Evaluation of antioxidant properties of Za'atar (*Thymbra spicata*) essential oils as natural antioxidant for stability of palm olein during deep-fat frying process

Medeni Maskan¹ · Erhan Horuz¹

Revised: 17 January 2017 / Accepted: 24 March 2017 / Published online: 6 April 2017
© Association of Food Scientists & Technologists (India) 2017

Abstract The yield of Za'atar (*Thymbra spicata*) essential oils were found to be 2.5–3.4% at extraction process temperatures of 100–175 °C. The essential oils contained 79.5–86.2% carvacrol. Effects of BHT and Za'atar essential oil on stability of palm olein during deep-fat frying of potato slices were studied at 180 °C. Changes in peroxide, para-anisidine, iodine values, free fatty acid and color were determined. Za'atar essential oil and BHT reduced free fatty acid content of olein from 0.27 to 0.21% (oleic acid) after 50 frying cycles. Antioxidant addition did not change the peroxide value of oil. Frying decreased Hunter *L* value and increased *a*, *b*, and total color difference values of used oils. The *P*-anisidine value changed from 15 to 33 for control oil during frying. BHT and Za'atar essential oil reduced this value to 28. The iodine values of olein reduced from an initial value of 54.5 to 45, 49 and 49 for control, BHT and Za'atar essential oil added frying oils, respectively. Za'atar essential oils could be used for preserving palm olein during deep-fat frying process.

Keywords Deep-fat frying · Palm olein · Za'atar · Antioxidant · Stability · Oxidation

Introduction

Deep-fat frying is one of the most commonly used procedures for the preparation and manufacture of foods throughout the world. A number of chemical reactions,

including oxidation, polymerization and hydrolysis occur during this time (Lalas and Dourtoglou 2003). All these chemical reactions give rise to the formation of numerous volatile and non-volatile compounds. Some of the products formed include free fatty acids, aldehydes, di- and mono-glycerides and polymeric triglycerides (Bansal et al. 2010). As deep-fat frying is normally carried out at high temperatures (160–180 °C) and also in the presence of air and moisture, these frying oils and fats will undergo physical and chemical deterioration which will affect their frying performance and the flavor, texture, shelf life as well as nutrients of fried foods (Razali et al. 1999; Nor et al. 2008).

Traditionally, low cost chemically synthesized compounds, such as butylated hydroxy-anisole (BHA), butylated hydroxytoluene (BHT) and tertiary butylhydroquinone (TBHQ) are often used as antioxidants in oil products to retard oxidation. However, some of these compounds have been questioned for their toxic and carcinogenic effects. They are allowed for use within legal limits in the food industry (Tan et al. 2015; Li et al. 2014). They are very effective during storage and transport of oils and fats, but are less effective at frying temperatures due to their volatility (Nor et al. 2008). During the last few years, research on natural antioxidants for frying purposes has increased worldwide (Kalucka et al. 2005; Iqbal and Bhanger 2007; Nor et al. 2008; Erkan et al. 2009; Zhang et al. 2010). Plant extracts, especially those obtained from edible herbs and spices, have been proposed for stabilizing frying oils and fried products (Inanc and Maskan 2013, 2014). Their use in food industry may serve to replace synthetic antioxidant food additives and may provide additional health benefits, compared to synthetic antioxidants. For instance, polyphenols present in foods/plants may act as antioxidants in the inhibition of lipid peroxidation process (Vanzani et al.

✉ Medeni Maskan
maskan@gantep.edu.tr

¹ Food Engineering Department, Engineering Faculty,
Gaziantep University, 27310 Gaziantep, Turkey

2011). It is an area worth investigating due to current consumer concerns about health.

There are many reports on that many plant extracts and essential oils from medicinal plants, herbs and spices have been shown to possess antimicrobial and antioxidant activity and could serve as a source for antimicrobial and antioxidant agents for food preservation, pharmaceuticals, alternative medicine and natural therapies. Thymol and carvacrol are responsible for antimicrobial and antioxidant activity of *Thymbra spicata* essential oils and could be effective in retarding the process of lipid peroxidation in fatty foods (Kizil et al. 2014; Uysal et al. 2015). It has been reported that thymol and carvacrol applied at different concentrations (0.02, 0.05, 0.10, and 0.20%) differed in the mechanism of their oxidant inhibitory action, which depended on the character of the lipid medium, being thymol a better antioxidant in triacylglycerols of sunflower oil than in triacylglycerols of lard (Garcia et al. 2016). Inanc and Maskan (2014) studied effect of carvacrol on the oxidative stability of palm oil during frying of potato slices. The results revealed that the use of carvacrol significantly improved the oxidative stability of palm oil when compared to the control samples.

Za'atar which contains a variety of aroma compounds, is a thyme-like plant widely grown in Turkey. Generally, carvacrol is the main component but thymol chemotypes also exists (Table 1). Palm oil is one of the most common frying media and is used extensively, both domestically and on a commercial scale. Therefore, the purpose of the current study is to test frying stability of palm olein by adding synthetic antioxidant (BHT) and essential oils (extracted from Za'atar leaves) to the oil used for deep-fat frying process. By this way, it is believed that the oil used for frying process could be reused for subsequent frying for many times, thus, resulting in economic savings in commercial operation of frying industries.

Materials and methods

Materials

Refined, bleached and deodorized palm olein was obtained from a vegetable oil and margarine producing company established in Gaziantep. It doesn't contain any antioxidant. The fatty acid composition of palm olein supplied by the company was; myristic acid 1.07%, palmitic acid 40.73%, palmitoleic acid 0.14%, margaric acid 0.091%, heptadecenoic acid 0.021%, stearic acid 4.1%, oleic acid 42.74%, linoleic acid 10.27%, linolenic acid 0.15%, arachidic acid 0.36%, gadoleic acid 0.24%, behenic acid 0.09%. Fresh potatoes (*Solanum tuberosum* L.) (c.v. Agria, Turkey) was purchased from a local supermarket. Za'atar

Table 1 Composition (% w/w) and yield of Za'atar essential oils extracted at different temperatures

	100 °C	125 °C	150 °C	175 °C
Essential oil content	2.0	2.5	3.4	3.2
α -Thujene	0.19	0.18	0.22	0.24
(-)- α -Pinene	0.37	0.43	0.44	0.42
Camphene	Nd	0.19	0.25	0.36
(+)- α -Pinene	0.50	0.69	0.62	0.62
Sabinen	Nd	Nd	Nd	0.84
α -Terpinene	Nd	Nd	Nd	0.22
<i>p</i> -Cymene	0.64	2.52	2.93	2.69
Limonene	Nd	Nd	Nd	0.18
<i>o</i> -Cymene	Nd	Nd	Nd	0.49
γ -Terpinen	1.90	0.38	0.58	0.37
E-3-carene-2-ol	3.08	6.72	7.71	7.16
Terpinen-4-ol	0.41	0.37	0.39	0.39
l-carvone	0.26	0.22	0.21	0.20
Thymol	3.67	1.92	1.24	0.97
Carvacrol	86.2	83.5	82.5	79.5
Caryophyllene	0.29	0.48	0.86	1.94
Spathulenol	Nd	Nd	Nd	0.28
Caryophyllene oxide	Nd	Nd	Nd	0.68
Unknown	2.52	2.41	2.10	2.46

Nd not detected

was collected from Nizip, Gaziantep (South-Eastern Turkey). The leaves were separated from the branches, air-dried and stored in polyethylene bags. All reagents used in this study were of analytical grade and obtained from Sigma–Aldrich Inc. (St.Louis, MO).

Methods

Extraction and compositional analysis of Za'atar essential oils

Extraction of Za'atar essential oils from dry Za'atar leaves, identification and compositional analysis of components found in essential oils were carried out by the method described by Özel et al. (2003). Briefly, essential oils from the leaves of *Thymbra spicata* were extracted using subcritical water extraction method. The components of essential oils of *Thymbra spicata* were removed from the aqueous extract by C18 solid phase extraction. The identification of components was carried out by using two-dimensional gas chromatography (GC)-Time of flight/Mass Spectrometry (TOF/MS). The separated essential oils were dried over anhydrous sodium sulphate and stored in dark glass bottles until used. The yields of essential oils at four different subcritical water extraction temperatures (100, 125, 150 and 175 °C) and composition of essential oils

were given in Table 1. Since the essential oil obtained at 100 °C contains more carvacrol and thymol, it was used in the frying experiment.

Frying experiments

The potatoes were peeled and washed under tap water. The washed potatoes were cut into slices by using a vegetable slicer. The sliced potatoes were soaked in a 2.5% NaCl solution for 5 min. This reduces oil absorption capacity and prevents darkening of the potato surfaces due to oxidation. Fresh, sliced potato was fried at 180 °C in an electrical deep fat fryer (Fantom 7400 Fritöz, Turkey) with a thermostat to regulate temperature. Total oil capacity of the fryer was 2 L. The frying was carried out with 1.5 L (initial) of refined palm olein 10 times a day to complete a total 50 fryings for 5 consecutive days. In each application, 100 g sliced potato samples were fried for 6 min. Each day after 10 fryings, 50 ml samples of oil was taken for analyses and stored in sealed bottles at 4 °C until analyzed. Fresh oil was not added between batches and the used oil was re-used for all frying operations (Horuz and Maskan 2015).

The synthetic antioxidant (BHT) or natural antioxidant Za'atar essential oils were added to two separate samples of the same brand of palm olein in order to test and compare their antioxidant ability. Another sample that contains neither BHT nor Za'atar essential oils was used as control oil. After each frying cycle (10 fryings), oil samples (BHT and Za'atar essential oils added and control) were filtered and analysed.

In the frying experiments, the amount of synthetic antioxidant (BHT) added into the oil before frying was 0.02% and of Za'atar essential oils was 0.04% of the total oil. The concentration of Za'atar essential oils was decided from previous study of Yagci (2005) which was carried out in the same laboratory with the same antioxidants and palm olein. The rationale for using 0.02% BHT is due to the legal limit for incorporation of synthetic antioxidants. A study conducted in our lab (% scavenging effect of Za'atar essential oils and BHT vs their concentrations) revealed that 0.04% Za'atar essential oils has equivalent antioxidant activity (% scavenging effect) as 0.02% BHT (Yagci 2005).

Oil analysis

Analyses were carried out on frying oil samples before and during frying cycles. Changes in oil quality were monitored on the samples treated under the same conditions using the peroxide value (PV), the *P*-anisidine value (p-AV), the iodine value (IV) and free fatty acids (FFA) according to the methods described in AOAC (1990). Total oxidation

value (TOTOX) was calculated as the sum of the *P*-anisidine value and twice the peroxide value. TOTOX number is a measure of the total oxidation in a sample and given by the equation: TOTOX value = p - AV + 2*(PV) (Wai et al. 2009). Color measurements of the oil samples were carried out using a HunterLab Colorflex (A-60-1010-615 Model Colorimeter, HunterLab, Reston, VA) as described by Maskan (2003). The total color difference (TCD) is a colorimetric parameter extensively used to characterize the variation of color in foods during processing. It is a combination of Hunter *L*, *a* and *b* values and can be calculated according to Eq. 1.

$$\text{TCD} = \sqrt{(L_o - L)^2 + (a_o - a)^2 + (b_o - b)^2} \quad (1)$$

where, L_o (61.25), a_o (−3.30) and b_o (10.24) refer to reference values, i.e., color values of fresh palm olein and L , a , and b , refer to color values at any time during frying.

Rheological measurements

The rheological measurements were carried out using a Haake Rheostress RS1 (Karlsruhe, Germany) controlled stress rheometer equipped with TCP/P peltier temperature controller unit and a Haake thermostat DC10 (Karlsruhe, Germany). A cone-plate sensor (diameter 3.5 cm and angle = 2°) was used with enough oil to fill the gap between cone sensor-plate base. The shear rate range was adjusted to 1–400 s^{−1}. The rheological behaviour of used oil samples was determined at 25 °C.

Statistical analysis

All experiments and analyses were conducted in duplicate, and the results presented are the average of the obtained values. The results were compared by two-way ANOVA to test for significant differences between parameters of control and antioxidants added-frying oils, and between the frying numbers at 5% significance level. Means of the groups were compared by Least Significant Difference (LSD) multiple range test using STATGRAPHICS statistical package program. Trends were considered significant when means of compared pairs differed at $P < 0.05$ level.

Results and discussion

The Za'atar essential oil contains 12 compounds among which the composition of carvacrol is the highest (79.5–86.2%) as shown in Table 1. This compound shows high antioxidant activity which is ascribed to hydrogen donation and its ability to scavenge peroxy radicals. The carvacrol and thymol contents were seen to be higher

(~90%) which is advantageous since they are known as antioxidants when used in foods (Inanc and Maskan 2014; Horuz and Maskan 2015). The yield of essential oil changed from 2.0 to 3.4% (w/w). Although essential oil extraction yield at 150 °C was higher (3.4% yield) than the other temperature (Table 1), the essential oil obtained at 100 °C (2.0% yield) was used in frying experiment. The reason for this is due to the high content of active component carvacrol (86.2%) that the essential oil contains.

Change in peroxide value

Peroxide value represents primary reaction products of lipid oxidation. It can be measured by their ability to liberate iodine from potassium iodide. However, peroxide value is not generally used to measure frying oil deterioration because peroxides are very unstable at frying temperature. They are useful as indicators of oxidation at the initial stages (Farhoosh and Moosavi 2009). In general, PV increased with frying number from 3 to 7 (Table 2). Such observations have been confirmed by Goburdhun et al. (2000) in the study of potato frying using canola oil.

PVs measured in oil samples containing Za'atar essential oils (natural antioxidant) and synthetic antioxidants were lower than that of the control oil sample at each frying cycle, but not significant ($P > 0.05$). This may be due to the instability of peroxides at frying temperatures that do not reflect the peroxide formation exactly. Statistical analysis showed that frying number exhibited significant effect on the PV of oil samples ($P < 0.05$).

Change in free fatty acids content

It is known that the frying of food introduces water into the oil and results in increased hydrolysis which is then reflected by high values of free fatty acids. The increase in FFAs could be attributed to hydrolysis of fats, especially the polyunsaturated fatty acids, diglycerides and monoglycerides. High FFA content is not accepted in any commercial product because of the strong off-flavor caused by the degradation products of the free fatty acids during deep-fat frying. The free fatty acid content of palm olein samples increased as the number of frying increased (Fig. 1). This result agrees well with the previous investigations carried out by various researchers (Maskan and Bağcı 2003; Houhoula et al. 2004; Nor et al. 2008).

The free fatty acid content of palm olein samples increased from 0.08 to 0.27% for control sample and from 0.08 to 0.21% (as oleic acid) when Za'atar essential oils or BHT were used during repeated frying. Statistical analysis revealed that the frying number and addition of antioxidant (either Za'atar essential oils or BHT) changed FFA content of oil samples significantly ($P < 0.05$). Moreover, multiple

Table 2 TOTOX, TCD values and Hunter color parameters (L , a , b) of palm olein during deep-fat frying process

Frying no	TOTOX value			Peroxide value			Hunter-L value			Hunter-a value			Hunter-b value			TCD value		
	CO ^x	BHTO ^y	ZEO ^y	CO ^x	BHTO ^y	ZEO ^y	CO ^x	BHTO ^y	ZEO ^y	CO ^x	BHTO ^y	ZEO ^y	CO ^x	BHTO ^y	ZEO ^y	CO ^x	BHTO ^y	ZEO ^y
0 (Fresh oil)	20.90	20.90	20.90	3.00	3.00	3.00	46.30	46.23	46.20	-2.15	-2.05	-2.12	18.97	19.03	19.00	0.00	0.00	0.00
10	25.55	26.30	22.96	3.50	4.20	3.70	44.72	45.47	45.77	-1.90	-2.00	-2.01	19.71	19.42	18.97	1.76	0.85	0.44
20	29.78	27.33	23.23	5.21	4.89	3.82	44.00	45.28	45.00	-1.17	-1.70	-1.56	20.47	19.96	19.68	2.91	1.37	1.48
30	33.83	30.60	29.22	6.51	5.70	5.60	43.36	45.13	44.68	-0.88	-1.24	-1.35	22.08	20.00	20.51	4.46	1.67	2.27
40	38.12	33.95	33.85	6.73	5.71	6.10	43.09	44.48	44.30	-0.02	-0.78	-0.69	23.00	20.50	20.78	5.57	2.61	2.97
50	47.38	41.07	41.63	7.00	6.20	6.80	42.69	44.18	44.00	0.30	-0.34	-0.25	23.72	20.74	21.00	6.44	3.17	3.51

The individual parameters in the first row (TOTOX, Peroxide value, Hunter-L, -a, -b, TCD) that are followed by different letters (x,y) are significantly different from each other [e.g., TOTOX values of control oil (CO^x) are different from oils containing BHT (BHTO) and Za'atar essential oils (ZEO)]

* Control oil contains no antioxidants

Fig. 1 Change in FFA (% oleic acid) versus number of frying for palm olein. Each point represents mean $\pm$ SE

range test showed that both antioxidants significantly ($P < 0.05$) lowered the FFA content of palm olein during frying process. On the other hand, the difference between the FFA content of BHT and Za'atar essential oils added palm olein samples were not significant ($P > 0.05$). It is apparent from these results that addition of BHT and Za'atar essential oils retarded the development of hydrolytic rancidity in palm olein. Similar results were obtained by Nor et al. (2008) who investigated antioxidant efficiency of various natural antioxidants during frying of foods.

Change in iodine value

Results given in Fig. 2 show that iodine value of all oils decreased during frying. The initial IV of palm olein was approximately 54.5. After 50 frying cycle the lowest iodine values were found to be 45, 49 and 49 for control, BHT and Za'atar essential oils added oil samples, respectively. For control oil, there is a significant decrease ($P < 0.05$) in IV

Fig. 2 Change in IV (g I_2 /100 g oil) versus number of frying for palm olein. Each point represents mean $\pm$ SE

with frying number implying a decrease in the degree of unsaturation of the oil. The decrease in IV during frying can be explained by the fact that as a result of the degradation of the fatty acid molecules during frying the number of double bonds decreases resulting in a decrease in the iodine value (Goburdhun et al. 2000; Matthauss et al. 2014).

The decrease in IV indicates polymerization of unsaturated fatty acids during frying process (Man and Jaswir 2000). Contribution of antioxidants to the oil (BHT and Za'atar essential oils) could protect the oils in terms of IV reduction significantly ($P < 0.05$) when compared to control oil. In addition, no difference was detected among the antioxidants effectiveness in reducing the IV statistically ($P > 0.05$). The difference in IVs of the oil during frying are also indicative of the increased rate of oxidation. Similar results were found by Man and Jaswir (2000) and Nor et al. (2008). In all studies, IVs of antioxidant-added oils were higher than that of control.

Change in para-anisidine value

Anisidine value (p-AV) is an assay for secondary oxidation products that occur after primary oxidation products (hydrogen peroxides) are degraded into alcohols, carboxylic acids, aldehydes and ketones (Merwe et al. 2003; Nor et al. 2008). The data on p-AV with number of frying and the effect of Za'atar essential oils and BHT antioxidants were presented in Fig. 3. As can be seen, p-AV increased from 15 to 33 for control palm olein during frying. Detailed statistical analyses by multiple range test revealed that p-AV of control oil is significantly higher than those of oils when BHT and Za'atar essential oils were added. Increase in p-AV is a good index of lipid deterioration of the control samples, as evidenced by significantly ($P < 0.05$) higher level of this parameter. These findings are in good agreement with those of Nor et al. (2008), Samotyja and

Fig. 3 Change in p-AV (mg aldehydes/kg oil) versus number of frying for palm olein. Each point represents mean $\pm$ SE

Malecka (2010), Enriquez-Fernandez et al. (2011) and Inanc and Maskan (2014). Also, Houhoula et al. (2004) reported that addition of ground oregano or its ethanol extract resulted in a depression of the p-AV. Analysis of variance showed that antioxidants and frying number significantly affected ($P < 0.05$) the p-AV formation of palm olein.

Change in TOTOX value with number of frying

PV represents peroxide and other similar oxidation products. p-AV primarily measures the secondary oxidation products, namely unsaturated aldehydes. PV in conjunction with p-AV can be used to map past and future degradation profiles. TOTOX is useful for quantifying oxygen-directed oil degradation. Change in TOTOX value of palm olein during frying was shown in Table 2. As was observed in the case of p-AV, addition of BHT and Za'atar essential oils significantly reduced ($P < 0.05$) the TOTOX value of palm olein, i.e., the TOTOX values of control oils were greater than those of the oils when both antioxidants were contributed for 50 fryings. The lower TOTOX value of antioxidant added palm oleins shows that the oils are more stable to oxidative rancidity than the control oil used as reported by Abdulkarim et al. (2007).

Change in color values of oils during deep-fat frying

The color of oils has been widely used as a subjective or objective index to determine the quality of used oil. It is an important parameter to be controlled during frying process. Table 2 shows the change in Hunter parameters L , a , b values of used palm olein with and without antioxidant treatments. Almost all the color parameters (L , a , b , TCD) of control oil were significantly different from the oils with BHT and Za'atar essential oils for 50 fryings. The control oil sample resulted in lower Hunter- L , higher Hunter- a and b values. Incorporation of BHT and Za'atar essential oils to frying oil increased lightness and decreased redness and yellowness of palm olein significantly ($P < 0.05$), i.e., the control oil darkened at a faster rate than the oil including antioxidant. Darkening of oils was probably due to the presence of oxidised fatty acids and carbonized food as reported by Bansal et al. (2010). The darkening may be as a result of oxidation and the formation of browning pigments from the potato chips. Hunter L -value of control oil is lower than those of BHT and Za'atar essential oils added palm olein. The Hunter- a and b values of control oil is higher than that of BHT and Za'atar essential oils added palm olein. The darkening of oil (decrease in L value) may be because of the scorching of food pieces during frying. The products of Maillard reaction from the interactions of ingredients and food nutrients such as sugar and amino

acids, and the oxidized lipids entering in the Maillard reaction also contribute to the darkening of oil color. As with the case of lightness parameter L , Hunter- a value was also affected by the repeated frying. It increased as frying number increased (Table 2). In general, increase in Hunter- a parameter is not desired, meaning a more red oil is not acceptable (Krokida et al. 2001). The yellow color, represented by the Hunter- b value, also increased dramatically during frying. Similar results were obtained by Maskan (2003). In general, frying number and antioxidants significantly affected all the Hunter parameters ($P < 0.05$). Multiple range test showed that the Hunter L , a and b values of control oil were significantly different ($P < 0.05$) from those of BHT and Za'atar essential oils containing frying oils. It means that antioxidant slowed the rate of color change during frying. On the other hand, no difference was determined among the antioxidant activity of BHT and Za'atar essential oils in changing the color parameters of palm olein ($P > 0.05$).

Change in TCD of used palm olein before and after antioxidant treatments was shown in Table 2. Total color changes of palm olein with and without antioxidants during frying showed significant differences ($P < 0.05$). TCD value increased significantly in the oil sample containing no antioxidants, almost three times greater than oils containing BHT and Za'atar essential oils added one. On the other hand, no difference was determined among the antioxidant activity of BHT and Za'atar essential oils in reducing changing the color parameters of palm oleins ($P > 0.05$).

Change in rheological behaviour of palm olein during deep-fat frying

Viscosity of oil is strongly affected by its degradation products, increasing as a result of formation of dimers, trimers, polymers and hydrocarbons. At temperatures commonly used in frying process, unsaturated fatty acids in triglycerides combine to form high molecular weight polar compounds known as dimers. The dimeric triglycerides and fatty acids again cross-link during further exposure to frying conditions and form polar trimers, tetramers, oligomers and polymers, all of which contribute to the increase in viscosity. Figure 4 shows flow behavior of Za'atar essential oils added palm olein samples as an example. Palm olein showed non-Newtonian behaviour exhibiting shear thinning characteristics at all frying cycles for control, BHT (data not shown) and Za'atar essential oils added frying oils. Increase in shear rate decreased the viscosity of palm olein samples.

Frying process did not change viscosity of the frying oil samples significantly ($P > 0.05$). It can be observed that

Fig. 4 Rheological behavior of palm olein (including Za'atar essential oils) during frying

rheological behavior was independent of the presence of antioxidants and number of frying. Similar observations have been reported by Inanc and Maskan (2014). They studied effect of carvacrol on oxidative stability of palm oil during frying by measuring several physical and chemical properties of oil. They found that neither frying numbers nor antioxidant treatment importantly changed viscosity of the oil samples. Also, incompatible with our results that Santos et al. (2005) observed an increase in viscosity of some vegetable oils with frying probably due to the formation of undesirable compounds caused by oxidation and polymerization reactions.

Conclusion

BHT and Za'atar essential oils were very effective against oxidative deterioration of palm olein during frying process. These can be used for preserving frying palm olein. Thus, Za'atar essential oils can be considered as an alternative to BHT in preserving physical and chemical quality of frying oil. Since food habits worldwide are mostly based on deep fried foods, oxidative-resistant oils are needed and demanded. This demand can be only conveniently met through the addition of natural antioxidants into the frying oils. Since natural antioxidants have not been investigated completely from toxicology point of view, studies related to this could be increased. Moreover, due to the strong flavor of natural antioxidants especially, herbs and spices, researchers should investigate their use in frying oils without contribution of undesirable sensorial characteristics to the foods.

Acknowledgements This research project was supported by the University of Gaziantep, Scientific Research Projects Governing Unit (Turkey) which led to this paper.

References

- Abdulkarim SM, Long K, Lai OM, Muhammad SKS, Ghazali HM (2007) Frying quality of high-oleic *Moringa oleifera* seed oil in comparison with other vegetable oils. *Food Chem* 105:1382–1389
- AOAC (1990) Association of Official Analytical Chemists. *Official methods of analysis*, 15th edn., Washington
- Bansal G, Zhou W, Barlow PJ, Lo HL, Neo FL (2010) Performance of palm olein in repeated deep frying and controlled heating processes. *Food Chem* 121:338–347
- Enriquez-Fernandez BE, Yanez LAC, Sosa-Morales ME (2011) Comparison of the stability of palm olein and a palm olein/canola oil blend during deep-fat frying of chicken nuggets and French fries. *Int J Food Sci Technol* 46:1231–1237
- Erkan N, Ayranci G, Ayranci E (2009) A kinetic study of oxidation development in sunflower oil under microwave heating: effect of natural antioxidants. *Food Res Int* 42:1171–1177
- Farhoosh R, Moosavi SMR (2009) Evaluating the performance of peroxide and conjugated diene values in monitoring quality of used frying oils. *J Agr Sci Technol* 11:173–179
- Garcia IR, Silva-Espinoza BA, Ortega-Ramirez LA, Leyva JM, Siddiqui MW, Cruz-Valenzuela MR, Gonzalez-Aguilar GA, Ayala-Zavala JF (2016) Oregano essential oil as an antimicrobial and antioxidant additive in food products. *Crit Rev Food Sci Nutr* 56:1717–1727
- Goburdhun D, Seebun P, Ruggoo A (2000) Effect of deep-fat frying of potato chips and chicken on the quality of soybean oil. *J Cons Stud Home Econ* 24:223–233
- Horuz TI, Maskan M (2015) Effect of the phytochemicals curcumin, cinnamaldehyde, thymol and carvacrol on the oxidative stability of corn and palm oils at frying temperatures. *J Food Sci Technol* 52(12):8041–8049
- Houhoula DP, Oreopoulou V, Tzia C (2004) Antioxidant efficiency of oregano during frying and storage of fried products. *Eur J Lipid Sci Technol* 106:746–751
- Inanc T, Maskan M (2013) Testing the antioxidant effect of essential oils and BHT on corn oil at frying temperatures: a response surface methodology. *J Am Oil Chem Soc* 90:1845–1850
- Inanc T, Maskan M (2014) Effect of carvacrol on oxidative stability of palm oil during frying. *Grasas Aceites* 65(4):e042
- Iqbal S, Bhangar MI (2007) Stabilization of sunflower oil by garlic extract during accelerated storage. *Food Chem* 100:246–254
- Kalucka M, Korezak J, Dratwia M, Szczapa E, Siger A, Buchowski M (2005) Changes in antioxidant activity and free radical scavenging potential of rosemary extract and tocopherols in isolated rapeseed oil triacylglycerols during accelerated tests. *Food Chem* 93:227–235
- Kizil S, Hasimi N, Tolan V (2014) Biological activities of *Origanum, Satureja, Thymbra* and *Thymus Species* grown in Turkey. *J Essent Oil Bear Pl* 17(3):460–468
- Krokida MK, Oreopoulou V, Maroulis ZB, Marinos-Kouris D (2001) Colour changes during deep fat frying. *J Food Eng* 48:219–225
- Lalas S, Dourtoglou V (2003) Use of rosemary extract in preventing oxidation during deep-fat frying on potato chips. *J Am Oil Chem Soc* 80(6):579–583
- Li L, Ham H, Sung J, Kim Y, Lee HSJJ (2014) Antioxidant activities of methanolic extracts from four different rose cultivars. *J Food Nutr Res* 2(2):69–73
- Man YBC, Jaswir I (2000) Effect of rosemary and sage extracts on frying performance of refined, bleached and deodorized (RBD) palm olein during deep-fat frying. *Food Chem* 69:301–307
- Maskan M (2003) Change in colour and rheological behaviour of sunflower seed oil during frying and after adsorbent treatment of used oil. *Eur Food Res Technol* 218:20–25

- Maskan M, Bağcı Hİ (2003) The recovery of used sunflower seed oil utilized in repeated deep-fat frying process. *Eur Food Res Technol* 218:26–31
- Matthaus B, Pudiel F, Chen Y, Achary A, Thiyam-Hollander U (2014) Impact of canolol enriched extract from heat-treated canola meal to enhance oil quality parameters in deep frying: a comparison with rosemary extract and TBHQ-fortified oil systems. *J Am Oil Chem Soc* 91:2065–2076
- Merwe GH, van der Plessis LM, Taylor JRN (2003) Changes in chemical quality indices during long-term storage of palm olein oil under heated storage and transport-type conditions. *J Sci Food Agric* 84:52–58
- Nor FM, Mohamed S, Idris NA, Ismail R (2008) Antioxidative properties of *Pandanus amaryllifolius* leaf extracts in accelerated oxidation and deep frying studies. *Food Chem* 110:319–327
- Özel MZ, Gogus F, Lewis AC (2003) Subcritical water extraction of essential oils from *Thymbra spicata*. *Food Chem* 82:381–386
- Razali I, Fauziah A, Nor Aini S (1999) Frying performance of palm olein and high oleic sunflower oil during batch frying of potato crisps. *Palm Oil Devel* 33:1–7
- Samotyja U, Malecka M (2010) Antioxidant activity of blackcurrant seeds extract and rosemary extracts in soybean oil. *Eur J Lipid Sci Technol* 112:1331–1336
- Santos JCO, Santos IMG, Souza AG (2005) Effect of heating and cooling on rheological parameters of edible vegetable oils. *J Food Eng* 67:401–405
- Tan LH, Zhang D, Yu B, Zhao SP, Cao WG (2015) Antioxidant activity of the different polar solvent extracts of *Magnolia officinalis* leaves and purification of main active compounds. *Eur Food Res Technol* 240:815–822
- Uysal B, Gencer A, Oksal BS (2015) Comparative antibacterial, chemical and morphological study of essential oils of *Thymbra spicata* var. *spicata* leaves by solvent-free microwave extraction and hydro-distillation. *Int J Food Prop* 18:2349–2359
- Vanzani P, Rossetto M, Marco VD, Rigo A, Scarpa M (2011) Efficiency and capacity of antioxidant rich foods in trapping peroxy radicals: a full evaluation of radical scavenging activity. *Food Res Int* 44:269–275
- Wai WT, Saad B, Lim BP (2009) Determination of TOTOX value in palm oleins using a FI-potentiometric analyzer. *Food Chem* 113:285–290
- Yağcı E (2005) Antioxidative effect of essential oils of *Thymbra spicata* on palm and corn oils. A Master's Thesis in Food Engineering, University of Gaziantep
- Zhang Y, Yang L, Zu Y, Chen X, Wang F, Liu F (2010) Oxidative stability of sunflower oil supplemented with carnosic acid compared with synthetic antioxidants during accelerated storage. *Food Chem* 118:656–662