Original article

Effects of roasting and boiling on the chemical composition, amino acids and oil stability of safflower seeds

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Summary The objective of this study was to determine the effects of roasting and boiling on compositional and oil stability of safflower seeds. The moisture, carbohydrate and fibre contents decreased because of roasting and boiling treatments while fat and protein contents increased. The fatty acid compositions of treated samples changed slightly compared with control. The total amount of amino acids in control sample was 151.29, and this amount increased to 158.8 and 186.9 mg g\(^{-1}\) N by roasting and boiling, respectively. The peroxide value of the oil increased because of roasting and boiling, and it reaches above the accepted value to consumer. Concentrations of major elements such as Na, K and Cu in raw safflower seeds were significantly (\(P < 0.05\)) higher than roasted and boiled seeds. The effects of roasting and boiling with regard to loss and retention of the nutrients differed significantly (\(P > 0.05\)), with only the roasting retaining more of the nutrients than boiling. The peak intensities of control oil using FTIR spectroscopy were changed in comparison with treated oils.

Keywords Amino acid, boiling, fatty acid, FTIR, roasting, safflower.

Introduction

Vegetable oils are the fundamental components in foods and have important functions regarding human health and its nutritional physiology. The demand for vegetable oils for food purposes has entailed a considerable expansion of oilseed crops production (Çamaş et al., 2007). Safflower (Carthamus tinctorius L.) of the compositae family is deep-rooted and drought-tolerant plant. The seeds are white or cream in colour and contain 26–37% oil and 12–22% protein (on dry matter base). Initially, safflower oil was used as a source of oil for paint industry, and now it is edible oil used for cooking, making margarine and salad oil (Emongor, 2010). Safflower is also grown for its flowers that are used as cut flowers, colouring and flavouring foods, making dyes for the textile industry, livestock forage, vegetable, making herbal tea and medicinal purposes (Emongor, 2010).

The effects of various processing methods used to prepare oilseeds for human consumption are of utmost importance. Roasting is heat treatment used to induce the development of the typical colour, taste and flavour; it also changes the chemical composition, modifying nutritional value and shelf life (Ozdemir & Devres, 2000). During roasting, pleasant aromas and flavours (nut-like or peanut butter-like) transfer to the oil. Roasting is the key step for making condiment oil, because the colour, flavour, composition and quality of the oil are affected by the processing conditions used (Lee et al., 2004). Lipid oxidation strongly affects shelf life and sensory characteristics of oil seeds and depends on many factors such as the concentrations of unsaturated fatty acids, enzymatic activity, mineral composition and the presence of natural antioxidants (Ozdemir & Devres, 2000). As far as we know, this is the first time to study the effect of roasting and boiling temperature on the stability of oil extracted from Sudanese safflower cultivar. The present study investigated the effects of roasting and boiling on the chemical composition of safflower seeds and the quality and oxidative stability of the recovered oil.

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Materials and methods

Safflower seed

Safflower cultivar seeds (5 kg) were collected from the experimental farm of Sudan University of Science and Technology, Department of Field Crops, during the season of 2009/2020. The seeds were collected in plastic bags and then stored at 4 °C for further analysis.

Preparation of safflower seeds

Roasting
Whole safflower seeds were arranged a single layer in aluminium foil dishes (12 × 8 cm) and then placed in an electric forced air oven (FN400, NO.03822, Turkey). The seeds were roasted at 180 °C for 10, 20 and 30 min. Three dishes were treated once at each of the different roasting times to prepare sufficient sample material for analysis and testing. The roasted safflower seeds (SSR) were allowed to cool to ambient temperature, then ground in an electric grinder (Panasonic, Japan) and stored at room temperature for further analysis (Lee et al., 2004).

Boiling
The seeds were put into boiling tap water (100 °C) in a 500-ml beaker on magnetic stirred hot plate at ratio of 1:4 seed : water for 40 min until the pieces were well cooked and tender. The boiled samples were dried and ground in grinder (Panasonic, Kyoto, Japan) and used in proximate chemical analysis and oil extraction. Control samples were not only treated with either of two techniques described above but also ground at the same methods mentioned above.

Chemical composition

Physicals characteristics
One hundred safflower seeds were picked by hand and accurately weighed using a top loading balance and examined for their average weight. The previously weighed hundred seeds were dehulled (decorticated) by hand, and care being taken not to lose any separated hulls or kernels. Hulls and kernels were weighed using portable advanced Ohaus balance separately, and the ratio weight of hull and kernel was calculated.

Proximate analysis
Moisture, lipid, ash and crude fibre contents were determined following the standard methods of the Association of Official Analytical Chemists (AOAC 1990). The organic nitrogen content was quantified using the micro Kjeldahl method, and an estimate of the crude protein content was estimated by multiplying the organic nitrogen content by a factor of 6.25 (Sosulski & Imafidon, 1990). Two different samples were analysed in triplicate. Total carbohydrate content was calculated by difference.

Mineral analysis
The mineral contents were measured in triplicate according to the standard methods of the Association of Official Analytical Chemists (AOAC 1990) using an atomic absorption spectrometer (3110; Perkin Elmer, Waltham, MA, USA).

Amino acid composition
The dry matter and total N contents were determined following the standard methods of the Association of Official Analytical Chemists (AOAC 1990). The amino acid contents (except for tryptophan) in defatted safflower seeds were determined using an Amino Acid Analyzer (L-8900 Hitachi-hitech, Tokyo, Japan) under the experimental conditions recommended for protein hydrolysates. Samples containing 5.0 mg of protein were acid hydrolysed with 1.0 mL of 6 N HCl in vacuum-sealed hydrolysis vials at 110 °C for 22 h. The ninhydrine was added to the HCl as an internal standard. The tubes were cooled after hydrolysis, opened and placed in a desiccator containing NaOH pellets under vacuum until dry (5–6 days). The residue was then dissolved in a suitable volume of NaS buffer, pH 2.2 filtered through a Millipore membrane (0.22-μm pore size, Millipore, Billerica, MA, USA) and analysed for amino acids by ion-exchange chromatography in a Beckman (model 7300, Pickering Laboratories, Inc., Mountain View, CA, USA) instrument, equipped with an automatic integrator. Amino acid nitrogen was determined by multiplying the concentration of individual amino acid by corresponding factors calculated from the percentage N of each amino acid (Mosse, 1990). The ammonia content was included in the calculation of protein nitrogen retrieval, as it comes from the degradation of some amino acids during acid hydrolysis (Yeoh & Truong, 1996; AOCS 1993). The ammonia nitrogen content was calculated by multiplying the ammonia content by 0.824 (N = 82.4% NH₃).

Fatty acid composition
Oil samples were derivatized to methyl esters according to a method reported by Christie (Christie, 1989). Methyl ester sample (1 μL) was injected into gas chromatography (Shimadzu, GC-2010A series; Shimadzu, Tokyo, Japan) equipped with a flame ionisation detector and a BPX70 capillary column of 30 m × 0.32 mm i.d. (SGE, Melbourne, Australia). The initial temperature of 140 °C was held for 2 min, which was then increased at 8 °C min⁻¹ to 220 °C where it was held for another 5 min. The oven, the injector and the detector ports were set at 140, 240 and 260 °C, respectively. The carrier gas was helium with column flow rate
at 1.10 mL min\(^{-1}\) at a 50:1 split ratio. The fatty acid peaks were identified by comparing the retention times with those of a mixture of standard FAMEs (Sigma Chemicals, Deisenhofen, Germany).

Oxidative stability of safflower oil

To study the oxidative stabilities of oils extracted from raw, roasted and boiled safflower seeds, 60 g of oil was transferred in duplicate to 100-mL glass beakers. The samples were stored in forced-drafted air oven at 70 °C for 3 days (72 h) (Lee et al., 2004). The oxidative stability of oils was determined by the increase in peroxide value, which was determined in triplicate according to AOCS official methods (AOCS 1993).

FTIR spectroscopy

The IR spectra were collected using a Vector 22 FTIR spectrometer (8400S; Shimadzu) with OPUS software (version 3.1). A film of oil (five drops) was placed on the attenuated total reflectance (ATR) device, which was equipped with a ZnSe crystal (Van de Voort et al., 1994). The spectra were obtained using 128 scans and ratioed against the spectrum of the clean crystal. The range from 4000 to 400 cm\(^{-1}\) with a resolution of 4 cm\(^{-1}\) was used to obtain spectral information. After each measurement, the ATR plate was carefully cleaned by wiping it with analytical-grade acetone and dried with a soft tissue before it was filled with the next sample. Three spectra replicates were obtained for each sample.

Statistical analysis

Each reported value is the mean of determinations for triplicate samples (except fatty acids) prepared from replicated roasting and boiling processing technique, the data were analysed and the discussion was based on one-way analysis of variance (ANOVA). Statistical significance was accepted at a level of \(P < 0.05\) (Statgraphics 1985–1989).

Results and discussion

Physicals characteristics

The weight of hundred seeds was 4.63 g while the hectolitres weight was 5.4 kg, and the ratio weight of hull and kernel was 4:6. The hull content of the seeds was up to 40% and was within the limits specified in the literature (Isigigur et al., 1995). Lower hull content improves the nutritional value of the meal and influences the production cost of the oil (Rahamatalla et al., 2001).

Effect of processing techniques on seed chemical composition

Results in Table 1 show the proximate composition of safflower seeds prepared with roasting and boiling processing techniques, and from these results, moisture content of raw safflower seed was 5.3 ± 0.16 and decreased to 3.4, 2.4 and 1.9, respectively, with increase of roasting time, and to 4.0 by boiling technique. Roasting processes decreased moisture content faster than boiling as seeds were subjected to high temperature during roasting. These results are in good agreement with those reported by Abayomi et al. (2002) and Adegoke et al. (2004) who reported that roasting processes decreased moisture content of peanut. The results obtained proved that the roasting temperature and time were the main factors affecting the moisture content.

From Table 1, the oil content of safflower seed prepared using different processing techniques increased from 34.1 (g per 100 g) in raw sample to more than 36.0 (g per 100 g) in samples prepared by roasting and boiling techniques. The protein content increased slightly from 13.2 (g per 100 g) in raw samples to 13.6 in SSR 180⁄10, 13.7 in SSR 180⁄20, 13.8 in SSR 180⁄30 and 13.4 in boiled sample, respectively. The carbohydrate and fibre contents decreased from 43.5 and 2.6 in raw samples to 42.3 and 2.1 in safflower seeds roasted at 180 °C for 30 min and to 41.7 and 2.1 in boiled safflower seeds, respectively.

### Table 1 Proximate composition of safflower seeds prepared with different processing techniques (g per 100 g)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture</th>
<th>Fat</th>
<th>Protein</th>
<th>CHO</th>
<th>Fibre</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>5.3 ± 0.16</td>
<td>34.1 ± 0.86</td>
<td>13.2 ± 0.09</td>
<td>43.5 ± 0.29</td>
<td>2.6 ± 0.16</td>
<td>1.3 ± 0.31</td>
</tr>
<tr>
<td>SSR180⁄10</td>
<td>3.4 ± 0.02</td>
<td>36.9 ± 0.17</td>
<td>13.6 ± 0.22</td>
<td>41.0 ± 0.10</td>
<td>2.3 ± 0.45</td>
<td>2.8 ± 0.02</td>
</tr>
<tr>
<td>SSR180⁄20</td>
<td>2.4 ± 0.12</td>
<td>36.5 ± 0.53</td>
<td>13.7 ± 0.03</td>
<td>42.2 ± 0.06</td>
<td>2.4 ± 0.51</td>
<td>2.8 ± 0.03</td>
</tr>
<tr>
<td>SSR180⁄30</td>
<td>1.9 ± 0.3</td>
<td>36.5 ± 0.03</td>
<td>13.8 ± 0.22</td>
<td>42.3 ± 0.34</td>
<td>2.5 ± 0.17</td>
<td>2.7 ± 0.02</td>
</tr>
<tr>
<td>SSB</td>
<td>4.0 ± 0.23</td>
<td>36.1 ± 0.19</td>
<td>13.4 ± 0.24</td>
<td>41.7 ± 0.04</td>
<td>2.1 ± 0.32</td>
<td>2.7 ± 0.05</td>
</tr>
</tbody>
</table>

All determinations were carried out in triplicate and mean value ± standard deviation (SD) were reported.

SSR180⁄10, safflower seed roasted at 180 °C for 10 min; SSR180⁄20, safflower seed roasted at 180 °C for 20 min; SSR180⁄30, safflower seed roasted at 180 °C for 30 min; SSB, safflower seed boiled.
The increase in oil and protein content in safflower seed is seemed to be as result of subjection of samples to temperature of roasting and boiling techniques. These results were in good agreement with those indicated by different authors (Damame et al., 1990; El-Badrawy et al., 2007) who reported that the oil and protein content of raw peanut increased as a result of roasting process.

Effect of processing techniques on mineral composition

Mineral analyses are essential to guarantee the quality of any food product. There are many minerals that are considered nutrients and are vital for the proper functioning of the body.

Equally, there are a number of minerals that are toxic to the human body and interfere with its functioning and undermine health. Potassium plays an important role in human physiology, and sufficient amounts of it reduce the risk of heart stroke, while calcium plays an important role in building stronger, denser bones early in life and keeping bones strong and healthy later in life.

Table 2 summarises the results of mineral composition of raw, roasted and boiled safflower seeds. Concentrations of major elements such as Na, K and Cu in raw safflower seeds (8690, 293 and 245 ppm) were significantly ($P < 0.05$) higher than roasted safflower seeds (5285, 91 and 69 ppm) and boiled seeds (990, 91 and 68 ppm).

Table 2 shows how roasting and boiling affected sodium, calcium, copper, iron, magnesium, manganese, potassium and zinc contents of the safflower seeds in varying proportions. Roasting affected significantly ($P < 0.05$) the mineral contents of the safflower. Roasting decreased the sodium and calcium content of raw seeds by about 39.2 and 18.1 per cent while boiling decreased these elements by 88.6% and 14.5%, respectively. Potassium, magnesium, manganese and zinc were more stable during roasting and boiling processes and as such had minimal losses. These losses were attributed to leaching of these minerals into the boiling water.

Table 2 Minerals in safflower seeds prepared with different processing techniques (ppm wet basis)

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Raw</th>
<th>SSR</th>
<th>SSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (Na)</td>
<td>8690 ± 0.5</td>
<td>5285 ± 0.4</td>
<td>990 ± 0.3</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>110 ± 0.1</td>
<td>90 ± 0.2</td>
<td>94 ± 0.3</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>245 ± 0.5</td>
<td>69 ± 0.2</td>
<td>68 ± 0.2</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>293 ± 0.5</td>
<td>51 ± 0.1</td>
<td>91 ± 0.2</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>750 ± 0.5</td>
<td>745 ± 0.5</td>
<td>750 ± 0.5</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>138 ± 0.3</td>
<td>122 ± 0.4</td>
<td>119 ± 0.3</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>25 ± 0.1</td>
<td>18.0 ± 0.1</td>
<td>23 ± 0.2</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>40 ± 0.2</td>
<td>40 ± 0.2</td>
<td>38 ± 0.1</td>
</tr>
</tbody>
</table>

Values are means ± standard deviation (SD) of two replicates.

Effect of processing techniques on fatty acid composition

Vegetable oils undergo changes in terms of chemical and physical properties when they interact with the food or atmosphere. Some food-processing techniques can affect fatty acid composition (FAC) of oils when hardly subjected to successive heating (Lee et al., 2004). Types of reaction that are known to lead to degradation of vegetable oils include polymerisation, oxidation and hydrolysis. The FAC of oil can be an indicator of its stability, physical properties and nutritional value. The FAC determined by GC-FID of safflower seed oils is listed in Table S2. The result shows that the major fatty acids in safflower seed oils were linoleic, oleic and palmitic. These results agreed with Lee et al. (2004) who reported that safflower oil (unroasted) consisted of 5.5% palmitic, 1.6% stearic, 11.0% oleic, 81.5% linoleic and 0.4% linolenic acids. Safflower oil from seeds roasted at 180 °C for different times and that boiled was not different from oil of untreated (Raw) safflower seeds. FAC of safflower oils did not change with roasting and boiling temperatures.

Amino acid profile

The amino acid profile of safflower seeds analysed by amino acid hydrolysis is presented in Table S3. Because safflower seeds are consumed as a major oil and protein source in food, it is very important that the amino acid contents should not be compromised during the various food-processing methods such as roasting and boiling. It was observed that the processes of boiling and roasting generally have very high total amino acid contents compared with the fresh samples. This was in good agreement with the results of Oluwaniyi et al. (2010) who observed that the processes of boiling and roasting of fishes generally have very close (or slightly higher) total amino acid contents compared with the fresh samples.

The total amount of amino acids in safflower seeds of control sample was 151.29, and this amount increased and affected positively by roasting and boiling. Subjecting safflower seeds to 180 °C for 10, 20 and 30 min increased the total amino acids from 151.29 mg g⁻¹ N in the control sample to 158.8, 205.6 and 163.19 mg g⁻¹ N in roasted samples, respectively.

The percentage of sulphur-containing amino acids (methionine and cysteine) in safflower seeds of control sample was 2.29 mg g⁻¹ N, and this percentage was affected by roasting at 180 for 10, 20 and 30 min and increased to 2.6, 2.56 and 2.75 mg g⁻¹ N, respectively. Boiling technique also increased the percentage of sulphur-containing amino acids to reach 2.8 mg g⁻¹ N. The total aromatic amino acid levels (phenylalanine and tyrosine) found in safflower seeds of control sample was 9.77 and increased during roasting to
The human bodies do not synthesise the essential amino acids, but can be obtained from food. Eight amino acids are generally regarded as essential for humans: phenylalanine, valine, threonine, tryptophan, isoleucine, methionine, leucine and lysine (Young, 1994). Additionally, cysteine (or sulphur-containing amino acids), tyrosine (or aromatic amino acids), deficiency in these amino acids may hinder healing recovery process (Mat et al., 1994). All of these essential amino acids are found to be present in the safflower seed samples investigated except tryptophan, which was not determined. Lysine was found to be the first limiting amino acid in safflower seed followed by methionine and isoleucine. The total essential amino acids increased during roasting and boiling, and the essential amino acids represent 36% of the total amino acids in the raw sample; during roasting at 180 °C for 10, 20 and 30 min, this essential amino acid represented 35.9%, 30.6%, 36.3% and 39.3% of the total amino acids. Roasting and boiling had more desirable effects on the amino acid composition and should be encouraged as better methods of processing safflower seeds for consumption.

According to Burger & Walters (1973), three major types of reactions are responsible for the nutritional changes that occur in processed foods. One of these is the Maillard reaction in which amino groups (notably the e-amino group of lysine) reacts with aldehyde groups of reducing sugars or carbonyls from oxidised fat, thus making those amino acids metabolically unavailable; cross-linkage reactions, that is, protein–protein interactions, an example of which is the formation of =CH–N= links (instead of normal peptide bonds) that are resistant to enzymatic hydrolysis in the gut; and damage to sulphur amino acids by oxidation or desulphydration (Oluwaniyi et al., 2010).

**Effect of processing techniques on oxidative stability of safflower oils measured by peroxide value**

The oxidative stability of safflower oils was monitored using peroxide value and FTIR analysis. Table 3 shows the changes in peroxide values in oils extracted from raw, roasted and boiled safflower seeds during storage at 70 °C. Peroxide value in raw safflower oil increased ($P < 0.05$), resulting in 65.25 meq O$_2$ per kg oil after 3 days of storage at 70 °C. Peroxide values of the oils obtained from safflower seeds roasted at 180 °C for 10, 20 and 30 min, respectively, increased from 3.9, 37.0 and 38.0 meq O$_2$ per kg oil in zero time to 63.0, 96.1 and 121.2 meq O$_2$ per kg oil after 3 days of storage at 70 °C, respectively. After 3 days of storage, peroxide value of the oil from boiled safflower seeds was 71.6 meq O$_2$ per kg oil, which was above the accepted values (10 meq kg$^{-1}$) to consumer. Peroxide values of safflower oils extracted from roasted and boiled seeds increased gradually as the storage time increased. Oxidative

### Table 3: Peroxide value of oil extracted from safflower seeds prepared with different processing techniques and stored for 0–3 days under oxidative conditions

<table>
<thead>
<tr>
<th>Peroxide value</th>
<th>Zero time</th>
<th>1st day</th>
<th>2nd day</th>
<th>3rd day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>1.5 ± 0.20$^a$</td>
<td>9.8 ± 0.07$^a$</td>
<td>33.6 ± 0.38$^a$</td>
<td>65.3 ± 0.26$^a$</td>
</tr>
<tr>
<td>SSR180/10</td>
<td>3.9 ± 0.11$^b$</td>
<td>11.6 ± 0.05$^b$</td>
<td>35.6 ± 0.38$^b$</td>
<td>63.0 ± 0.04$^b$</td>
</tr>
<tr>
<td>SSR180/20</td>
<td>37.0 ± 0.10$^c$</td>
<td>45.6 ± 3.64$^c$</td>
<td>66.8 ± 1.16$^c$</td>
<td>96.1 ± 1.84$^c$</td>
</tr>
<tr>
<td>SSR180/30</td>
<td>38.0 ± 0.00$^d$</td>
<td>62.8 ± 4.74$^d$</td>
<td>80.8 ± 0.53$^d$</td>
<td>121.3 ± 1.95$^d$</td>
</tr>
<tr>
<td>SSB</td>
<td>25.0 ± 0.10$^e$</td>
<td>29.58 ± 0.35$^e$</td>
<td>60.9 ± 0.05$^e$</td>
<td>71.6 ± 0.09$^d$</td>
</tr>
</tbody>
</table>

All determinations were carried out in triplicate and mean value ± standard deviation (SD) is reported. Values with different superscript letters within the same column are statistically different ($P < 0.05$). SSR, safflower seed roasted at 180 °C for 10, 20 and 30 min; SSB, safflower seed boiled.
The stability of safflower oils, based on the changes of peroxide values, was in agreement with Lee et al. (2004) but disagreed with Abayomi et al. (2002). Therefore, the oils from safflower seeds roasted at 180 °C for longer time had a much greater peroxide values (less stable) than oils from safflower seeds unroasted or boiled.

**FTIR data**

To study the oxidative stability of safflower oil, the extracted oils from unroasted, roasted and boiled safflower seeds were stored in forced-drafted air oven at 70 °C for 3 days (72 h) then studied by FTIR.

FTIR has few advantages over classical parameters in the measurements of oil stability. With only a small drop of oil and a couple of minutes to prepare the sample, the infrared spectrum collected can give information on different functional groups present. Also, minimal errors in the determination of frequency and absorbency can be expected because it is fully computerised (Guillen & Cabo, 2004). The FTIR spectra of safflower oil showed the typical characteristic absorption bands for other vegetable oils. In the characterisation of vegetable oils, the bands of interest are absorption peaks at 3600–2800 and 1800–700 cm\(^{-1}\) (Henna Lu & Tan, 2009). The band assignments and their respective mode of vibration are shown in Table S1 and Fig. 1. As clearly indicated in Fig. 1, there were eleven visible peaks at frequencies of 3008, 2923, 2854, 1747, 1654, 1463, 1377, 1238, 1163, 1099 and 723 cm\(^{-1}\) have been investigated in spectrum of safflower oil (control).

Figures 2 and 3 show FTIR spectra of safflower oil extracted from safflower seeds roasted at 180 °C for 10, 20 and 30 min stored for the first day (Fig. 2) and for 3 days (Fig. 3) under oxidative conditions compared with the control oil. The peak intensities (absorbencies) of control oil were changed in comparison with oil subjected to roasting indicating a clear effect of roasting temperature on the oil, and the band near 3006 cm\(^{-1}\) experienced a clear decrease in intensity (Figures 2 and 3d) that indicates a decrease in degree of unsaturation as a consequence of oxidation process (Henna Lu & Tan, 2009).

Figure S1 shows FTIR spectra of safflower oil extracted from boiled safflower seeds stored for 0 day (Fig. 4b) and for 3 days (Fig. 4c) the peak changes during boiling, and the prominent peak change observed was at frequency of 1747 cm\(^{-1}\), which corresponded to the carbonylic compounds (esters, aldehydes, ketones, lactones) resulted from the hydroperoxide decompositions during boiling.

Figure 4 also shows the safflower oil (boiled) spectra recorded on days 0 and 3. The main changes to the spectra appeared at the region 2854–3008 cm\(^{-1}\), the absorbance of the band at approximately 3008 cm\(^{-1}\) (because of the stretching vibration of CH cis-olefinic groups), changed in boiled samples in comparison with the control and at the region 1099–1408, the five bands in this region showed change in absorbance as a result of boiling technique.
In conclusion, the results obtained in the present work have shown that the proximate chemical analysis as well as seedcake amino acids and oil fatty acids of safflower seeds can be affected by roasting and boiling. Boiling and roasting heat has significantly affected the stability of safflower oils as shown by peroxide values and absorbance (intensity) in the FTIR spectra of safflower oil. Roasting at 180 °C for 10 min seems to be the best technique for the quality of safflower seeds. Roasting and boiling techniques improve the nutritional value of safflower seeds by increasing the total and some individual amino acids.

References


Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. FTIR spectra of fresh safflower oil.

Table S1. FTIR absorbance bands and their characteristic functional groups.

Table S2. Fatty acid (FA) composition (%) of oil extracted from safflower seed prepared with different processing techniques.

Table S3. Total amino acid and ammonia contents (mg/g N) of safflower prepared with different processing techniques.

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