ANTIOXIDANT ACTIVITY OF BENE HULL OIL COMPARED WITH SESAME AND RICE BRAN OILS DURING THE FRYING PROCESS OF SUNFLOWER OIL

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ABSTRACT

The antioxidant activity of Bene hull oil (BHO) was compared with that of sesame oil (SEO) and rice bran oil (RBO) during the frying process of sunflower oil (SFO) at 180°C. The ratio between the polyunsaturated and saturated fatty acids and calculated oxidizability were statistically greater for the SFO (4.26 and 6.48, respectively), followed by the SEO (3.18 and 6.27, respectively), RBO (1.53 and 4.37, respectively) and BHO (0.37 and 1.67, respectively). Peroxide and acid values of the oils studied ranged from 0.34 to 3.07 mEq/kg and from 0.19 to 5.20 mg/g, respectively. Total tocopherols and phenolics contents of the SEO (1093.28 and 1042.43 mg/kg, respectively) were significantly higher than those of the SFO (740.27 and 38.68 mg/kg, respectively), BHO (573.41 and 276.67 mg/kg, respectively), and RBO (832.98 and 67.98 mg/kg, respectively). In total, based on the conjugated diene value and carbonyl value measurements during the frying process, the BHO showed an antioxidant activity higher than those of the SEO and RBO at the level of 2%, and the levels higher than 2% of the antioxidative oils caused to decrease the oxidative stability of the SFO, indicating the pro-oxidant effect of the oils added at these levels.

PRACTICAL APPLICATIONS

This research introduces the oil obtained from the hull of Bene, a species of pistachio growing wild in Iran, as a new source of vegetable oil for human consumption.

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nutrition with antioxidant activity significantly higher than sesame and rice bran oils, which are considered as very stable and antioxidative vegetable oils because of the presence of very strong indigenous antioxidants, during the frying process.

**INTRODUCTION**

Edible fats and oils undergo extensive deterioration under the frying conditions of foodstuff. Lipid oxidation is one of the major factors resulting in loss of vegetable oil quality by formation of products having negative effects on taste, aroma and nutritional value of the food, and are a health hazard and cause of biological damage to living tissues and increase risk cardiovascular disease (Addis and Park 1989; Chow 1992). Antioxidants are major ingredients that protect the quality of oils and fats by retarding oxidation (Wanasundara et al. 1994). Low-cost synthetic antioxidants propyl gallate, butylated hydroxytoluene, butylated hydroxyanisole and tertiary butylhydroquinone are often used to retard lipid oxidation. They are very effective during storage and transport of oils and fats, but are less effective at frying temperatures because of their volatility and decomposition (Nawar 1996). Moreover, there are some serious problems concerning the safety and toxicity of such synthetic antioxidants related to their metabolism and possible absorption and accumulation in the body organs and tissues (Linderschmidt et al. 1986; Tappel 1995). A consumer-friendly way of improving oxidative stability of frying oils and fats is the addition of natural antioxidants. Therefore, search for finding useful natural antioxidative sources is highly desirable.

Rice bran oil (RBO) is considered useful for health and for cooking because of its unique high level of unsaponifiable matter (Gopala Krishna 2002). The unsaponifiable matter of RBO comprises of sterols, higher alcohols and \( \gamma \)-oryzanol at about 2% (w/w) (Nicolosi et al. 1994). Gama-oryzanol inhibits tumor promotion (Yasukawa et al. 1998), reduces serum cholesterol levels (Guardiola et al. 1996) and platelet aggregation (Seetharamaiah et al. 1990) as well as possessing antioxidant properties in several oil models (Juliano et al. 2005). Various characteristics of RBO make it a preferred oil for frying and baking applications compared with other vegetable oils.

Sesame (Sesamum indicum L.) is one of the world’s most important oilseed crops. The oil has a mild odor and a pleasant taste and, as such, is a natural salad oil requiring little or no winterization. Oxidative stability of sesame oil (SEO) is superior to that of other vegetable oils although it contains nearly 85% unsaturated fatty acids (Sonntag 1981; Abou-Gharbia et al. 1996). The remarkable stability of the SEO may be because of the presence of unique unsaponifiable constituents namely lignans (predominantly sesamin and sesa-
molin) and tocopherols. These compounds possess strong antioxidant activity and cardio-protective properties, and may have the potential of inhibiting the process of aging in man and in biological systems (Budowski and Markely 1951; Namiki 1995).

*Pistacia atlantica* subsp. *mutica* widely grows in the Zagrossian region of Iran at 600 to 3,000 m above the sea level (Sabeti 1994). Its fruits, which are called “Bene” in Iran, are round to oval, somewhat flat, 0.5–0.7 cm in diameter, and covered with a rather dry hull that could be easily removed by pressing between fingers. This soft hull is dark green in color, comprises ~24% of the whole fruit (~25% kernel and ~51% hard shell), and yields up to ~30% oil (Daneshrad and Aynehchi 1980). Previous studies on *P. atlantica* deal with the chemical composition and oxidative stability of the kernel oil from its current subspecies in Iran (Farhoosh et al. 2008b), and there is no information about the chemical composition and oxidative stability of the Bene hull oil (BHO) in the literature. Our initial findings indicated a higher oxidative stability for BHO than SEO and RBO. In this research, the antioxidant effect of the BHO, which can be considered to be a new source of edible oil with some interesting properties, on the sunflower oil (SFO) during frying process at 180°C was compared with those of the SEO and RBO.

**MATERIALS AND METHODS**

**Materials**

The ripe fruits of Bene were collected from the fields of Islamabad in the Ilam province. Refined, bleached and deodorized SFO with no added antioxidants was supplied by Segol (Nishaboor, Iran). The SEO and RBO were purchased from a local shop (about 3 months after production). The ripe fruits of Bene and oil samples were stored at −18°C until use. The BHO, SEO, and RBO were added to SFO at 2, 4 and 8%. Fatty acid methyl ester (FAME) standards, and all chemicals and solvents used in this study were of analytical reagent grade and were purchased from Sigma-Aldrich (St. Louis, MO) and Merck (Darmstadt, Germany).

**Oil Extraction**

After drying in the shade, the dark green soft hulls of Bene fruits were separated from the dark brown hard shells. The hulls were ground in a grinder. The powders were extracted with *n*-hexane (1:4 w/v) by agitation in a dark place at ambient temperature for 48 h. The solvent was evaporated *in vacuo* at 40°C to dryness.
Frying Process

Potatoes were peeled and cut into pieces (7.0 cm × 0.5 cm × 0.3 cm) and submerged in water until needed. Potato pieces were fried in the frying oils. The oil (2.5 L) was placed in a 2.5-L capacity bench-top deep-fryer (Tefal model 1,250, Paris, France) and heated to 180°C. Potato pieces were fried in 20-g batches at constant frying temperature. The batches were fried at 7-min intervals for 8 h per day for four consecutive days. At the end of each 4 h, about 10 g of the frying oil was filtered into a screw-cap vial and promptly stored in the dark at 4°C until analyzed. The volume of oil was not replenished during the frying process. Frying experiments were conducted in duplicate on each frying medium (Tyagi and Vasihtha 1996).

Fatty Acid Composition

The fatty acid composition of the oils was determined by gas–liquid chromatography and was reported in relative area percentages. Fatty acids were transesterified into their corresponding FAMEs by vigorous shaking of a solution of oil in hexane (0.3 g in 7 mL) with 2 mL of 7 M methanolic KOH at 50°C for 10 min. The FAMEs were identified using an HP-5890 chromatograph (Agilent, Palo Alto, CA) equipped with a CP-Sil 88 (Supelco, Bellefonte, PA) capillary column of fused silica, 60 m in length × 0.22 mm in internal diameter, 0.2-μm film thickness, and a flame ionization detector. Nitrogen was used as carrier gas with a flow rate of 0.75 mL/min. The oven temperature was maintained at 198°C, and that of the injector and the detector at 250°C (Farhoosh et al. 2008a).

Calculated Oxidizability (Cox) Value

The Cox value of the oils was calculated by the percentage of unsaturated C_{18} fatty acids, applying the formula proposed by Fatemi and Hammond (1980):

\[
\text{Cox} = \left(1[18:1%] + 10.3[18:2%] + 21.6[18:3%]\right)/100
\]

(1)

Peroxide Value (PV)

The spectrophotometric method of the International Dairy Federation as described by Shantha and Decker (1994) was used to determine the PV (thiocyanate method).

Acid Value (AV)

The AV was determined according to the AOCS (1993) Official Method Cd 3d-63.
Total Tocopherols (TT) Content

The TT content was determined according to the colorimetric method described by Wong et al. (1988).

Total Phenolics (TP) Content

The TP content was determined spectrophotometrically using Folin–Ciocalteau’s reagent according to the method described by Capannesi et al. (2000). A calibration curve of gallic acid in methanol was performed in the concentration range of 0.04–0.40 mg/mL.

Conjugated Diene Value (CDV)

The CDV was measured spectrophotometrically at 234 nm and read against a high-performance liquid chromatography grade hexane as blank. The oil samples were diluted to 1:600 with hexane. An extinction coefficient of 29,000 mol/L was utilized to quantify the concentration of conjugated dienes formed during oxidation (Saguy et al. 1996).

Carbonyl Value (CV)

The CV of the oils was measured according to the method developed by Endo et al. (2001) using 2-propanol and 2,4-decadienal as solvent and standard, respectively (Farhoosh and Moosavi 2006).

Statistical Analysis

All experiments and measurements were carried out in triplicate, and data were subjected to analysis of variance (ANOVA). ANOVA and regression analyses were performed according to the MStatC (Michigan State University, East Lansing, MI) and SlideWrite (Advanced Graphics Software, Carlsbad, CA) softwares. Significant differences between means were determined by Duncan’s multiple range tests. P-values less than 0.05 were considered statistically significant.

RESULTS AND DISCUSSION

The initial characteristics of the SFO along with those of the antioxidative oils studied (BHO, SEO, and RBO) are summarized in Table 1. The highest statistically significant percentage of the saturated fatty acids (SFA, mainly palmitic acid, 16:0) was found in the BHO (26.04%), RBO (23.06%), SEO (16.52%), and SFO (13.40%), respectively. The percentage of palmitoleic acid
In the BHO is considered to be unique among all common vegetable oils (12.39% versus <2%); its level in animal fats and marine oils is ranged from 2 to 9% and from 3 to 17%, respectively (deMan 1991). Because of the high levels of palmitic and oleic (18:0) acids, BHO showed the highest statistically significant percentage of monounsaturated fatty acids (64.28%), followed by the RBO (41.49%), SEO (30.20%) and SFO (28.62). The lowest statistically significant percentage of polyunsaturated fatty acids (PUFA) was observed in the BHO (9.67% versus 35.12, 52.57, and 57.04% in RBO, SEO and SFO, respectively). From the information stated earlier, the PUFA/SFA ratio and Cox value were statistically greater for the SFO, followed by the SEO, RBO and BHO. The PUFA/SFA ratio and Cox value are usually taken as measures of tendency of oils to undergo autoxidation (Fatemi and Hammond 1980; Mendez et al. 1996).

The PV and AV of the oils studied ranged from 0.34 to 3.07 mEq/kg, and from 0.19 to 5.20 mg/g, respectively. The higher amounts of these two parameters, especially for BHO, can likely be caused by improper storage and/or

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SFO</th>
<th>BHO</th>
<th>SEO</th>
<th>RBO</th>
</tr>
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<tbody>
<tr>
<td>Fatty acids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14:0</td>
<td>0.11 ± 0.16&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>–</td>
<td>0.09 ± 0.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.67 ± 0.23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>16:0</td>
<td>8.54 ± 0.21&lt;sup&gt;d&lt;/sup&gt;</td>
<td>22.4 ± 0.01&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>10.4 ± 0.10&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19.5 ± 0.83&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>16:1</td>
<td>0.21 ± 0.05&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.4 ± 0.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.22 ± 0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.39 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>18:0</td>
<td>4.76 ± 0.11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.65 ± 0.06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.77 ± 0.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.86 ± 0.04&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>18:1</td>
<td>28.0 ± 0.04&lt;sup&gt;d&lt;/sup&gt;</td>
<td>51.6 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.6 ± 0.25&lt;sup&gt;c&lt;/sup&gt;</td>
<td>40.2 ± 0.62&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>18:2</td>
<td>54.2 ± 0.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.27 ± 0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>47.6 ± 0.50&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32.0 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>18:3</td>
<td>2.84 ± 0.20&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.40 ± 0.04&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.99 ± 0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.12 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>20:0</td>
<td>–</td>
<td>–</td>
<td>0.30 ± 0.02</td>
<td>–</td>
</tr>
<tr>
<td>20:1</td>
<td>0.42 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.37 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.43 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.94 ± 0.02&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>22:0</td>
<td>0.94 ± 0.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>–</td>
<td>0.61 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.34 ± 0.48&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>SFA</td>
<td>13.4 ± 0.47&lt;sup&gt;d&lt;/sup&gt;</td>
<td>26.0 ± 0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.5 ± 0.34&lt;sup&gt;c&lt;/sup&gt;</td>
<td>23.1 ± 1.03&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>MUFA</td>
<td>28.6 ± 0.07&lt;sup&gt;d&lt;/sup&gt;</td>
<td>64.3 ± 0.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.2 ± 0.11&lt;sup&gt;c&lt;/sup&gt;</td>
<td>41.5 ± 0.53&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>PUFA</td>
<td>57.0 ± 0.40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.67 ± 0.10&lt;sup&gt;d&lt;/sup&gt;</td>
<td>52.6 ± 0.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>35.1 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>PUFA/SFA</td>
<td>4.26 ± 0.18&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.37 ± 0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.18 ± 0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.53 ± 0.07&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cox value</td>
<td>6.48 ± 0.06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.67 ± 0.02&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.27 ± 0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.37 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>PV</td>
<td>0.34 ± 0.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.87 ± 0.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.52 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.07 ± 0.03&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>AV</td>
<td>0.19 ± 0.01&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5.20 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.82 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.25 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>TT content</td>
<td>740 ± 14.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>573 ± 9.81&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1093 ± 38.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>833 ± 35.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>TP content</td>
<td>38.7 ± 6.83&lt;sup&gt;c&lt;/sup&gt;</td>
<td>277 ± 16.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1042 ± 24.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>68.0 ± 15.6&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Mean ± SD (standard deviation) within a row with the same lowercase letters are not significantly different at $P < 0.05$. AV, acid value (mg KOH per g oil); Cox, calculated oxidizability; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acid; PV, peroxide value (mEq O<sub>2</sub> per kg oil); SFA, saturated fatty acids; TP, total phenolics (mg gallic acid per kg oil); TT, total tocopherols (mg α-tocopherol per kg oil).

(16:1) in the BHO is considered to be unique among all common vegetable oils (12.39% versus <2%); its level in animal fats and marine oils is ranged from 2 to 9% and from 3 to 17%, respectively (deMan 1991). Because of the high levels of palmitic and oleic (18:0) acids, BHO showed the highest statistically significant percentage of monounsaturated fatty acids (64.28%), followed by the RBO (41.49%), SEO (30.20%) and SFO (28.62). The lowest statistically significant percentage of polyunsaturated fatty acids (PUFA) was observed in the BHO (9.67% versus 35.12, 52.57, and 57.04% in RBO, SEO and SFO, respectively). From the information stated earlier, the PUFA/SFA ratio and Cox value were statistically greater for the SFO, followed by the SEO, RBO and BHO. The PUFA/SFA ratio and Cox value are usually taken as measures of tendency of oils to undergo autoxidation (Fatemi and Hammond 1980; Mendez et al. 1996).

The PV and AV of the oils studied ranged from 0.34 to 3.07 mEq/kg, and from 0.19 to 5.20 mg/g, respectively. The higher amounts of these two parameters, especially for BHO, can likely be caused by improper storage and/or
handling conditions of the oils (Farhoosh and Pazhouhanmehr 2009). The TT and TP contents of the SEO (1,093.28 and 1,042.43 mg/kg, respectively) were significantly higher than those of the SFO (740.27 and 38.68 mg/kg, respectively), BHO (573.41 and 276.67 mg/kg, respectively) and RBO (832.98 and 67.98 mg/kg, respectively). Tocopherols and phenolic compounds are particularly important functional constituents of the unsaponifiable fraction of vegetable oils. Tocopherols have antioxidant properties and they are active as vitamin E, which makes them particularly important for human health. Interest in phenolic compounds is related primarily to their antioxidant activity; nevertheless, they also show important biological activity in vivo and may be beneficial in combating diseases related to excessive oxygen radical formation exceeding the antioxidant defense capacity of the human body (Aparicio et al. 1999; Morello et al. 2004).

Table 2 shows the CDV of the SFO as affected by BHO, SEO and RBO during the frying process at 180°C. It has been reported that the conjugated dienes increase initially and then reach a plateau during heat treatment. This has been related to the establishment of an equilibrium between the rate of formation of conjugated dienes and the rate of formation of polymers formed by a Diels–Alder reaction involving conjugated dienes (White 1995). In the present study, all the oil samples showed a similar trend of changes in the CDV with frying time. During the 32 h heating process, the CDVs linearly increased and no plateau was observed until the end of the process. The results calculated from the linear relationship between the CDV and frying time for the oils studied are shown in Table 3. The slope of the linear equations (a values), which were considered to be a measure of the rate of CDV increase during the frying process, was significantly different for the oils. SFO showed the lowest

### Table 2.
CONJUGATED DIENE VALUE (CDV) OF THE SUNFLOWER OIL (SFO) AS AFFECTED BY THE BENE HULL OIL (BHO), SESAME OIL (SEO) AND RICE BRAN OIL (RBO) DURING THE FRYING PROCESS AT 180°C

<table>
<thead>
<tr>
<th>Time (hour)</th>
<th>SFO</th>
<th>BHO (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>0</td>
<td>10.6 ± 0.53&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>9.74 ± 0.77&lt;sup&gt;AB&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>17.3 ± 0.43&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>14.4 ± 0.48&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>23.7 ± 0.12&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>18.4 ± 0.54&lt;sup&gt;DE&lt;/sup&gt;</td>
</tr>
<tr>
<td>12</td>
<td>32.6 ± 0.44&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>24.1 ± 0.71&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
<tr>
<td>16</td>
<td>34.8 ± 0.96&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>29.4 ± 1.57&lt;sup&gt;B&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>45.5 ± 0.03&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>32.6 ± 1.37&lt;sup&gt;E&lt;/sup&gt;</td>
</tr>
<tr>
<td>24</td>
<td>48.7 ± 0.91&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>38.5 ± 1.73&lt;sup&gt;D&lt;/sup&gt;</td>
</tr>
<tr>
<td>28</td>
<td>58.5 ± 0.98&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>42.2 ± 1.61&lt;sup&gt;BCDE&lt;/sup&gt;</td>
</tr>
<tr>
<td>32</td>
<td>61.6 ± 1.18&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>44.9 ± 1.24&lt;sup&gt;BCDE&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means ± SD (standard deviation) within a column with the same lowercase letters are not significantly different at P < 0.05.

Means ± SD within a row with the same uppercase letters are not significantly different at P < 0.05.
frying stability \((a = 1.63)\), and there was no statistically significant difference between its \(a\) value and those of the SFOs containing 8\% SEO \((a = 1.54)\) or RBO \((a = 1.53)\). This indicates that SEO and RBO had no antioxidative effect on the SFO at the level of 8\%. The lowest statistically significant \(a\) value belonged to the SFOs containing 2\% BHO (1.14) or SEO (1.17), indicating the

### Table 3.

THE RESULTS CALCULATED FROM THE LINEAR RELATIONSHIP BETWEEN THE CONJUGATED DIENE VALUE (CDV) AND THE FRYING TIME FOR THE SUNFLOWER OIL AS AFFECTED BY THE BENE HULL OIL (BHO), SESAME OIL (SEO) AND RICE BRAN OIL (RBO) DURING THE FRYING PROCESS AT 180\(^\circ\)C

<table>
<thead>
<tr>
<th>Oil</th>
<th>CDV = (a) (time) + (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a \pm SE)</td>
</tr>
<tr>
<td>SFO</td>
<td>1.63 (\pm 0.06^a)</td>
</tr>
<tr>
<td>BHO (%)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>SEO (%)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
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<tr>
<td>RBO (%)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

Means within a column with the same lowercase letters are not significantly different at \(P < 0.05\). SE, standard error.
highest antioxidant potential for these two antioxidative oils at this level. As shown in Table 3, the levels higher than 2% of the antioxidative oils decreased the oxidative stability of SFOs (increases in $a$ values), indicating a pro-oxidant effect of the oils added at these levels. With regard to TT and TP contents of BHO being approximately one-half and one-fourth of those of the SEO, respectively (Table 1), it can be concluded that the phenolic fraction of the BHO may contain component(s) with antioxidant activity similar to or even more effective than that of lignans (sesamin and sesamolin) of the SEO and/or $\gamma$-oryzanol of the RBO.

Table 4 shows the CV of the SFO as affected by the addition of BHO, SEO and RBO during the frying process at 180°C. In a previous research, the CV of a set of frying oils increased and reached a maximum value during the frying process, and then decreased as a result of further heat treatment. This was attributed to the decomposition of carbonyl compounds during the prolonged heating period and the formation of new compounds that were not detectable by the CV assay (Farhoosh and Moosavi 2008). Except for the SFOs containing 4% RBO and 8% of each of the three antioxidative oils, the other oil treatments showed an increasing trend of CV to the end of the frying process. If the CV of a used frying oil is $43.5 \mu$mol/g, the oil is still considered as being safe and acceptable, flavorwise (Farhoosh and Moosavi 2008). Assuming that the limit of acceptance for the CV is $43.5 \mu$mol/g, the time required to reach this limit was considered as a measure of frying stability ($t_{43.5}$). As can be seen in Fig. 1, 2–4% BHO showed the highest antioxidant activity among all levels of the antioxidative oils studied, and in all oil treatments, a pro-oxidant effect was observed with increase in the level of the antioxidative oils added to 8%.

**Table 4.** CARBONYL VALUE (CV) OF THE SUNFLOWER OIL (SFO) AS AFFECTED BY THE BENE HULL OIL (BHO), SESAME OIL (SEO) AND RICE BRAN OIL (RBO) DURING THE FRYING PROCESS AT 180°C

<table>
<thead>
<tr>
<th>Time (hour)</th>
<th>SFO</th>
<th>BHO (%)</th>
<th>2</th>
<th>4</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.89 ± 0.54$^{A}_{E}$</td>
<td>8.47 ± 0.32$^{A}$</td>
<td>8.67 ± 0.93$^{A}$</td>
<td>8.30 ± 0.98$^{A}$</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>22.2 ± 1.11$^{A}_{E}$</td>
<td>16.2 ± 1.85$^{A}_{E}$</td>
<td>12.9 ± 1.02$^{A}$</td>
<td>11.1 ± 1.06$^{A}_{E}$</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>24.6 ± 1.24$^{A}_{E}$</td>
<td>21.5 ± 1.59$^{A}_{E}$</td>
<td>14.8 ± 0.84$^{A}_{E}$</td>
<td>18.9 ± 1.09$^{A}_{E}$</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>35.8 ± 1.40$^{A}_{E}$</td>
<td>24.6 ± 1.66$^{A}_{E}$</td>
<td>17.8 ± 1.70$^{A}_{E}$</td>
<td>23.0 ± 1.71$^{A}_{E}$</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>39.4 ± 2.37$^{A}_{E}$</td>
<td>26.1 ± 1.25$^{A}_{E}$</td>
<td>21.7 ± 1.48$^{A}_{E}$</td>
<td>28.6 ± 1.87$^{A}_{E}$</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>47.6 ± 2.43$^{A}_{E}$</td>
<td>30.9 ± 1.16$^{A}_{E}$</td>
<td>23.4 ± 1.85$^{A}_{E}$</td>
<td>44.7 ± 2.16$^{A}_{E}$</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>58.1 ± 2.53$^{A}_{E}$</td>
<td>34.5 ± 0.71$^{A}_{E}$</td>
<td>27.1 ± 1.26$^{A}_{E}$</td>
<td>32.9 ± 0.53$^{A}_{E}$</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>70.8 ± 1.49$^{A}_{E}$</td>
<td>35.8 ± 0.90$^{A}_{E}$</td>
<td>27.9 ± 1.36$^{A}_{E}$</td>
<td>36.2 ± 1.16$^{A}_{E}$</td>
<td></td>
</tr>
</tbody>
</table>

Means ± SD (standard deviation) within a column with the same lowercase letters are not significantly different at $P < 0.05$.

Means ± SD within a row with the same uppercase letters are not significantly different at $P < 0.05$. 

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