 0.01bDE
	3	0.27 ± 0.01aC	0.21 ± 0.01bCD	0.19 ± 0.01bD
	4	0.42 ± 0.02aB	0.26 ± 0.01bC	0.25 ± 0.01bC
	5	0.52 ± 0.02aA	0.37 ± 0.01bB	0.35 ± 0.01bB
	6	0.59 ± 0.02aA	0.42 ± 0.02bA	0.44 ± 0.02bA
Polymer content (%)	0	0.01 ± 0.00aG	0.01 ± 0.00aG	0.01 ± 0.00aG
	1	0.71 ± 0.05aF	0.44 ± 0.03bF	0.39 ± 0.01cF
	2	1.00 ± 0.05aE	0.73 ± 0.05bE	0.70 ± 0.06bE
	3	1.29 ± 0.10aD	1.09 ± 0.09bD	1.12 ± 0.12bD
	4	1.55 ± 0.12aC	1.30 ± 0.10bC	1.35 ± 0.14bC
	5	1.97 ± 0.21aB	1.52 ± 0.22bB	1.50 ± 0.20bB
	6	2.65 ± 0.20aA	1.82 ± 0.25bA	1.90 ± 0.19bA
Viscosity (centipoise)	0	50.2 ± 1.23aF	50.1 ± 1.42aE	50.1 ± 1.20aE
	1	53.2 ± 1.64aE	51.2 ± 1.40bDE	52.0 ± 1.35abD
	2	54.2 ± 1.23aE	52.7 ± 1.52bD	53.1 ± 1.20bCD
	3	57.3 ± 1.30aD	55.6 ± 0.99bC	54.4 ± 1.35bD
	4	62.1 ± 1.25aC	59.6 ± 1.15bB	58.9 ± 1.12bC
	5	66.4 ± 0.96aB	61.6 ± 1.10bB	61.0 ± 1.20bB
	6	71.1 ± 1.40aA	65.3 ± 1.35bA	64.2 ± 1.25bA
C18:2/C16:0 ratio	0	0.29 ± 0.01aA	0.29 ± 0.01aA	0.29 ± 0.01aA
	1	0.26 ± 0.01bB	0.28 ± 0.00aAB	0.28 ± 0.01aA
	2	0.26 ± 0.00bB	0.27 ± 0.01abB	0.28 ± 0.00aA
	3	0.24 ± 0.01bC	0.25 ± 0.00aC	0.24 ± 0.01bB
	4	0.21 ± 0.01aD	0.25 ± 0.00aC	0.24 ± 0.01aB
	5	0.20 ± 0.00aD	0.22 ± 0.01aD	0.23 ± 0.01aB
	6	0.17 ± 0.01bE	0.20 ± 0.01aE	0.21 ± 0.01aC

[a] Mean of three replicates.
[b] a–b,Means within a row with different letters are significantly different ($P < 0.05$).
[c] A–G, Means with a column with different letters are significantly different ($P < 0.05$).

appeared that the rosemary extract was as effective as a mixture of BHA, BHT, propyl galate and citric acid when used in animal fat and was superior to this commercial antioxidant mixture in vegetable oils. As for sage extract, the authors noted that this antioxidant was comparable to the rosemary extract.

Results from Table 1 also indicate that time of frying had a significant ($P < 0.05$) effect on peroxide values of all samples. The peroxide values increased with the increased time of frying until day 5 of frying. Augustin and Berry (1983b) reported that hydroperoxides, the products of primary oxidation, react to form secondary products of which aldehydic components are measured by the anisidine test. This test has an enhanced sensitivity for unsaturated aldehydes, especially 2,4-dienals, but does not measure the ketonic secondary products of oxidation (Augustin and Berry, 1983b). In this study, there was a marked increase in anisidine values on the first day. After one-day of frying, the anisidine value for control increased from 0.96 to 32.5, while for rosemary and sage treatments, increases were from 0.95 to 25.6 and from 0.96 to 26.2, respectively. It was also shown that during frying, for all treatments, the time of frying significantly influenced the anisidine value. At day 6, the anisidine value of control reached 62.0, while, for rosemary and sage treatments the values were, 50.2 and 50.8, respectively.

Iodine value is a measure of the total number of unsaturated double bonds present in an oil. The differences in iodine values of the oil during frying are also indicative of the increased rate of oxidation during frying. A significant ($P < 0.05$) change in iodine values can be observed when there is excessive deterioration of the oil (Augustin & Berry, l983b). Similarly to peroxide and anisidine values, in this study, rosemary and sage gave a significant effect on iodine value. However, at day 3, the iodine value of control (45.3 g I_2/100 g) was not significantly ($P < 0.05$) different from that of the sample with rosemary treatment (46.71 g I_2/100 g). Meanwhile, during frying, the iodine values of all treatments decreased significantly ($P < 0.05$) from day 0 to day 6. For control, the iodine value decreased from 56.1 g I_2/100 g at day 0 to 41.00 g I_2/100 g at day 6, while for samples with treatments of rosemary and sage, they decreased from 55.8 to 43.2 and from 55.6 to 42.4 g I_2/100 g, respectively. The percentage losses of unsaturation were 27, 24 and 24% for control, rosemary and sage-treated oils. The changes in iodine value showed that, during the frying period, oils had degraded significantly. This demonstrates that the two natural antioxidants used in this study are not reducing the overall oxidation of the oil.

3.3. Free fatty acid

The changes in percentage of free fatty acid (FFA) of the oils during frying are shown in Table 1. The FFA content of all treatments increased gradually from day 0 to day 6 of frying. The increase in the FFA content could be caused by the increase in rate of hydrolysis when water is introduced into the frying system by the potato crisps. Results also show that both rosemary and sage extracts significantly ($P < .05$) reduce the FFA contents of the oils during frying. This might be due to their higher antioxidative activity.

According to Kun (1990), the increase in the FFA content could also be caused by further oxidation of the secondary products formed during frying.

3.4. Polymer content

Results of polymer content analysis of the oils during frying revealed that both length of frying and the use of the natural antioxidants in this study had a significant ($P < 0.05$) effect on the content (Table 1). The polymer contents of all samples at day 0 were similar, 0.01%. At day 1, the polymer content of control increased to 0.71 while, for rosemary- and sage-treated samples, they were 0.44 and 0.39%, respectively. At the final day of frying, the polymer content of control reached 2.65%, while samples with treatments of rosemary and sage were only 1.82 and 1.90%. The lower values shown by the samples using the two antioxidants compared to the value of the control sample could be caused by the ability of the antioxidant to retard the deterioration of the oils during frying. Meanwhile, the increase in polymer content during frying occurred because the longer the frying time, the greater the amount of decomposition products which would lead to polymer formation. The presence of the free radicals from hydrolysis of hydroperoxides, for example, can react to form polymers and other complex products (Lumley, 1988).

3.5. C18:2/C 16:0 ratio

There was a significant ($P < 0.05$) difference in the C 18:2/ C 16:0 ratio between oils with added antioxidants and control as shown in Table 1. This result was not surprising since, during frying, the changes in the C 18:2/C 16 ratio occur due to the oxidation of double bonds of the oils (Varela, Roso & Varela, 1988). A marked decrease in C18:2/C16:0 ratio was found during the 6-day frying, which was consistent with the increase in the deterioration in oil quality under these conditions.

3.6. Viscosity

The viscosities of oils during frying are presented in Table 1. For control, the viscosity ranged from 50.2 cp at day 0 to 71.1 cp at day 6. For samples treated with rosemary and sage, the ranges were slightly shorter. At day 0, the viscosity of the sample with rosemary treatment was 50.1 cp and reached 65.3 cp at the end of the frying, while for the sample with sage treatment, the increase in the viscosity was from 50.1 cp (day 0) to 64.2 cp (day 6). The statistical analysis indicated that the addition of the antioxidants to oils significantly ($P<0.05$) lowers the viscosity; however, no significant difference between the two antioxidants was detected. In terms of frying time, there was a significant ($P<0.05$) correlation between the days of frying and the viscosity of the samples. According to Berger (1984), the faster the rate of oxidation of unsaturated fatty acids, the faster the increase in viscosity. He also reported that polymeric materials were mainly responsible for the increase in viscosity.

3.7. Absorbances at 232 and 268 nm

Like the peroxide value, the absorbance at 232 nm also measures the degree of primary oxidation. In general, the results obtained in this (Fig. 2) were closely related to the peroxide value, as described above. There was a trend of increasing diene content with progress in frying days. The absorbances of samples treated with rosemary and sage extracts were also significantly ($P<0.05$) different from the control sample. However, unlike the peroxide value for the control where the value tended to decrease after day 5, the absorbance for this sample still increased until day 6. The difference, according to Augustin and Berry (1983b) arises because smaller increases in diene content occurred at later stages of frying when equilibrium between the rate of formation of conjugated dienes and the rate of formation of polymers is attained.

There was a significant ($P<0.05$) effect of the use of the antioxidants and days of frying on the absorbance at 268 am (Fig. 3). The absorbance of the control oil sample was significantly ($P<0.05$) higher than samples with the treatments of rosemary or sage extracts. Meanwhile, the longer the frying time, the higher the absorbances of oils. These phenomena were commensurate with the anisidine values, although the theoretical background of absorbance at 268 mm and anisidine analyses are not totally similar. Although the two analyses are based on secondary oxidation of oil, the absorbance at 268 am measures, particularly, the diethylenic ketones, whereas ketones are not monitored in the anisidine test (Augustin and Berry, 1983b).

3.8. Sensory evaluation of potato crisps

Table 2 shows the sensory scores of potato crisps during the 6-day frying. In general, except for the crispiness

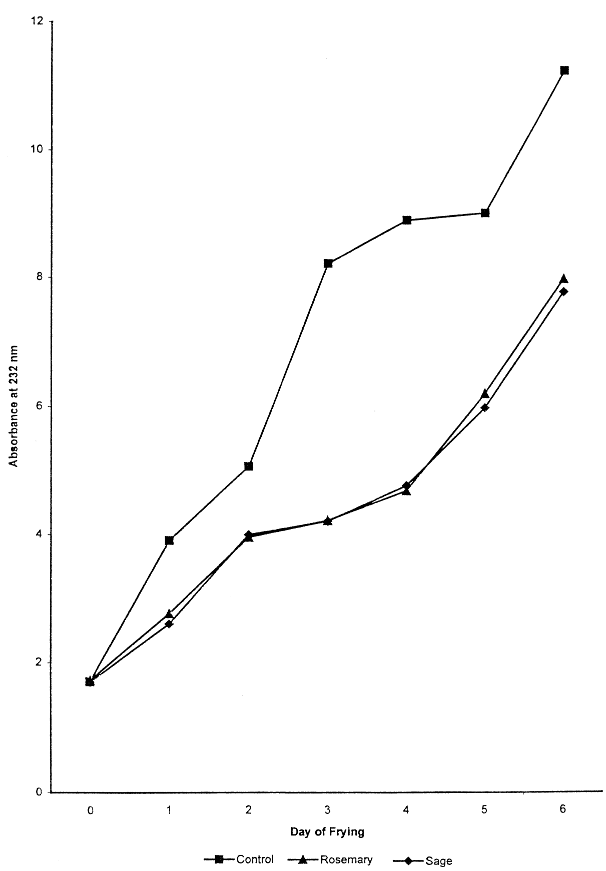

Fig. 2. Changes in absorbances at 232 nm of RBD palm olein during deep-fat frying.

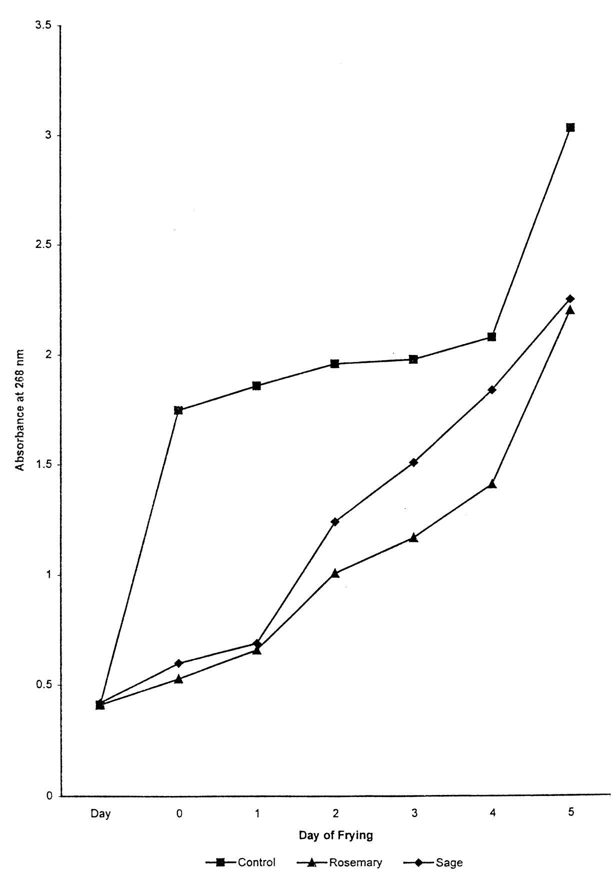

Fig. 3. Changes in absorbances at 268 nm of RBD palm olein during deep-fat frying.

attribute, the use of rosemary and sage in the frying operation significantly ($P<0.05$) improved the sensory scores of potato crisps. It is also shown that the sensory scores for all attributes examined, decreased significantly from day 1 until day 6; however, no sample was unacceptable by panellists, even after the frying at day 6. A score of more than 3.5 was considered acceptable on a 7-point hedonic scale test. The appearance scores of potato crisps fried using control oil ranged from 5.57 at day 1 to 4.00 at day 6, while for products fried using rosemary-treated oil, they ranged from 6.25 to 5.00. The appearance scores for the product fried using sage-treated oil fell from 6.29 at day 1 to 5.00 at day 6. The decrease in appearance scores was closely related to the deterioration of oils during frying which caused a darkening of frying oil.

Evaluation of taste scores conducted at day 1 of frying did not give any significant difference among all three types of sample. There was even no significant difference between taste score of control and that of sample fried in sage-treated oil until day 3. After day 3, the decrease in taste score for control was more rapid compared with other samples. As with taste, evaluation of odour acceptability also showed the same trend. At day 1, scores given by panellists to all three types of sample were not significantly different However, due to the deterioration of oil during frying, the scores decreased until day 6 with the control having a bigger decrease. The effect of some chemical reaction occurring during frying on flavour and odour quality of fried product, has been reported by Frankle, Warner and Moulton (1985).

Unlike other sensory parameters, there were no significant differences in crispiness scores between samples fried using antioxidant-added oils or control. At day 1, the scores of crispiness of the three types of sample ranged from 6.29 to 6.35, and at day 6 from 5.05

In terms of overall acceptability, both rosemary and sage extract, added to oils during frying, significantly ($P<0.05$) improved the quality of potato crisps. For rosemary treatment samples, the scores ranged from 6.30 at day 1 to 5.25 at day 6, while for sage treatment samples, the scores given ranged from 6.27 at day 1 to 5.30 at day 6. A sharper decrease was exhibited by the control sample where the score at day 1 was 6.10 and at day 6 only 4.60.

In this study, rosemary and sage extracts effectively could retard the palm olein deterioration during a 6-day frying of potato crisps. The two natural antioxidants were significantly ($P<0.05$) proven to lower the rate of oxidation of the oil during frying. In terms of peroxide value, anisidine value, free fatty acid and polymer content, results showed that samples prepared *using* oils treated, with either rosemary or sage, had lower values than the control. Organoleptically, except for crispiness scores, both rosemary and sage extracts could improve acceptability of fried potato crisps. However, no sample was unacceptable by panellists until the 6th day of frying.

Table 2
Effect of rosemary and sage on sensory acceptability[c] of potato crisps during deep-fat frying[d]

Sensory characteristic	Day	Frying system		
		Control[b]	Rosemary	Sage
Appearance[a]	1	5.57 ± 0.91bA	6.25 ± 0.96aA	6.29 ± 0.85aA
	2	5.50 ± 0.97bA	6.20 ± 0.88aA	6.10 ± 0.65aB
	3	5.28 ± 0.97cB	5.75 ± 0.85aB	5.57 ± 0.67bC
	4	4.50 ± 0.94bC	5.35 ± 0.75aC	5.29 ± 0.58aD
	5	4.20 ± 0.89bD	5.10 ± 0.91aD	5.10 ± 0.64aE
	6	4.00 ± 0.89bE	5.00 ± 0.56aD	5.00 ± 0.49aE
Crispiness	1	6.30 ± 1.01aA	6.35 ± 0.95aA	6.29 ± 1.03aA
	2	6.15 ± 0.88aB	6.18 ± 0.48aB	6.15 ± 0.96aB
	3	5.75 ± 0.94aC	5.80 ± 0.65aC	5.79 ± 0.87aC
	4	5.55 ± 0.93aD	5.60 ± 0.67aD	5.60 ± 0.59aD
	5	5.25 ± 0.78aE	5.25 ± 0.75aE	5.29 ± 0.93aE
	6	5.05 ± 0.45aF	5.05 ± 0.72aF	5.10 ± 0.61aF
Taste	1	6.20 ± 1.05aA	6.15 ± 0.95aA	6.15 ± 0.49aA
	2	6.00 ± 0.95bB	6.07 ± 0.96abA	6.10 ± 0.50aAB
	3	5.70 ± 0.86bC	5.87 ± 0.78abB	5.95 ± 0.98aB
	4	5.35 ± 0.87cD	5.50 ± 0.89bC	5.63 ± 0.64aC
	5	4.95 ± 1.10bE	5.30 ± 0.85aD	5.35 ± 0.63aD
	6	4.21 ± 0.86bF	5.05 ± 0.75aE	5.10 ± 0.70aE
Odour	1	6.12 ± 0.65aA	6.15 ± 0.95aA	6.15 ± 0.65aA
	2	5.90 ± 0.65bB	6.00 ± 0.90aB	6.02 ± 0.65aB
	3	5.85 ± 0.70bB	5.95 ± 1.02aBC	5.92 ± 0.48abB
	4	5.60 ± 0.96cC	5.90 ± 0.86aC	5.80 ± 0.50bC
	5	5.25 ± 0.88cD	5.50 ± 0.65bD	5.60 ± 0.75aD
	6	4.90 ± 0.80cE	5.10 ± 0.66bE	5.25 ± 0.57aE
Overall Acceptability	1	6.10 ± 1.05bA	6.30 ± 0.90aA	6.27 ± 0.80aA
	2	5.85 ± 0.65bB	6.25 ± 0.90aA	6.25 ± 0.80aA
	3	5.70 ± 0.65bC	5.90 ± 0.85aB	5.90 ± 0.56aB
	4	5.20 ± 0.75bD	5.80 ± 0.65aB	5.75 ± 0.65aC
	5	5.05 ± 0.85bE	5.50 ± 0.75aC	5.50 ± 0.66aD
	6	4.60 ± 0.90bF	5.25 ± 0.80aD	5.30 ± 0.75aE

[a] a–c, Means within a row with different letters are significantly different ($P<0.05$).
[b] A–G, Means with a column with different letters are significantly different ($P<0.05$).
[c] Using a 7-point hedonic scale (1 = dislike extremely, 4 = moderate, 7 = like extremely).
[d] Mean of 18 panellists.

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