EFFECTS OF DIFFERENT PROCESSING TREATMENTS ON ALMONDS (BADAM)

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ABSTRACT

Almonds are nutrient dense and possess wide range of antioxidants. Almond consumption has been associated with generation of satiety, regulation of body weight, improvement in the intestinal microbiota profile and modification of intestinal bacterial activities, reduce oxidative stress and inflammation, elevated levels of high density lipoproteins, lower low density lipoproteins, reduced cholesterol levels in blood, protective effect against cancers, increases brain acetylcholine levels and improves memory function. It is important to know the impact of processing treatments on the internal profile of almonds. Current review focuses on the impact of processing conditions on the microstructure and nutritional composition of almonds. Present study would be helpful in identifying the processing treatment for maximization of health benefits of almonds to consumers.

INTRODUCTION

The Almond fruit, biologically a drupe is known worldwide for its high nutrient density. Global almond production for 2017-18 has been reported to be 6 percent higher i.e. 1.3 million metric tons basis on record output in the United States, Australia, and the European Union. Global almonds consumption was increased from 927 000 tons in 2007, to 1 307 000 tons in 2016 and is expected to continue expanding to a record 1.2 million tons in 2017-18.

Almonds are nutrient dense and can rightly be termed as potential all-rounder among tree nuts. In just a handful, or more precisely, in a standard 28 g serving, almonds abode 164 kcal of energy which is derived mainly from their high fat content i.e. 49.4% of the total weight. However, it is important to note that almonds have low metabolisable energy content. More than 90% of the lipids present in almonds are in the form of unsaturated fats (MUFA~66% and PUFA > 25% mainly n-6) and some phytosterols widely known for their cholesterol lowering properties. The saturated lipids, so called ‘bad fats’, are only around 8 percent. In the same serving size, these abode high amounts of vitamin E (36.4% by weight i.e. providing >20% DV). Also, almonds are excellent source of manganese (36.0% of DV) and good source of (expressed as % DV) magnesium (19.5%), copper (16.0%), phosphorus (13.4%), fiber (13.2%, with insoluble/soluble fiber at 4:1), riboflavin (13.5%) and protein (12.1%) (USDA 2019). Recent studies show the presence of prebiotic factors in almonds which on fermentation into SCFAs promote cellular health of large intestine (Ukhanova et al., 2014). These also consist of wide range of...
phenols and polyphenolic compounds. Almonds contain a good amount of antioxidants like a-tocopherol and many other components such as folic acid, calcium, potassium, magnesium, copper, zinc (Griel and Etherton, 2006).

As expected, store house of diverse range of nutrients have several positive impacts on human health. Preliminary researches conducted worldwide have associated almond consumption with generation of satiety (Hull et al., 2015), regulation of body weight (Lutz and Luna 2016), improvement in the intestinal microbiota profile and modification of intestinal bacterial activities (Liu et al., 2014), reduce oxidative stress and inflammation (Lesser et al., 2015), elevated levels of high density lipoproteins (Jamshed et al., 2015), lower low density lipoproteins (Berryman et al., 2011), reduced cholesterol levels in blood, protective effect against cancers, increases brain acetylcholine levels and improves memory function (Batool et al., 2016).

Almonds are processed before packaging or consumption to either improve their sensory attributes or for safety. After some cases of salmonellas were traced to almonds, USDA, in 2007 approved a resolution to pasteurize almonds before being sold to public (Anonymous, 2010). Almonds are also soaked, blanched, dry roasted, roasted in oil with addition of salt or spices before consumption. Any treatment applied, whether for palatability or safety may bring significant structural and nutritional changes in the fruit. So, it is important to know the impact of processing treatments on the internal profile of almonds. Current review focuses on the impact of processing conditions on the microstructure and nutritional composition of almonds. Present study would be helpful in identifying the processing treatment for maximization of health benefits of almonds to consumers.

Figure 1: Proposed health benefits of almonds
**MOISTURE**

Dried commercial almonds have a moisture content of not more than 6%. During blanching of Indian almonds for 10 min, the moisture content was increase from 5.55% to 8.3% (Adu et al., 2015). moisture contents of soaked, blanched and autoclaved kernels were increased as compared to the raw kernels. On the other hand, roasting decreased the moisture content (Folasade and Subomi, 2016). Since this moisture content is too high for long term storage, water blanched almonds are usually dried before storage.

On roasting, the temperature of the nut rises way above 100°C. As it reaches 130°C, the rate of temperature rise slows as moisture starts evaporating which may reach to as low as 2% giving a crunchy texture. Roasting of almonds at 150°C for 10, 20, 30 minutes reduced the moisture content of almonds from 5.2±0.0 to 3.4±0.1, 1.7±0.1, 0.9±0.1 respectively (Acar et al., 2009). Roasting at 200°C for 6 min decreased the moisture content from 6.1% to 0.8% (Varela et al., 2006).

**MICROSTRUCTURE**

Almonds possess a highly compartmentalized honeycomb microstructure. The lipids are enclosed in a mono layer membrane as small globular structures, roughly 1 to 2 µm in diameter, called oleosomes which are further separated by a membraneous network and forms a honeycomb structure. This compartmentalization protects lipids from any oxygen access (Young et al., 2004).

On heating, the intracellular membrane ruptures, oleosomes burst, volume of extracellular pores and intracellular membrane increases. This change leads to coalescence of oil bodies and agglomeration of proteins (Varela et al., 2008). On roasting almonds at 200°C for 6 minutes a heterogenous, uneven fractured surface was observed (Varela et al., 2006). Lipids exposed to environmental oxygen accelerate oxygen transfer due to increased porosity. Disruption of parenchymatous layer and decline in moisture content leads to increase in brittleness, crispness, and crunchiness. However, Perren and Escher (2013) recommended that the structural changes in almond depend mainly on roasting temperature whilst roasting duration plays a less important role.

Morphological analysis of almond microstructure studied by (Altan et al 2011) revealed the mean area of 4332 pixels for raw almonds. On processing, the mean area increased to 4463 pixels on blanching at 100°C and 4691 pixels for air roasted samples. On roasting with oil, the mean area was found to increase from 5252 pixels at 140°C and 5727 pixels at 150°C. Perren and Escher (2000) measured the pore volume of almonds on processing and observed that it increased from 26 mm³/g to 37 26 mm³/g on roasting at 145°C. Further expansion to 71 mm³/g was observed when heated to 180°C.

**ENERGY**

Almonds are believed to be energy dense foods and their energy is derived mostly from the lipid fraction. However, a study conducted on 18 healthy adults consuming almond containing diet for 18 days found the
energy content to be only 129 kcal/28g serving which was significantly less than the energy content of 168-170g/serving when calculated by Atwater factors (Janet A Novotny et al., 2012). There is dietary net energy gain in almonds on high temperature processing. The energy value of oil roasted samples was found to be the highest preceded by air roasted and blanched.

As already discussed above oil-roasted samples (with temperatures above 140°C) showed higher degree of structural damage when compared to the hot air-roasting and blanching processes making them more susceptible to release oil during storage (Altan et al., 2011). In vitro studies showed that on exposure to high temperatures large amounts of lipids are available for lipase adsorption onto oil droplet surface on disruption of oleosin layer (Gallier and Singh, 2012). These lipases may “pre-digest” oil bodies, promoting subsequent lipolysis which increases the dietary net energy content.

**CARBOHYDRATES**

Sucrose is the main component of carbohydrates in almonds with a mean level of 5.52g/100g along with traces of fructose, glucose, sorbitol, and inositol (Fourie and Basson, 1990). The content of reducing sugars increase from kernel to shell and vice versa for oligosaccharides.

On high temperature processing, the content of reducing sugars in almonds decline as they are utilized in non enzymatic maillard browning. Raw almonds contain 0.286g/100g of glucose which reduced to .07 g/100g on roasting at 130°C for 22.5 min which were further reduced to 0.011 g/100g at 180°C for 7 min. Similar trend was observed for fructose which declined from initial level of 0.2 g/100g in raw to 0.09 and 0.014 g/100g on roasting at 130 and 180°C respectively. The utilization of reducing sugars for browning was confirmed by measuring the acrylamide concentration which while not detected in raw almonds was formed upto a concentration of 79ug/kg on roasting at 130°C. Roasting at 180°C elevated the acrylamide levels to 1,718 ug/kg (Amrein et al., 2005).

The dietary fibre content of raw almonds is the highest among nuts (9.2%-12.5%). USDA data shows that the content of total dietary fibre reduces on processing. Figure shows the effect of different treatments on dietary fibre. Blanching reduces the content from 12.5g to 9.9g. Roasting with air and oil reduced the fibre content to 10.9g and 10.5g respectively. The reduction can be associated with disruption and degradation of cell wall polymers. The reasons for decline in blanching can be explained with the help of the study conducted by Mandalari et al., in 2010 in which the carbohydrates present in blanched almond peel and blanch water were characterised. On blanching almond peels for 2-3 minutes, it was found that blanched water contained mostly glucose (72.28% of total sugar content), followed by galactose (13.27% of total sugar content) and mannose (6.26% of total sugar content) along with small amounts of galacturonic acid, xylose and rhamnose. Hence it can be concluded that high decline in dietary fiber can be due to the losses due to water solubility of degraded...
polymer units. Earlier similar results were obtained by Ellis et al., (2004) who studied the cell wall composition of almond skins from the monomer units.

Almonds are also considered as potential prebiotics. In almond skin, high concentration of arabinose, uronic acids and rhamnose are suggestive of arabinose-rich polysaccharides’ presence, including the pectic substances. The high glucose concentration is indicative of cellulose, and the ratios of glucose, xylose and galactose indicate that these derived from xyloglucans (Schlörmann et al., 2015, USDA 2016). The potential prebiotic properties of almonds and their skins (prebiotic index= 3.3) are comparable to fructooligosachharides (prebiotic index= 4.2) found commercially (Liu et al., 2014, Mandalari et al., 2010). Almond skins separated by industrial blanching had slightly lower their prebiotic potential (prebiotic index= 3.2) which was determined by means of a gastrointestinal model (Mandalari et al., 2010a). Almonds affect the faecal and caecal microflora in a positive way. Raw almonds have shown to have a greater stimulatory effect on Lactobacillus and Bifidobacterium and inhibitory effect on E. Coli and Enterococcus spp. than their processed counterparts. Almonds also have a potential modulating effect on intestinal bacterial enzymes. Raw almonds possessed greater bacterial enzyme, including β-galactosidase, β-glucuronidase and azoreductase regulation effects which were correlated with the changes of intestinal bacteria (Liu et al., 2016).

PROTEINS

Protein content of 16–23 g/100 g has been reported in Almonds (Grundy et al 2016). Amandin, also referred to as ‘almond major protein’ (AMP) is the chief protein identified in almonds. It belongs to the legumin class and globulin family of proteins with at least two types of polypeptides with different molecular weight ranges (20,000–22,000 and 38,000–42,000) connected with disulfide bonds (Yada et al., 2011). Almond protein contains very low amount of free amino acids. Asparagine was reported to be the major free amino acid in raw almonds (Amrein et al 2005). It accounts for 20-50% of total free amino acids. Thirty percent of the total protein in almonds constitute of essential amino acids. Methionine is the major limiting amino acid found in amandin. The major limited essential amino acids are methionine and cysteine (Sathe et al 2002). Other amino acids found in low quantity are lysine and threonine (Ahrens et al. 2005).

Heat treatments are important determinants which affect the quantity and quality of proteins. Exposure to elevated temperature reduces the solubility of almond proteins. Processing treatments like drying and roasting significantly increased the crude protein content in Baru almonds (19.19±1.35 % and 18.89± 0.70 % respectively) in comparison to raw and (16.36±1.23 % and 17.62±0.85 respectively) (Adu et al., 2014). Similar results were obtained by Lima e Silva et al., (2014) in defatted Baru almond flour. When the flour was toasted at 200°C for 15 min, the crude protein content increased to 34.92 ±1.379 from 31.95 ± 0.538 in raw flour. The reported increase can be attributed to reduced moisture content on toasting. This correlation seemed justified as only a small decline from 35.95 to 35.41 g/100 g was observed when calculations were done on dry basis which can be attributed to denaturation. Hence it can be concluded that proteins present in almonds are very much
stable to processing temperature up to 200°C. Effects of high pressure processing and dry heat application on protein recovery were observed by Zhang et al., (2016). In their study, on exposure of almond flour to high heat temperatures (100 or 200°C for 10 min). The authors observed that protein recovery remained constant (p > 0.05) on exposure of almond flour to elevated temperature. However, recovery rate started reducing at 250°C for 10 min. On increasing the temperatures to 400°C (10 min) resulted in no protein recovery. Effect of moisture content was also observed in the same study and concluded that presence of moisture resulted in smaller protein recovery.

Application of heat also have an impact on interaction of protein with other nutrients in food (Renzone et al., 2015). It also change the vulnerability of proteins to digestion in the gastrointestinal tract, absorption and their property to cause allergies.

**LIPIDS**

Almonds are reported to be rich source of monounsaturated fatty acids and contain fewer amounts of saturated fats, so are very beneficial for the heart patients (Griel and Etherton, 2006).

Processing treatments like thermal processing and oil extraction lead to significant changes to the physical structure on almonds. Loss of compartmentalization and increase in porosity hasten mass transfer and facilitate the entry of oxygen into the nut tissue. This shows that tissue breakdown is a major factor controlling lipid stability in roasted nuts. Lipid oxidation rate is directly proportional to roasting temperature and is also affected by the antioxidants formed by non-enzymatic browning.

Raw almonds consist of 49.4g/100g of total fats, 3.7g/100g of saturated fatty acids, 30.9g/100g of monounsaturated fatty acids and 12.1g/100g of polyunsaturated fatty acids (Kumari, 2017).

Change in fatty acid composition of almonds has been reported by Mexis et al., 2009. The content of total saturated fatty acids (SFA) was reduced by 15.47%, monounsaturated fatty acids (MUFA) by 66.16% and polyunsaturated fatty acids (PUFA) by 18.37% after the irradiation dose of 7 kGy. Whereas in non-irradiated almond was 11.85, 69.69 and 18.46% respectively. This can be because of the formation of hydrocarbons by rupturing if side chains of fatty acids (Mexis et al., 2009).

Changes in fatty acid amount in two different varieties of almonds (i.e. Drake and Nonpareil) after one year of cold storage were observed by Agar et al., 1998. They reported that oleic acid (MUFA) content was decreased by 4.7 % and linoleic acid (PUFA) content was increased by 4.7 % in drake variety. But there was not any significant change observed in oleic and linoleic acid content in nonpareil variety. Overall change in fatty acid content was reported to be 2.91 % and 1.21 % increased in drake and nonpareil variety respectively after one year of cold storage (Agar et al., 1998).
Fatty acid composition is also changes with treatments like roasting and frying which is given by Valdes et al., 2015. Initially, raw almonds were contained total saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) i.e. 8.67, 67.54 and 23.79% respectively. After the process of roasting, it was observed that total saturated fatty acids slightly increased by 0.24 % and became 8.91 %, monounsaturated fatty acids decreased by 1.93 % and became 65.61 % and polyunsaturated fatty acids were slightly increased by 1.69 % and became 25.48%. After the process of frying it was observed that saturated and monounsaturated fatty acids were decreased (7.22, 66.41 % respectively) and polyunsaturated fatty acids were slightly increased 26.38% (Valdes et al. 2015).

After roasting and frying, the changes in fatty acid profile were also observed by Ghazzawi and Ismail in 2017. SFA content was increased from 7.2±0.07 to 7.63±0.18, oleic acid content was decreased from 69.31±0.18 to 68.37±0.22, linoleic acid and linolenic acid slightly increased after roasting. Whereby, SFA content was increased to 8.15±0.27, oleic acid decreased to 65.1±0.53, linoleic acid increased to 26.69±0.48 and linolenic acid was reported to be increased to 0.066±0.01. This might be due to the fact that during frying, nuts are having the pores which can absorb the oil median inside the nuts (Ghazzawi and Ismail, 2017). This increase in fat was due to that complex organic compounds broken to release more fat molecules at high temperature and decrease could be due to solid loss during treatments (Folasade and Subomi, 2016).

MICRONUTRIENTS:

As macronutrients, micronutrients are also very important for human body. Minerals and vitamins play a vital role in maintenance of human health. Raw almonds contain good amount of minerals and vitamins. It consists of B complex vitamins such as thiamine 0.35 mg/100 g, riboflavin 0.15 mg/100 g and niacin 0.19 mg/100 g and vitamin E 26 mg/100 g. It consists of minerals in amount of 710 mg potassium, 260 mg calcium, 275 mg magnesium and 3.7 mg iron per 100 g of almonds (Kumari, 2017). Mineral composition is reported to be increased by treatments like roasting (Folasade and Subomi, 2016).

After soaking, vitamin B1, vitamin B2 and vitamin B3 was reduced in range of 34.3–45.7%, 11.315.3% and 36.8–42.1% respectively. After 18 hours the reductions were increased by 51.4%, 20.0% and 57.9% respectively (Folasade and Subomi, 2016).

Almonds are good source of Vitamin E. Arslan et al., 2017 estimated the amount of vitamin E by HPLC method. This method showed that the concentration of vitamin E in whole almonds was 119.4 mg/kg. After soaking, the content was increased to 259 mg/kg and after blanching vitamin E was slightly increased to 189 mg/kg (Arslan et al., 2017).
PHYTOCHEMICALS AND ANTI NUTRIENTS:

Almonds consist of various phytochemicals such as terpenoids, phenols, flavonoids etc. Phenolic compounds are the major among phytochemicals which are present in almonds (Prgomet et al., 2017). But various cooking processing techniques affects these phytochemical contents in almonds. Blanching affects polyphenols by more than 60 %. As skin of fresh almonds contain 3474.1±239.8 mg GAE/100 g while after blanching it has been reported to be decreased up to 278.9±12.0 mg GAE/100 g (Prgomet et al., 2017).

Ghazzawi and Ismail in 2017 reported the changes in total phenols and flavonoids content after roasting and frying. Total flavonoids were reported to be decreased after roasting (from 6.49±2.43 to 4.58±1.16) and increased after frying (from 6.49±2.43 to 10.60±1.23). total phenolic content was reported to be increased after roasting (from 5.87±1.55 to 8.46±1.38) and also increased after frying (from 5.87±1.55 to 8.24±1.55) (Ghazzawi and Ismail, 2017). In another study, the phenolic composition and antioxidant potential of almond skin obtained from different processes was analysed. From this analysis, 31 compounds exhibiting anti-nutritional properties were extracted and identified like, flavonol glycosides (9-36%), flavan-3-ols (33-56%), flavanone glycosides (3-7.7%) etc. Roasting doubled the phenol content. Industrial drying increased the phenol content more than double. This was characterized by high antioxidant activity in roasted samples (0.803 to 1.08 mmol Trolox/g) followed by blanching and drying (0.398-0.575 mmol Trolox/g). High phenolic content on roasting is partly due to solubilisation of phenols from the skin during blanching and partly due to degradation of other phenolic structures (high polymerized proanthocyanidins of low extractability (Garrido et al 2008).

ANTINUTRITIONAL FACTORS

Along with phytochemicals, there are some anti-nutrients present the almonds which affects the functioning of nutrients. Various processing treatment affects the quantity of anti nutrients also. The content of oxalate in almond kernels was reported to be 0.15mg/100g. After the treatment of soaking, it was decreased to 0.12-0.14mg/100g. Similarly with the treatments of blanching, autoclaving and roasting, the content of oxalate was decreased to 0.10-0.13mg/100g, 0.02-0.08 mg/100g and 0.01-0.02 mg/100g respectively. Soaking reduced oxalate concentration by 6.7-20.0%. Blanching reduced oxalate content by 13.3-33.3%, autoclaving by 46.7-86.7% and roasting by 86.7-93.3%. It proved that oxalate is thermo-labile in nature (Folasade and Subomi, 2016).

The phytate content of raw almond kernels was 0.13mg/100g. It was observed that, soaking reduced the phytate content by 7.7-30.8%, blanching by 15.4-38.5% autoclaving by 30.8-61.5% and roasting by 46.2-92.3% (Folasade and Subomi, 2016).
<table>
<thead>
<tr>
<th>Almond</th>
<th>Compound</th>
<th>Processing treatment</th>
<th>Processing conditions</th>
<th>Initial content</th>
<th>Percent change</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kernel</td>
<td>Free fatty acid</td>
<td>Roasting</td>
<td>150°C for 5 min 20 min 20°C for 5 min 20 min</td>
<td>891.90 ± 42.38</td>
<td>1.8 % increase 6.5 % increase 5.4% increase 16.3% decrease</td>
<td>Lin et al 2015</td>
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<tr>
<td>Defatted Kernel</td>
<td>Total phenols</td>
<td>Roasting</td>
<td>150°C for 5 min 20 min 20°C for 5 min 20 min</td>
<td>7.50 ± 0.20</td>
<td>70 % decrease 11.6% decrease 76.8% decrease 156% increase</td>
<td>Lin et al 2015</td>
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<td>Ethanolic extract of Defatted Kernel</td>
<td>Total flavonoids</td>
<td>Roasting</td>
<td>150°C for 20 min 20°C for 20 min</td>
<td>2.43 ± 0.15</td>
<td>70.4% decrease 124.3% increase</td>
<td>Lin et al 2015</td>
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<tr>
<td>Kernel</td>
<td>Flavonoids and phenols</td>
<td>Pasteurization-steam</td>
<td>Less than 1 minute</td>
<td>1809 ± 12</td>
<td>12% decrease</td>
<td>Bolling et al 2010</td>
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<td>Kernel</td>
<td>Flavonoids and phenols</td>
<td>PPO fumigation</td>
<td>Less than 1 minute</td>
<td>1809 ± 12</td>
<td>12% decrease</td>
<td>Bolling et al 2010</td>
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<td>Kernel</td>
<td>Flavonoids and phenols</td>
<td>Roasting</td>
<td>295°C for 14 minutes</td>
<td>1557 ± 18</td>
<td>1% decrease</td>
<td>Bolling et al 2010</td>
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<td>Kernel</td>
<td>Total phenols</td>
<td>Pasteurization-steam</td>
<td>Less than 1 minute</td>
<td>27.6 ± 13.8</td>
<td>29.4% decrease</td>
<td>Bolling et al 2010</td>
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<td>Kernel</td>
<td>Total phenols</td>
<td>PPO fumigation</td>
<td>Less than 1 minute</td>
<td>27.6 ± 13.8</td>
<td>39% decrease</td>
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<td>16% decrease</td>
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<td><strong>Skin</strong></td>
<td><strong>Total polyphenols</strong></td>
<td><strong>Blanching</strong></td>
<td>703.031 ± 15.916</td>
<td>56 % decrease</td>
<td>Smeriglio et al., 2016</td>
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<td><strong>Dry heat</strong></td>
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<td><strong>Autoclaving</strong></td>
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<td>With PBS</td>
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<td><strong>Carbohydrate</strong></td>
<td><strong>Roasting</strong></td>
<td>35.6 %</td>
<td>7.3 % decrease</td>
<td>Mbah et al., 2013</td>
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<td><strong>Seeds</strong></td>
<td><strong>Fibre</strong></td>
<td><strong>Roasting</strong></td>
<td>10 %</td>
<td>12 % increase</td>
<td>Mbah et al., 2013</td>
<td></td>
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<tr>
<td><strong>Kernels</strong></td>
<td><strong>Total unsaturated fatty acids</strong></td>
<td><strong>Oil roasting</strong></td>
<td>150 deg C (5 min)</td>
<td>830.78 ±40.10</td>
<td>1.75 % increase</td>
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<td>(10 min)</td>
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<td></td>
<td></td>
<td>180 deg C (5 min)</td>
<td></td>
<td>3.32 % incr</td>
<td></td>
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<td></td>
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<td></td>
<td>(10 min)</td>
<td></td>
<td>5.70 % incr</td>
<td></td>
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<tr>
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<td></td>
<td>(20 min)</td>
<td></td>
<td>7.70 % incr</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td>200 deg C (5 min)</td>
<td></td>
<td>4.99 % incr</td>
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</tbody>
</table>

**Note:** All percentages are relative to the untreated samples.
<table>
<thead>
<tr>
<th>(10 min)</th>
<th>(20 min)</th>
<th>11.37 % dec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>16.13 % dec</td>
</tr>
</tbody>
</table>
REFERENCES:

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