Partial Replacement of Pork Back-Fat by Vegetable Oils in Burger Patties: Effect on Oxidative Stability and Texture and Color Changes during Cooking and Chilled Storage

J.G. Rodríguez-Carpena, D. Morcuende, and M. Estévez

Abstract: The present study was aimed to examine the impact of partial back-fat replacement (50%) by avocado (A), sunflower (S), and olive (O) oil on the chemical composition, oxidative stability, color, and texture of porcine burger patties (10% fat) subjected to oven cooking (170 °C/18 min) and chilling (+4 °C/15 d). The addition of vegetable oils caused a significant reduction of saturated fatty acids and a concomitant enrichment in unsaturated fatty acids. The incorporation of vegetable oils to porcine patties caused a significant reduction of TBARS formed as a result of cooking and the subsequent chilling. The usage of vegetable oils as back-fat replacers had no impact on the formation of protein carbonyls. Porcine patties with A- and O-patties displayed a more favorable ratio between volatiles contributing to rancidity and those contributing pleasant odor notes. Treated and control patties underwent similar discoloration during processing. The usage of vegetable oils and particularly, avocado and olive oils, as back-fat replacers, could be an interesting strategy to improve the nutritional and technological properties of porcine patties.

Keywords: color, fat-replacers, oxidative stability, pork burger patties, texture, vegetable oils

Practical Application: The present study highlights the potential nutritional and technological benefits of replacing animal fat by vegetable oils in porcine patties subjected to cooking and chilling. The industrial application of vegetable oils in processed meat products would meet the current consumers’ interest towards healthier food products. In addition, the usage of avocado oil would contribute to boost the avocado industry by providing an additional value to a by-product of fruit is known for its pleasing taste and high oil content with considerable high levels of oleic acid (Rodriguez-Carpena and others, in press), but its feasibility as a fat replacer in meat products has not yet been studied.

Introduction

The intense socio-economical changes occurred during the last 50 y in western countries have influenced the food-related lifestyle which have led, in turn, to a rapid growth in convenience, ready-to-eat meat products (Grunert 2006). To extend their shelf life, precooked meats such as burger patties are frequently chilled during distribution and display at supermarkets. Chemical and structural changes underwent by lipids and proteins during chilled storage of precooked meat products have an undesirable impact on their quality (Morrisssey and others 1998; Lund and others 2011). The source of fat employed for the formulation of meat products plays important role on the oxidative stability of the final product and in other relevant technological and sensory aspects (Gandemer 2002). The technological quality and appropriateness of pork back-fat gets into conflict with nutritional aspects as it provides high amounts of saturated fatty acids (SFA) and cholesterol (Jiménez 2000). In this sense, animal fat has been recognized as a major concern for consumers owing to the scientific evidences on the relationship between the intake of saturated lipids and the development of affluence diseases (Webb and O’Neill 2008).

The replacement of animal fat with vegetable oils in meat products has been found to be an efficient and successful strategy for decreasing SFA levels and, therefore, enhance the nutritional value of muscle foods (Ansorena and Astiasaran, 2004). A variety of marine and vegetable oils (olive [O], sunflower [S], linseed, and soybean) have been employed in meat products as partial replacers of animal fats (Yilmaz and others 2002; Muguerza and others 2003). Some researchers have experimented with vegetable oils in frankfurters (Jiménez-Colmenero and others 2010) and fermented sausages (Muguerza and others 2003) without adverse effects on processing yield. O oil is commonly used as animal fat replacer because of its beneficial biological attributes which usually ascribed to the high levels of monounsaturated fatty acids (MUFA) (Jiménez-Colmenero and others 2010; López-López and others 2010). Similar studies have been accomplished by using other vegetable oils such as S oil (Yilmaz and others 2002). The avocado fruit is known for its pleasing taste and high oil content with considerable high levels of oleic acid (Rodriguez-Carpena and others, in press), but its feasibility as a fat replacer in meat products has not yet been studied.
The usage of avocado (A) oil as animal fat replacer improves the nutritional profile of patties through the modification of the fatty acid profile (Rodriguez-Carpema and others, in press). However, the impact of such replacement on the oxidative stability and quality characteristics of burger patties is unknown. The aim of the present study was to study the effect of the partial replacement of pork back-fat by A, S, and O oils on the oxidative stability, color, and texture of porcine burger patties subjected to cooking and a subsequent chilled storage.

Materials and Methods

Chemicals

All chemicals and reagents used for the present study were purchased from Panreac (Panreac Química, S.A., Barcelona, Spain), Merck (Merk, Darmstadt, Germany), and Sigma Chemicals (Sigma–Aldrich, Steinheim, Germany).

Materials

Commercial O and S oils were purchased from a local supermarket in Caceres (Spain). The A oil was purchased from a market in Mexico D.F. Vegetable oils were stored under refrigeration (+4 °C) prior to analysis and the manufacture of patties. The meat (porcine longissimus dorsi muscle) and back-fat belonged to industrial genotypes slaughtered in local slaughterhouses in Caceres (Spain). The day after slaughter, the meat was freed from visible fat while the back-fat was cleaned and freed from the skin. Raw materials were immediately manually chopped with a knife into pieces (2 cm²), frozen (–18 °C, 24 h) and used as such for the manufacture of burger patties.

Manufacture of burger patties

Four types of porcine burger patties were prepared depending on the addition of different vegetable oils—A, S, and O—including a control (C) batch manufactured with pork back-fat and no added oil. In the basic formulation, the ingredients per kilogram of patties were as follows: 700 g meat, 180 g distilled water, 100 g back-fat, and 20 g sodium chloride. In the formulation of patties manufactured with vegetable oils, 50% of the pork back-fat was replaced with each of the oils (50 g oil per kilogram of burger patty). All ingredients were minced in a Stefan UMC 5 Electronic cutter at 10000 rpm for 5 min until a homogeneous emulsion-type raw batter was obtained. Total of 18 burger patties of each kind were prepared in 2 independent manufacturing processes (9 patties per oil treatment and processing treatment). CO patties were formed using a conventional patty-maker (model MH3, J2, Barcelona, Spain), Merck (Merk, Darmstadt, Germany), and Sigma Chemicals (Sigma–Aldrich, Steinheim, Germany).

Proximate composition of burger patties. Moisture and total protein contents were determined using official methods (AOAC 2000). The method of Folch and others (1957) was used for determining fat content in burger patties.

Analysis of polyunsaturated fatty acids (PUFA) Fatty acid methyl esters (FAMEs) were prepared by acidic esterification in the presence of sulfuric acid following the method described by Estévez and others (2003). FAMEs were analyzed by gas chromatography using a Hewlett-Packard HP-5890A gas chromatograph, equipped with an on-column injector and a flame ionization detector, using a polyethylene glycol capillary column (Supelcowax-10, Supelco, Bellefonte, Pa., U.S.A.) (60 m × 0.32 mm i.d. × 0.25 μm film thickness). GC conditions are detailed elsewhere (Estévez and others 2003). Individual FAMEs peaks were identified by comparison of their retention times with those of standards (Sigma, St. Louis, Mo., U.S.A.). Tridecanoic acid was used as internal standard. Results were expressed as grams per 100 g of detected FAMEs.

Determination of total protein carbonyls. Protein oxidation, as measured by the total carbonyl content, was evaluated by derivatisation with dinitrophenylhydrazine (DNPH) according to the procedure described by Ganhaio and others (2010) with slight modifications. Patties (1 g) were minced and then homogenized 1:10 (w/v) in 20 mM sodium phosphate buffer containing 0.6 M NaCl (pH 6.5) using an ultraturrax homogenizer for 30 s. Total of 2 equal aliquots of 0.2 mL were taken from the homogenates and dispensed in 2 mL eppendorf tubes. Proteins were precipitated by cold 10% trichloroacetic acid (TCA) (1 mL) and then centrifugation for 5 min at 5000 rpm. One pellet was treated with 1 mL 2 M HCl (protein concentration measurement) and the other with an equal volume of 0.2% (w/v) DNPH in 2 M HCl (carbonyl concentration measurement). Both samples were incubated for 1 h at room temperature. Afterwards, samples were precipitated by 10% TCA (1 mL) and washed twice with 1 mL ethanol : ethyl acetate (1:1, v/v) to remove excess of DNPH. The pellets were then dissolved in 1.5 mL of 20 mM sodium phosphate buffer containing 6 M guanidine HCl (pH 6.5), stirred and centrifuged for 2 min at 5000 rpm to remove insoluble fragments. Protein concentration was calculated from absorption at 280 nm using bovine serum albumin as standard. The amount of carbonyls was expressed as nanomol of carbonyl per milligram of protein using an absorption coefficient of 21 nM−1 cm−1 at 370 nm for protein hydrazones.

Determination of TBA-RS numbers. Thiobarbituric acid-reactive substances (TBA-RS) were assessed using the method described by Ganhaio and others (2011) with some modifications.
Animal fat compared with vegetable oils in pork patties...

Briefly, 5 g of burger patty were dispensed in cone plastic tubes and homogenized with 15 mL perchloric acid (3.86%) and 0.5 mL BHT (4.2% in ethanol). During homogenization, the plastic tubes were immersed in an ice bath to minimize oxidative reactions during extraction of TBARS. The slurry was filtered and centrifuged (3000 rpm for 4 min) and 2 mL aliquots were mixed with 2 mL TBA (0.02 M) in test tubes. The tubes were placed in a boiling water bath (100 °C) for 45 min together with the tubes from the standard curve. After cooling, the absorbance was measured at 532 nm. The standard curve was prepared using 1,1,3,3-tetraethoxyx propane (TEP) solutions in 3.86% perchloric acid.

Analysis of volatile compounds. Volatile compounds were analyzed from the headspace of R, CO, and CC burger patties by using the solid-phase micro extraction (SPME) and gas chromatography/mass spectrometry (GC/MS) following the method described by Estévez and others (2003) with minor modifications as follows: the SPME fiber, coated with divinylbenzene-carboxenpoly (dimethylicosane) (DVB/CAR/PDMS) 50/30 μm, was preconditioned prior to analysis at 220 °C during 45 min. One gram of minced sample was placed in a 4 mL SPME vial and sealed with a silicone septum. The sample was allowed to equilibrate during 30 min while immersed in water at 37 °C. During the extraction, the SPME fiber was inserted through the septum and exposed to the headspace of the vial. After extraction, the SPME fiber was immediately transferred to the injector of the chromatograph (HP5890GC series II gas chromatograph), which was in splitless mode at 220 °C. Volatiles were separated using a 5% phenyl-95% dimethyl polysiloxane column (Restek, Pa., U.S.A.) (30 m x 0.25 mm id., 1.05 μm film thickness). The GC/MS conditions were those previously reported by Estévez and others (2003). Volatiles compounds were whether tentatively identified by comparing their mass spectra with those from the Wiley library or positively identified by comparing the mass spectra and retention time with those displayed by the standard compounds. Results from the volatiles analysis were provided in arbitrary area units (AAU).

Texture measurements
Texture profile analysis (TPA) of R, CO, and CC burger patties was performed at room temperature with a Texture Analyzer TA-XT2i (Stable Micro Systems, Surrey, U.K.). Total of 3 cylinder samples (2.5 cm diameter) were taken from the middle of each patty and subjected to a 2-cycle compression test. The samples were compressed to 40% of their original height with a cylindrical probe of 5 cm diameter and a cross-head speed of 5 mm/s. Texture profile parameters were determined following descriptions by Bourne (1978).

Color measurements
Surface color measurements of R, CO, and CC burger patties were performed using a Minolta Chromameter CR-300 (Minolta Camera Corp., Meter Division, Ramsey, N.J., U.S.A.), which consisted of a measuring head (CR-300), with an 8 mm diameter measuring area and a data processor (DP-301). Before each measuring session the chromameter was calibrated on the CIE color space (CIE 1978) system using a white tile. Color measurements were made on the surface of each patty in triplicate at 3 randomly selected locations. Color measurements were made at room temperature (approximately 22 °C) with illuminant D65 and a 0° angle observer.

Statistical analysis
Total of 6 burger patties per oil and processing treatment were prepared in 2 independent manufacturing processes and used as experimental units (n = 6). A one-way analysis of variance (ANOVA) and Tukey tests were carried out to study the effect of the vegetable oil replacement in burger patties on their chemical composition, texture and color traits.

Table 1 – Chemical composition of raw patties produced using A, O, and S oils as replacement of pork back-fat and cooking and storage losses.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>A</th>
<th>O</th>
<th>SEMb</th>
<th>Pb-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisturea</td>
<td>71.67 ± 0.82</td>
<td>71.43 ± 0.57</td>
<td>71.72 ± 1.24</td>
<td>71.21 ± 1.17</td>
<td>0.24</td>
</tr>
<tr>
<td>Fatb</td>
<td>10.00 ± 0.94</td>
<td>9.98 ± 0.67</td>
<td>9.62 ± 1.46</td>
<td>9.51 ± 1.45</td>
<td>1.12</td>
</tr>
<tr>
<td>Proteinb</td>
<td>17.75 ± 1.20</td>
<td>17.01 ± 0.18</td>
<td>17.42 ± 0.42</td>
<td>17.09 ± 0.20</td>
<td>0.53</td>
</tr>
<tr>
<td>ΔF/SFAC,b,c</td>
<td>36.56 ± 2.26</td>
<td>24.99 ± 1.04</td>
<td>23.65 ± 1.16</td>
<td>24.60 ± 0.72</td>
<td>0.999</td>
</tr>
<tr>
<td>ΔMUFAB,d</td>
<td>47.44 ± 1.37</td>
<td>56.32 ± 0.84</td>
<td>36.94 ± 0.26</td>
<td>63.01 ± 1.66</td>
<td>1.991</td>
</tr>
<tr>
<td>ΔPUFAE</td>
<td>16.01 ± 1.33</td>
<td>18.69 ± 0.50</td>
<td>39.43 ± 1.34</td>
<td>12.34 ± 1.21</td>
<td>2.151</td>
</tr>
<tr>
<td>Cooking lossb</td>
<td>21.49 ± 1.38</td>
<td>22.20 ± 1.40</td>
<td>20.69 ± 1.69</td>
<td>21.85 ± 1.70</td>
<td>1.69</td>
</tr>
<tr>
<td>Storage lossb</td>
<td>1.00 ± 0.97</td>
<td>1.95 ± 0.75</td>
<td>2.00 ± 1.40</td>
<td>1.98 ± 1.70</td>
<td>1.40</td>
</tr>
</tbody>
</table>

Results are expressed as means ± SD. Values with a different letter (a,b,c) within a row are significantly different (P < 0.05)

Table 2 – PUFA in raw, cooked, and cooked and chilled burger patties produced using A, O, and S oils as replacers of pork back-fat.

<table>
<thead>
<tr>
<th></th>
<th>R4</th>
<th>COa</th>
<th>CCc</th>
<th>SEMb</th>
<th>%↓ R-COa</th>
<th>%↓ CO-CCb</th>
<th>%↓ R-CCc</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>16.01 ± 0.53</td>
<td>16.02 ± 0.59</td>
<td>15.11 ± 0.33</td>
<td>0.213</td>
<td>−0.10</td>
<td>5.71</td>
<td>5.62</td>
</tr>
<tr>
<td>A</td>
<td>18.60 ± 0.50</td>
<td>18.78 ± 0.46</td>
<td>17.85 ± 0.19</td>
<td>0.136</td>
<td>−0.45</td>
<td>4.94</td>
<td>4.51</td>
</tr>
<tr>
<td>S</td>
<td>39.47 ± 1.15</td>
<td>38.30 ± 2.22</td>
<td>38.08 ± 1.56</td>
<td>0.378</td>
<td>2.96</td>
<td>0.58</td>
<td>3.52</td>
</tr>
<tr>
<td>O</td>
<td>12.34 ± 1.21</td>
<td>12.53 ± 1.05</td>
<td>11.85 ± 0.40</td>
<td>0.218</td>
<td>−1.58</td>
<td>5.48</td>
<td>3.98</td>
</tr>
</tbody>
</table>

Results are expressed as means ± standard deviation. Values with a different letter (a,b,c) within a row are significantly different between means from different treatments (P < 0.05)

%↓ R-CO: %↓ CO-CC: and %↓ R-CC: denote statistical differences between means from raw oil (P < 0.05).

Source: aRaw, bCooked, cCooked and chilled. dStandard error of the mean.

Relative loss of PUFA as a result of cooking (%↓ R-CO), the subsequent storage (%↓ CO-CC) and the combined effect of both processing treatments.
Results and Discussion

Table 1 shows the chemical composition and fatty and profile of different raw burger patties manufactured using A, O, and S oils as well as the cooking and storage losses. However, replacing 50% of back-fat with vegetable oils in pork burger patties significantly modified the fatty acid profiles of different meat products when replacing animal fat by vegetable oil. The amounts of different fatty acids were measured and statistically compared to determine the effects of all the treatments (C, A, S, O) as well as the cooking and storage losses.

Table 3 - Protein hydrazones, TBARS, and lipid-derived volatiles in raw, cooked, and cooked and chilled burger patties manufactured using A, O, and S oils as replacers of pork back-fat.

<table>
<thead>
<tr>
<th>Protein Hydrazones</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.8&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.7&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>R&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.24&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.56&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.55&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.13&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.39&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-pentanone</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.29&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.35&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.65&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>3-hydroxy-2-butanonly</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.24&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>1-pentanol</td>
<td>0.52&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.26&lt;sup&gt;d&lt;/sup&gt;</td>
<td>9.71&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.21&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.23&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>1-hexanol</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>17.90&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.14&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.46&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-heptanol</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.11&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.19&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.38&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.53&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>heptanol</td>
<td>0.88&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>199.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.08&lt;sup&gt;d&lt;/sup&gt;</td>
<td>103.80&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>heptanal (E)</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.76&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.36&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-3-hexenal (E)</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.15&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.57&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-3-ctenane</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.66&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.35&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-pentyl furan</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.05&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.93&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.20&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>acetaldehyde</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.80&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.79&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.07&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>formaldehyde</td>
<td>0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.50&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.28&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.00&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.36&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values with a different letter (a, b, c) within a row are significantly different (P < 0.05).

<sup>a</sup> Statistical significance for the oil treatment (OT), the processing treatment (PT) and the interaction of both treatments (O × P).
<sup>b</sup> Standard error of the mean.
<sup>c</sup> Raw.
<sup>d</sup> Cooked.
<sup>e</sup> Cooked and chilled.
<sup>f</sup> Expressed as nanomol carbonyls per milligram protein.
<sup>g</sup> Expressed as milligram MDA per kilogram patty.
Animal fat compared with vegetable oils in pork patties.

PUFA loss to a lesser extent than C-patties. Muguerza and others (2003) also detected lower oxidation rates in Greek fermented sausages elaborated with O oil compared to the control ones. The degree of unsaturation in oils should predict their susceptibility to oxidative deterioration, which is directly related with the degradation of polyunsaturated fatty acids (Morrisey and others 1998). In the present study, however, patties enriched in PUFA such as S- and O-patties, had less intense PUFA losses than control patties. As discussed in detail subsequently, the presence of antioxidant compounds in such oils may have enhanced the stability of the treated patties against oxidative reactions.

**TBARS**

The initial TBARS numbers in R-patties increased significantly in all types of patties as a result of the application of the cooking procedure (Table 3). TBA-RS numbers above about 0.5 are critical since they indicate a level of lipid oxidation products, which produce a rancid odor and taste that can be detected by consumers (Shahidi, 1998). This rancidity level was reached right after cooking only by C-patties while the TBARS numbers in the treated counterparts remained below 0.5. The formation of TBARS increased once again during the subsequent chilled storage and the final lipid oxidation rates were significantly higher in control patties than in the treated counterparts. These results are in agreement with Paneras and Bloukas (1994) and Severini and others (2003) who reported that fermented and cooked sausages formulated with O oil had lower TBARS numbers than those formulated with animal fat. The protective effect of vegetable oils against oxidation could be attributed to natural components of the oils with proven antioxidant potential such as tocopherols, chlorophylls, and phenols (Wang and others 2010). Lipid oxidation decreases shelf life of meat products by causing serious deleterious effects on particular nutritional and sensory attributes (Gandemer 2002). Therefore, the use of vegetable oils in meat products appears as an efficient strategy to diminish the adverse effects caused by lipid oxidation.

**Protein carbonyls**

The carbonyl gain observed in burger patties during cooking and chilling proves that proteins were also affected by oxidative reactions (Table 3). The carbonylation of meat proteins was particularly intense during chilled storage of cooked patties, which is in agreement with previous observations by Ganhão and others (2010). According to these researchers, the increased susceptibility of cooked meats to protein carbonylation can be attributed to the disruption of the tissues as a result of high temperatures, which in turn, leads to the release of non-heme iron and enhance the incorporation of oxygen to the system. Certainly, non-heme iron has been recognized as a major promoter of the formation of carbonyl moieties from myofibrillar proteins (Estévez and Heinonen 2010).

The substitution of pork back-fat by vegetable oils did not affect the accumulation of protein oxidation products. Despite of the significant positive correlation between TBARS and protein carbonyls found in the present study ($r = 0.79; P < 0.05$) the lack of effect of the lipid substitution on protein carbonylation reflects a weak coupling between lipid and protein oxidation. In the same line, other authors have also reported that certain antioxidant strategies with proven effectiveness against lipid oxidation were not effective against protein oxidation (Haak and others 2009).

**Lipid-derived volatiles**

Amongst all lipid-derived volatiles, hexanal was the most abundant in the headspace of all meat samples (Table 3). This aldehyde is frequently employed as a lipid oxidation and rancidity indicator (Shahidi 1998). In agreement with the TBARS numbers, the counts of hexanal in cooked patties treated with A oil were significantly lower than those from the control group. In fact, a significant and positive correlation was found between both lipid
Animal fat compared with vegetable oils in pork patties... oxidation measurements ($r = 0.88; P < 0.05$). Similar results were obtained for 2-pentylfuran, 1-pentanol, and 1-hexanol. Interestingly, patties with added vegetable oils, namely A and O, had significantly lower amounts of certain PUFA-derived volatiles despite having larger amounts of PUFA. These results highlight that the increase of PUFA in A- and O-patties does not imply a larger oxidative instability as the modification of the fatty acid composition is satisfactorily compensated with the incorporation of antioxidant compounds that inhibit lipid oxidation. According to the results from the volatiles profile, this circumstance may not be applied to patties elaborated with S oil.

It is generally accepted that linoleic acid-derived volatiles, such as hexanal, contribute with rancid odors and off-flavors while certain oleic acid-derived volatiles, such as octanal and nonanal, contribute pleasant odors described as floral and sweet (Shahidi 1998). In this regard, the volatiles profile exhibited by cooked and chilled patties were linked by their fatty acid composition as patties with largest amounts of oleic acid and MUFA (A- and O-patties) also had the highest counts of octanal and nonanal. In the same line, the ratio between hexanal/octanal + nonanal (C : 49.0; A : 35.7; S : 86.9; O : 30.7) reflects the influence of the fatty acid composition on the volatiles profile and could reflect a more pleasant odor profile in A- and O-patties than in C- and S-patties.

Texture profile

Figure 1 shows the instrumental hardness measured in freshly cooked and in cooked and chilled patties. The level of fat replacement (50%) in patties containing 10% back-fat was insufficient to promote significant changes in the textural properties of cooked patties. The increase of hardness during the chilled storage could be attributed to the loss of water during storage as water provides less resistance to compression (Youssef and Barbut 2011). In agreement with the storage losses, the increase of hardness was undergone similarly by control and treated cooked patties. Ganhão and others (2010) also reported a significant increase of hardness in porcine cooked patties subjected to chilled storage. These researchers attributed the hardness increase to the constricting effect of cross-links formed via protein carbonylation during chilled storage. The researchers observed that the addition of phenolic-rich fruit extracts inhibited protein carbonylation and hence, hardness increase. The lack of differences between treatments in the present study prevents the detection of a clear link between protein oxidation and the instrumental texture of cooked patties. However, a significant correlation was found between protein carbonyls and instrumental hardness ($r = 0.53; P < 0.05$).

Cohesiveness was found to remain unaffected by chilled storage, except in S-burger (Figure 2). Youssef and Barbut (2009) observed that meat emulsions made with high-PUFA vegetable oils had small fat globules, which affect, in turn, protein-protein interactions and samples’ cohesiveness. Hence, the increased cohesiveness in S-patties may be due to the characteristics of S oil (higher PUFA content) and the size fat globules formed during the manufacture process.

Instrumental color

The partial replacement of pork back-fat with vegetable oils led to raw patties with higher $L^*$-values (Figure 3), which is in agreement with results reported by Youssef and Barbut (2009). Hammer (1992) reported that vegetable oils could be evenly dispersed and are better distributed than beef fatty tissue in frankfurters. According to Youssef and Barbut (2011), the small oil globules reflect more light (larger surface area) than the larger beef fat globules. Subsequent cooking and chilled storage caused sequential increases of lightness in all types of burger patties probably due...
Animal fat compared with vegetable oils in pork patties

to the coagulation of proteins and the loss of moisture occurring during such technological processes.

The redness of raw burger patties with added vegetable oils was lower than that of the control counterparts (Figure 4). A significant decrease of redness was observed in raw patties as a result of cooking and chilling. The discoloration of cooked meats during chilled storage has been profusely reported (Estévez and Cava 2004; Ganhalo and others 2010). Ganhalo and others (2010) proposed plausible mechanisms by which protein oxidation could influence the color changes occurred during chilled storage of cooked meats. The significant correlations found between protein carbonyls and the instrumental color parameters, redness ($r = -0.46; P < 0.05$) and lightness ($r = 0.57; P < 0.05$), support the likely implication of oxidation processes on color deterioration. At all stages, the lowest $a^*$-values were found in A-patties. This may be due to the large amount of polyphenols, pigments, and chlorophylls present, as natural components, in A oil (Wang and others 2010).

Conclusions

The usage of A and O oils as back-fat replacers enhances the oxidative stability of burger patties during cooking and the subsequent chilled storage. The positive influence of the back-fat replacement by vegetable oils on the nutritional and oxidative stability of the patties is achieved without causing major color and texture modifications. This extent, however, may be confirmed by the accomplishment of further sensory studies.

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