International Journal of Food Science and Nutrition
ISSN: 2455-4898; Impact Factor: RJIF 5.14
Received: 28-05-2020; Accepted: 23-06-2020; Published: 30-06-2020
www.foodsciencejournal.com
Volume 5; Issue 4; 2020; Page No. 28-35

Effect of roasting on nutritional compositions and bioactive compounds of two different varieties of flaxseeds (*Linum Usitatissimum L.)*

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Abstract
The aim of this study was to investigate the effect of roasting temperature (160°C, 180°C and 200°C) and roasting duration (5 minutes, 10 minutes and 15 minutes) on nutritional compositions as well as amounts of bioactive compounds of brown and golden flaxseeds. Determination of lipid contents, protein contents, carbohydrate contents/fiber contents, Total Phenolic Contents (TPC), Total Flavonoid Contents (TFC) and Antioxidant Capacity (AC) were thoroughly carried out. In general, the roasting process affected significantly ($p<0.05$) on nutritional compositions and bioactive compounds of two different varieties of flaxseeds. As the roasting temperature and time increased, both brown and golden flaxseeds decreased in lipid contents and protein contents, meanwhile carbohydrate contents/fiber contents, TPC, TFC and AC of flaxseeds increased. Among roasting conditions, both brown and golden flaxseeds roasted at 180/15 (temperature/time) produced a highest amount of TPC (2.33 ± 0.03, 2.59 ± 0.03 mg GAE/g defatted meal, respectively), TFC (0.49 ± 0.02, 0.52 ± 0.03 mg RE/g defatted meal, respectively), AC (47.49 ± 0.12, 46.92 ± 0.40%, respectively) with acceptable lipid contents around 36.33 ± 0.30, 36.23 ± 0.36%, respectively, protein contents around 13.32 ± 0.29, 14.44 ± 0.09%, respectively, carbohydrate contents around 33.12 ± 0.01, 33.76 ± 0.22%, respectively and fiber contents around 31.46 ± 0.01, 32.07 ± 0.21%, respectively. As a result, 180/15 roasting condition was suggested to be used to roast flaxseeds for consumption. Besides, there was no significant difference between the two selected varieties of flaxseeds regarding their lipid, protein and carbohydrate contents.

Keywords: flaxseeds, roasting, lipid contents, protein contents, carbohydrate/fiber contents total phenolic contents, total flavonoid contents, antioxidant capacity

Introduction

Flaxseed (*Linum usitatissiumum L.)*, whose regular name is flax or linseed, belongs to the genus *Linum* in the *Linaceae* family (Ganorkar & Jain, 2013) [1]. It is either an annual or biannual plant that has been considered to be one among the foremost helpful crops and cultivated as a commercial plant in more than thirty countries throughout the world (Gabiana, 2005) [2]. Flaxseeds are broadly known for their ancient utilizations for paint, linoleum, fiber crop as well as important food ingredient and supplement for human consumption (Lei, Li-Chan, Oomah, & Mazza, 2003; Oomah, 2001) [3, 4]. It is known as cultivated plant which has been domesticated from the wild plant species *Linum bienne* which is generally called "pale flax" (Allby, Peterson, Merriwether, & Fu, 2005) [5]. There are numerous alternative species within the same genus that have similar appearance to *L. usitatissiumum* (the same blue flowers), while others have white, yellow or red color flowers (Quanru Liu & Lihua Zhou, 2015) [6].

Flaxseed is rich in fat, protein and dietary fiber. It is also rich in several vitamins, minerals and amino acids that can provide health benefits beyond basic nutrition. The consolidation of flaxseeds in food industry has been increasing due to high amounts of essential omega-3 fatty acid, alpha-linolenic acid (ALA) and dietary fiber present in flaxseeds which provide human with health benefits including the reduction of tumor growth, serum cholesterol, breast cancer, prostate cancer and colon cancer (Morris, 2005) [7]. Flax does not contain gluten so it tends to be applied in gluten-free diets (Hussain, Anjum, Butt, & Sheikh, 2008) [8]. In the field of functional foods, flaxseed has become one of the key sources of phytochemical compounds (such as phenolic acids and flavonoids) which play as antioxidants that can exhibit several therapeutic properties such as anti-microbial, anti-inflammatory, anti-allergenic, anti-cardiovascular disease, etc. (Teh & Birch, 2013) [9]. The presence of flavonoids in flaxseeds exhibits antiseptic, anticancer, anti-inflammatory and mild hypersensitive properties (Pruthi *et al*., 2007) [10]. Consuming flaxseeds was proved to reduce LDL-cholesterol in the blood, thus, provide women and those with high cholesterol with greater health benefits (Pan, Yu, Demark-Wahnefried, Franco, & Lin, 2009) [11].

Flaxseed's phenolics are especially in the center of attention due to their antioxidant capacities. Currently, the effective method of isolation or extraction of flaxseed's phenolic compounds is desirable due to their potential applications in food industry (Touré & Xueming, 2010) [12].

In food industry, flaxseeds are emerging as one of the key sources of phytochemicals such as phenolic acids, flavonoids, etc. which are antioxidants that can affect cell development and their viability (Amin & Thakur, 2014) [13]. Recently, Vietnamese people are gradually shifting to consume seeds with high dietary benefits such as chia seeds, sesame seeds, flaxseeds, etc. in which flaxseeds are regularly roasted for instant consumption or milled into flaxseed meals in order to make different dishes. As a matter of fact, that there are several investigations into raw flaxseeds, only few researches reported the health benefits of roasted flaxseeds. Additionally, some previous studies

have indicated that roasting has significant influences on the physicochemical, functional and phytochemical properties of flaxseed meals (Khan & Saini, 2016) [14]. Consequently, the first and most important objective of this research was to investigate the effect of roasting on nutritional compositions and bioactive compounds of flaxseeds in order to find out suitable roasting conditions that can retain as much as possible the nutritional values of flaxseeds. On the other hand, the two generally utilized varieties of flaxseeds are brown and golden flaxseeds. Although both these varieties contain lot of nutritional benefits, they are still differed in certain ways. As a result, the main purpose of this research was to investigate the difference in nutritional compositions and bioactive compounds of brown and golden flaxseeds.

Materials and Methods

Materials

Brown and golden flaxseeds (*Linum usitatissimum L.)* were imported directly from France and provided by Beemart market. All reagents that were used in this research including Folin-Ciocalteu reagent, sodium carbonate (Na_2CO_3), gallic acid, 2,2-Diphenyl-1-picrylhydrazyl (DPPH) reagent, methanol, ethanol, aluminium chloride ($AlCl_3$), rutin, potassium acetate (CH_3COOK), hexane, pumices, copper sulfate ($CuSO_4$), potassium sulfate (K_2SO_4), sulfuric acid (H_2SO_4), boric acid (H_3BO_3), sodium hydroxide (NaOH), glucose and phenol were purchased from several chemical agents in Ho Chi Minh City, Vietnam.

Methods

Sample preparation

Brown and golden flaxseeds (*Linum usitatissimum L.*) were imported directly from France and provided by Beemart market. After the materials were transferred to the laboratory, they were stored under ambient temperature. For un-roasted samples, brown and golden flaxseeds were ground with a blender (PHILIPS Blender HR2116/01, China) and sieved through 20 mesh size (1 mm) sieving using a sieve shaker (RETSCH AS 200 Basic, Germany) to obtain flaxseed meals. For roasted samples, brown and golden flaxseeds were roasted using an oven (BLUESTONE Electric Oven EOB-7548, China) at 160ºC, 180ºC and 200ºC for 5, 10 and 15 minutes, based on the method of Kanmaz and Khan (Kanmaz, 2017a; Khan & Saini, 2016) [15, 14] with slight modification. After roasting, flaxseeds were allowed to cool at room temperature for 5 minutes then immediately ground by a blender (PHILIPS Blender HR2116/01) and sieved through 20 mesh size sieving to obtain flax seed meals. All ground samples were transferred to clean zip bags (which had been wrapped with aluminum foil to prevent samples from coming into contact with the light), sealed tight and stored inside a desiccator.

Solvent preparation

Solvent used in this experiment was water – methanol, of which was prepared with the ratio of methanol: water was at level 80:20.

Sample defatting and the extraction of free phenolic compounds

Flaxseed meals were defatted using Soxhlet method. The defatting process was carried out under Soxhlet apparatus (BEHR R106S, Germany) using hexane for 6 hours. After defatting, defatted flaxseed meals were stored in clean plastic bags which were wrapped by aluminum foil and sealed tight to avoid light and oxygen. All bags of flaxseed meals were stored in a desiccator at room temperature.

The extraction was carried out based on the method of Yaqoob (Yaqoob, Bhatti, Bhatti, & Jamil, 2015) [16] with slight modification. 1 g of defatted flaxseed meal was mixed with 10 mL of solvent. The mixture was shaken at 200 rpm using a digital orbital shaker (DAIHAN SHO-2D, Korea) for 1 hour under room temperature. The extraction was centrifuged at 2500 g (HETTICH Universal 320R, Germany) for 10 minutes under room temperature to collect the supernatant. After all supernatants were collected, the residues were re-extracted for 2 times more and all supernatants were combined. The seed extracts were stored at -18ºC until use.

Determination of lipid contents

Lipid contents was determined by using the Soxhlet method described by Min and Ellefson (Min & Ellefson, 2010) [17].

Determination of protein contents

Protein contents were determined by using the Kjeldahl method described by AOAC International methods (2007) [18]. 1 g of sample, 0.2 g of $CuSO_4$, 1 g of K_2SO_4 and 20 mL of concentrated H_2SO_4 were added into digestion tubes. Samples were digested using a digestion system (BEHR Inkjel M and BEHR Behrosog 3, Germany) for about 60 – 90 minutes until white fumes could be seen. Remained samples should be clear with no charred material remaining. Samples were allowed to cool down for 30 minutes then placed in the distillation apparatus (BEHR Distillation Unit S2, Germany) and 50 mL of NaOH 32% together with 50 mL of distilled water were added. The ammonia in samples was distilled for 8 minutes into a receiving flask contained 50 mL of boric acid 4% with 1 – 2 drops of Tashiro solution. Nitrogen contents were determined by titrating samples with H_2SO_4 0.1 N solution. Protein contents were calculated by using the following equation:

% Protein content = % Nitrogen content * 6.25

Determination of total carbohydrate contents and fiber contents

Total carbohydrate contents were determined by using the Phenol-Sulfuric acid method described by Dubois (Dubois, Gilles, Hamilton, Rebers, & Smith, 1956) [19]. 1 mL of sample which had been diluted as 1:2000 dilution and 1 mL of distilled water were pipetted into test tubes. 0.05 mL of phenol 80% was added and all tubes were well-shaken. 5 mL of concentrated H_2SO_4 was added and all tubes were mixed using a Vortex test tube mixer. Test tubes were incubated for 10 minutes then placed in a water bath at 25ºC (DAIHAN WCB-11, Korea) to cool down to room temperature. The absorbance was measured at 490 nm using the UV – visible spectrophotometer (JASCO V-730 UV-vis, Japan). The total carbohydrate contents of flaxseed extract were determined in triplicate and the final results were averaged. Amounts of total carbohydrate contents were calculated using a standard curve that was formed using glucose solution as a standard and the calibrations were made from 0, 20, 40, 60, 80 and 100 µg/mL.

The fiber contents of flaxseeds were determined by multiplying the total carbohydrate contents of flaxseeds by

95%, based on the Nutrient data provided by USDA Food Data Central (USDA SR-21) [20].

Determination of Total Phenolic Contents (TPC)

Total phenolic contents (TPC) of flaxseeds were measured by Folin-Ciocalteu method, based on the procedure of Yaqoob (Yaqoob *et al*., 2015) [27] with some modifications. 0.5 mL of extract was mixed with 0.5 mL of Folin-Ciocalteu reagent (diluted to 10-fold). The mixture was held at room temperature for 10 minutes and 1.5 mL of 20% sodium carbonate (w/v) was added. The mixture was adjusted to 10 mL with distilled water, mixed thoroughly by vortexing and heated in a water bath (DAIHAN WCB-11, Korea) for 20 minutes at 40°C. After heating, the mixture was allowed to stand at ambient temperature for 45 minutes until the characteristic blue color appeared. The absorbance was measured at 755 nm using the UV – visible spectrophotometer (JASCO V-730 UV-vis, Japan). Total phenolic contents of flaxseed extract were determined in triplicate and the final results were averaged. Amounts of total phenolic were calculated using a standard curve that was formed using Gallic acid as a standard and the calibrations were made from 0, 20, 40, 60, 80 and 100 µg/mL. Total phenolic contents were expressed as Gallic acid equivalents (mg GAE/g of defatted flaxseed meal).

Determination of Total Flavonoid Contents (TFC)

Total flavonoid contents of flaxseeds were measured by using Aluminum chloride colorimetric method described by Van Hung and Morita (Van Hung & Morita, 2008) [21]. Briefly, 0.5 mL of extract was mixed with 1.5 mL of ethanol 95%, 0.1 mL of $AlCl_3$ 10%, 0.1 mL of CH_3COOK 1M, filled up to 5 mL by distilled water and mixed well by vortex machine. All tubes were allowed to stand at room temperature for 30 minutes in dark condition. The absorbance was measured by a UV – visible spectrophotometer (JASCO V-730 UV-vis, Japan) at 415 nm. The results were expressed as milligram Rutin equivalents (RE) per gram of defatted flaxseed meal. All samples were analyzed in triplicate and the final results were averaged. Calibration curve was prepared by Rutin in different concentrations 0, 20, 40, 60, 80 and 100 µg/mL. Total flavonoid contents of the extract were measured by employing with the standard curve.

of Antioxidant Capacity (AC)

Antioxidant capacities of flaxseeds were determined spectrophotometrically, following the modified procedure described by Hatano (Hatano, Kagawa, Yasuhara, & Okuda, 1988) [22]. 3.6 mL of 0.15 mM DPPH-solution were pipetted into centrifuge tubes and 0.4 mL of extract was added. All mixtures were incubated in darkness for 30 minutes at room temperature. The absorbance of the mixtures was measured using a UV – visible spectrophotometer (JASCO V-730 UV-vis, Japan) at 515 nm. All samples were analyzed in triplicate and the final results were average. To prepare a control sample (blank sample), 3.6 mL of DPPH solution were mixed with 0.4 mL of methanol 80% and the absorbance of the blank was measured. The percentage (%) inhibition activities were calculated by the following formula:

$$\% \text{ DPPH scavenging} = ((A_o - A_1)/A_o) \times 100$$

Where,

A_o is the absorbance of the control sample at t = 0 min

A_1 is the absorbance of the tested extract/standard at t = 30 min

Data analysis

All experiments were done in triplicate and the final results were expressed as means ± standard deviation (S.D.). All data were analyzed by One-way Analysis of Variance (ANOVA) and the statistical analysis were carried out by using SPSS software (version 22). The probability values were considered to be statistically significant differences if $p<0.05$.

Results and discussion

Effect of different roasting conditions on lipid contents of two different varieties of flaxseeds

The changes in lipid content of un-roasted and roasted flaxseeds meals at different roasting condition are summarized and presented in Figure 1. The range of lipid contents of defatted brown flaxseeds meals were from 32.33 ± 0.33 to 43.89 ± 0.48 %Fat and defatted golden flaxseeds meals were from 31.50 ± 0.17 to 43.11 ± 0.39 %Fat.

Both defatted brown and golden flaxseeds meals that were un-roasted shown the highest amount of lipid contents (43.89 ± 0.48 and 43.11 ± 0.39 %Fat, respectively) which were much higher from the lipid content obtained from the research of Khan and Saini (Khan & Saini, 2016) [14] with 32.27 ± 0.39 %Fat. This may due to the differences in geographical locations in which the seeds were obtained. Meanwhile, the lowest amount of lipid contents was recorded at 200/15 (temperature/time) with roasted brown flaxseeds was 32.33 ± 0.33 %Fat and roasted golden flaxseeds was 31.50 ± 0.17 %Fat.

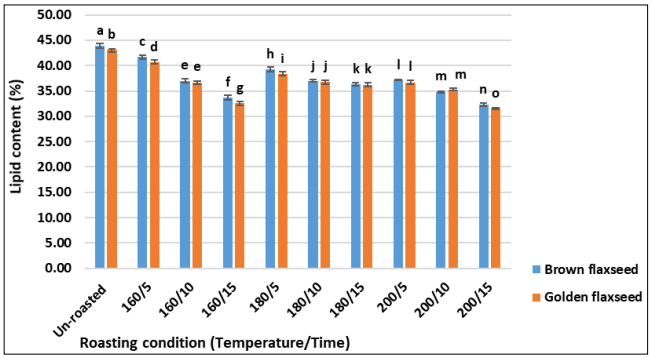

Fig 1: Effects of different roasting conditions on lipid contents of two different varieties of flaxseeds. The values are mean ± SD. Means sharing different letters are significantly different ($p<0.05$).

After the roasting process was applied, lipid contents of these two varieties of flaxseeds were about to be decreased. These obtained results indicated that thermal treatment had a significant effect on the lipid contents of flaxseeds meals. Lipid contents significantly decreased after being subjected to the cooking process (roasting process) and this decrease was associated with cooking temperature and time, which was, lipid oxidation was higher when the time was longer, and temperature was higher. Both Manthey and Schorno (Manthey, Schorno, & HALL III, 2009; Schorno, Manthey, & HALL III, 2010) [23, 24] reported that alpha-linolenic acid was mostly affect by the oxidation because autoxidation reaction rate increased with the number of double bonds present in fatty acid. The research of Kanmaz (Kanmaz,

2017b) [25] also showed the decrease in the level of alpha-linolenic acid in flaxseeds meals. They reported the decrease of Polyunsaturated Fatty Acid (PUFA) after flaxseed meals were roasted. (Bozan & Temelli, 2008) [26] reported that the oxidation process mainly involved with the degradation of PUFA. They also reported that the roasting process exposed the lipids and other constituents to oxidative processes, which led to a decrease in the lipid contents of flaxseeds meals. A reduction in lipid contents also noted in a research of Khan and Saini (Khan & Saini, 2016) [14] and they claimed that the decreased fat contents was due to the destruction of fat during the thermal treatment processes.

Difference in lipid contents of two different varieties of flaxseeds

The lipid contents obtained from brown flaxseeds at different conditions were reported to be slightly higher than that of golden flaxseeds, but in general, there was no significant difference in lipid contents of these two varieties of flaxseeds. No significant difference was also observed between two flaxseed varieties regarding total lipid contents in the research of Sargi (Sargi *et al*., 2013) [27], however, the reported lipid contents were much lower with the lipid contents of un-roasted brown and golden flaxseeds were 38.13% and 37.57%, respectively. Another study from Morris (Morris, 2007) [28] also demonstrated that the lipid contents of brown flaxseed (44,4%) was higher than that of golden flaxseed (43.6%). They also claimed that both brown and golden flaxseeds were available for human consumption based on price and appearance, since the nutritional values of these two varieties of flaxseeds were nearly similar.

Effect of different roasting condition on protein contents of two different varieties of flaxseeds

The effect of different roasting conditions on protein contents of two different varieties of flaxseeds are presented in Figure 2. The protein contents obtained from both brown and golden flaxseeds decreased as the roasting temperature increased and the roasting time was prolonged with the highest protein values were un-roasted brown and golden flaxseeds (17.69 ± 0.29 and 18.23 ± 0.35 %Protein, respectively) and the lowest were brown and golden flaxseeds roasted at 200ºC for 15 minutes (14.22 ± 0.21 and 14.20 ± 0.05 %Protein, respectively). The same result was observed in the research of Khan and Saini (Khan & Saini, 2016) [14] about the decrease in protein contents after flaxseed was roasted and they claimed that the results for a decrease in protein contents may be due to the fact that roasting have destroyed some of the protein compositions, however, their obtained value of un-roasted flaxseed samples was much higher (23.78%).

Another research of Hassan (Hassan, 2013) [29] also showed a decrease in protein contents of sesame seeds after being roasted. (Kumar & Bhattacharya, 2008) [30] reported that heating feed for a long period of times at high temperatures decrease the availability of amino acids which led to a decrease in the total protein contents. The same phenomenon was reported by Bashir (Bashir, Abdullahi, & Suleiman, 2016) [31] about the decrease in the protein contents of the processed samples. (Makinde, Adetutu, & Olorunyomi) [32] reported that raw sesame seeds were higher in protein than the roasted samples.

This result could be explained by the thermal treatment process (roasting) accelerated the Maillard reactions which made protein and its amino acids significantly unavailable for the digestion and led to a reduction in the protein contents of roasted meals (Makinde & Akinoso, 2013) [33].

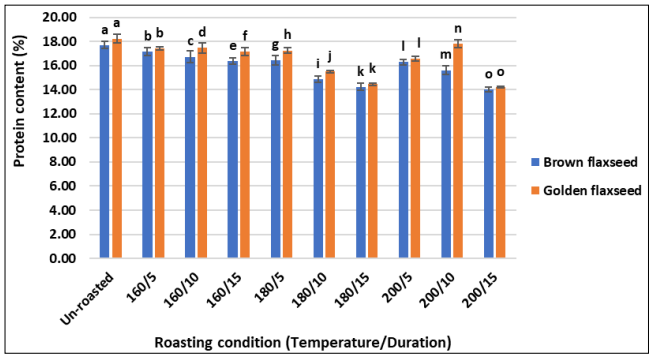

Fig 2: Effects of different roasting conditions on protein contents of two different varieties of flaxseeds. The values are mean ± SD. Means sharing different letters are significantly different ($p<0.05$).

Difference in protein contents of two different varieties of flaxseeds

The protein contents obtained from golden flaxseeds at different conditions were reported to be higher than that of brown flaxseeds which was also identical to the research of Morris (Morris, 2007) [28] with their obtained protein values for brown flaxseeds was 22.3% lower than that of golden flaxseeds (29.2%). However, another research of Sargi (Sargi *et al*., 2013) [30] showed that there was no significant difference in the protein contents of two different varieties of flaxseeds. They also claimed that golden flaxseeds (23.24%) contained lower protein contents than that of brown flaxseeds (24.42%).

Effect of different roasting conditions on carbohydrate contents and fiber contents of two different varieties of flaxseeds

Changes in total carbohydrate contents of brown and golden flaxseeds at different roasting conditions are shown in the Figure 3, of which increased from 20.73 ± 0.37 to 33.63 ± 0.07 % of Carbohydrate for brown flaxseeds and from 20.95 ± 0.03 to 33.76 ± 0.22 % of Carbohydrate for golden flaxseeds. The obtained total carbohydrates are lower than that from the research of Sargi (Sargi *et al*., 2013) [27] with 29.61% for un-roasted golden flaxseeds and 28.29% for un-roasted brown flaxseeds. The research of Khan and Saini (Khan & Saini, 2016) [14] also showed that after being roasted, % Total carbohydrate of flaxseed meals increased from 26.72% to around 29% which was due to a decrease in fat, protein and ash contents of the samples.

The result was also similar with the collected dat by Hassan (Hassan, 2013) [29] about an increase in % Total carbohydrate of roasted sesame seed meals from 9.6% (un-roasted samples) to 12.30%. The same phenomenon was also reported by Bashir (Bashir *et al*., 2016) [31] about the total carbohydrate contents of raw *Tamarindus* seeds (46.49%) were significantly differed from that of roasted samples (58.62%). An increase in carbohydrate contents of Chia seeds from 50.14% to 53.25% also noted in a research of Haripriya (Haripriya & Aparna, 2018) [34].

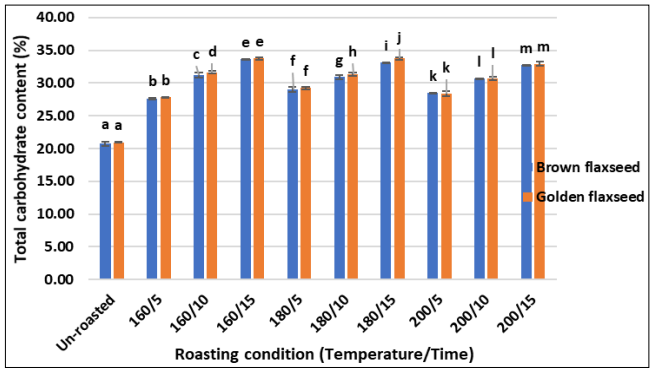

Fig 3: Effects of different roasting conditions on carbohydrate contents of two different varieties of flaxseeds. [The values are mean ± SD. Means sharing different letters are significantly different ($p<0.05$)]

Effects of different roasting conditions on fiber contents of two different varieties of flaxseeds

The total dietary fiber contents of un-roasted and roasted brown and golden flaxseeds are shown in Figure 4. Similar to the total carbohydrate contents, the un-roasted samples contained the lowest amounts (with 19.69 ± 0.35 %Fiber for brown flaxseeds and 19.90 ± 0.03 %Fiber for golden flaxseeds), meanwhile the highest concentrations were recorded in the 160/15 roasted samples for brown flaxseeds (31.95 ± 0.07 %Fiber) and 180/15 roasted samples for golden flaxseeds (32.07 ± 0.21 % Fiber). The obtained values for crude fiber contents were much higher than that in the research of Khan and Saini (Khan & Saini, 2016) [14].

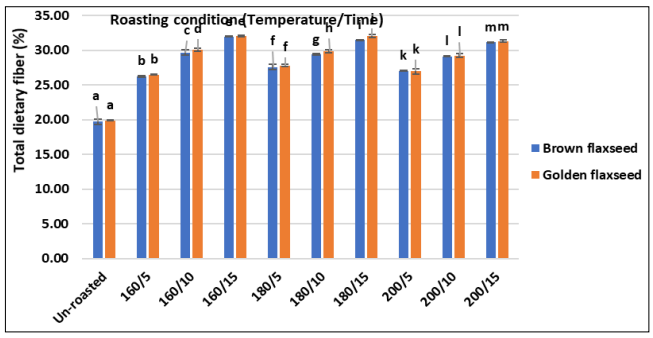

Fig 4: Effects of different roasting conditions on fiber contents of two different varieties of flaxseeds. [The values are mean ± SD. Means sharing different letters are significantly different ($p<0.05$).]

(Khan & Saini, 2016) [14] reported that no significant difference was observed in the crude fiber contents of un-roasted flaxseeds and roasted flaxseeds, however, the total dietary fiber contents of roasted flaxseeds (9.63 ± 0.29 %Fiber) was slightly higher than that of un-roasted samples (9.34 ± 0.22 % Fiber). This was consistent with findings reported by Bashir (Bashir *et al*., 2016) [31] that the values for total dietary fiber contents of raw (3.08%) and roasted (4.96%) samples of *Tamarindus* seeds differed significantly with the percentage of fiber contents of roasted samples were much higher than that of raw samples. (Makinde & Akinoso, 2013) [33] reported an increase in crude fiber contents of sesame flours. They claimed that the increase in fiber contents was the direct result of the loss of moisture. Another study of Hassan (Hassan, 2013) [29] also showed a slightly increase in percentage of crude fiber contents of roasted sesame seeds from 24.38% (raw samples) to 24.48% (roasted samples).

Difference in carbohydrate contents of two different varieties of flaxseeds

The total carbohydrate contents obtained from golden flaxseeds at different conditions were reported to be higher than that of brown flaxseeds. The same phenomenon was also reported in a research of Sargi (Sargi *et al*., 2013) [27] showed that there was no significant difference in carbohydrate contents of two different varieties of flaxseeds. They also claimed that golden flaxseeds (29.61%) contained higher carbohydrate contents than that of brown flaxseeds (28.29%).

Effect of different roasting conditions on Total Phenolic Contents (TPC) of two different varieties of flaxseeds.

Total phenolic contents of un-roasted and roasted flaxseeds meals are shown in the Figure 5 varied from 1.46 ± 0.01 to 2.57 ± 0.03 (mg GAE/g defatted meal) for brown flaxseeds and from 1.79 ± 0.03 to 2.67 ± 0.07 (mg GAE/g defatted meal) for golden flaxseeds. The total phenolic contents obtained from golden flaxseeds at different conditions were reported to be higher than that of brown flaxseeds. The un-roasted samples contained the lowest amount (1.46 ± 0.01 and 1.79 ± 0.03 mg GAE/g defatted meal for brown and golden flaxseeds, respectively), meanwhile, the highest concentrations were recorded in 200/15 (temperature/time) roasted samples (2.57 ± 0.03 and 2.67 ± 0.07 mg GAE/g defatted meal for brown and golden flaxseeds, respectively). As the roasting temperature and time increased, both the phenolic contents of two varieties of roasted flaxseeds were found to be significantly ($p<0.05$) higher than that of un-roasted samples. Hence, the results indicated the commonly used thermal processing method, roasting had had a remarkable effect on the total phenolic content of flaxseed meals. The similar result was reported by Kamalaja (Kamalaja, Prashanthi, & Rajeswari, 2018) [35] that roasting had caused an increase in the total phenolic contents of sesame seeds and ground nuts. The same phenomenon was also reported in a research of Win (Win, Abdul-Hamid, Baharin, Anwar, & Saari, 2011) [36] for oven-roasted peanut extracts. The roasting process was considered to contribute to the increase in the total phenolic contents through partial destruction of the cell structure that resulted in the release of several bound phenolic compounds which later became more extractable in the solvent (Zou, Yang, Zhang, He, & Yang, 2015) [59]. Additionally, the increase in total phenolic contents also led to the development of Maillard reaction products released during the roasting process.

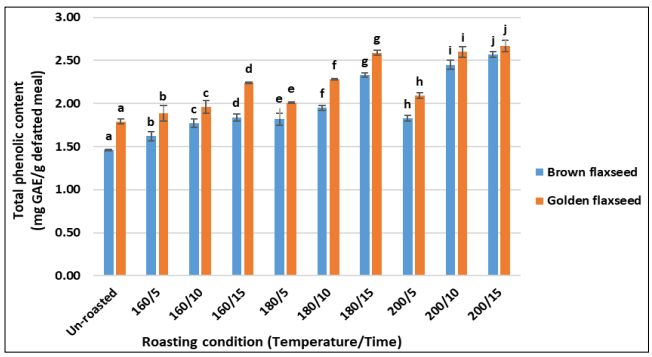

Fig 5: Effects of different roasting conditions on total phenolic contents (TPC) of two different varieties of flaxseeds. The values are mean ± SD. Means sharing different letters are significantly different ($p<0.05$).

Generally, thermal treatments (roasting or heating) applied to plant foods caused the evaporation of intracellular water which triggered many chemical reactions that could change the lignocellulosic structure and promoted the protein denaturation (Kamalaja *et al*., 2018) [35]. This resulted in a greater availability of phenolic compounds inside of the plant. Hence, thermal processes affected both the nutritional and bioactive properties of foods (Kamalaja *et al*., 2018) [35].

Effect of different roasting conditions on Total Flavonoid Contents (TFC) of two different varieties of flaxseeds.

Total flavonoid contents of un-roasted and roasted flaxseeds meals were showed in Figure 6 varied from 0.25 ± 0.03 to 0.74 ± 0.02 (mg RE/g defatted meal) for brown flaxseeds and from 0.28 ± 0.02 to 0.78 ± 0.02 (mg RE/g defatted meal) for golden flaxseeds. The total flavonoid contents obtained from golden flaxseeds at different conditions were reported to be higher than that of brown flaxseeds. The un-roasted samples contained the lowest amounts (0.25 ± 0.03 and 0.28 ± 0.02 mg RE/g defatted meal for brown and golden flaxseeds, respectively), meanwhile, the highest concentrations were recorded in 200/15 (temperature/time) roasted samples (0.74 ± 0.02 and 0.78 ± 0.02 mg RE/g defatted meal for brown and golden flaxseeds, respectively). The result from Kamalaja (Kamalaja *et al*., 2018) [35] also showed the increase in the total flavonoid contents of sesame seeds and ground nuts after being roasted. The significant increase in the total flavonoid contents was considered to be due to the fact that the binds in the structure of SDG lignin complex and other polyphenolic compounds were broken down during roasting process. Furthermore, it was considered that the breaking down of interactions between flavonoid compounds and polysaccharides cell walls (cellulose, hemicellulose, pectin, etc.) during heat treatment process caused an increase in phenolic contents. A similar trend was observed in the research of Rizki (Rizki, Kzaiber, Elharfi, Ennahli, & Hanine, 2015) [37] for this compounds that the content of flavonoids compounds of sesame seeds increased with the increase in roasting time and temperature.

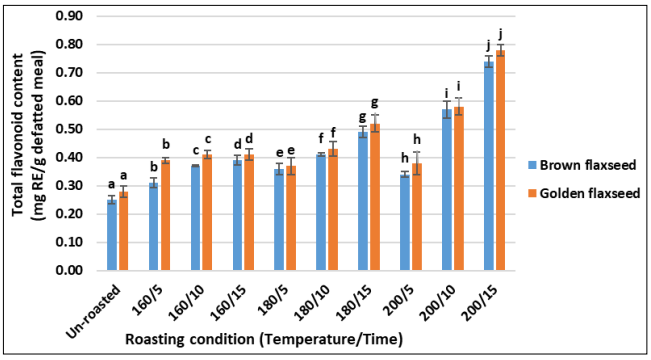

Fig 6: Effects of different roasting conditions on total flavonoid contents (TFC) of two different varieties of flaxseeds. The values are mean ± SD. Means sharing different letters are significantly different (p<0.05).

Effect of different roasting condition on Antioxidant Capacities (AC) of two different varieties of flaxseeds.

As showing in the Figure 7, the roasting process had a significant effect on the antioxidant capacities in two varieties of flaxseeds varied from 37.66 ± 0.06 to 54.92 ± 0.07 %Scavenging for brown flaxseeds and from 33.19 ± 0.05 to 48.83 ± 0.05 %Scavenging for golden flaxseeds. The un-roasted samples contained the lowest amount (37.66 ± 0.06 and 33.19 ± 0.05 %Scavenging for brown and golden flaxseeds, respectively), meanwhile, the highest concentrations were recorded in the 200/15 (temperature/time) roasted samples (54.92 ± 0.07 and 48.83 ± 0.05 %Scavenging for brown and golden flaxseeds, respectively). The total antioxidant capacities after food were roasted was the result of thermal degradation of naturally occurring antioxidant compounds as well as the formation of new Maillard reaction's products that have the antioxidant activities (Kamalaja *et al*., 2018) [35]. (Chandrasekara & Shahidi, 2011) [38] suggested that roasting foods at high temperature effectively enhanced their antioxidant activities which was also shown to be accurate in this study.

In the DPPH scavenging assay, antioxidant activity of food was measured based on the reduction in absorbance as the DPPH radical received an election or hydrogen radical from antioxidant compounds to become a more stable diamagnetic molecule

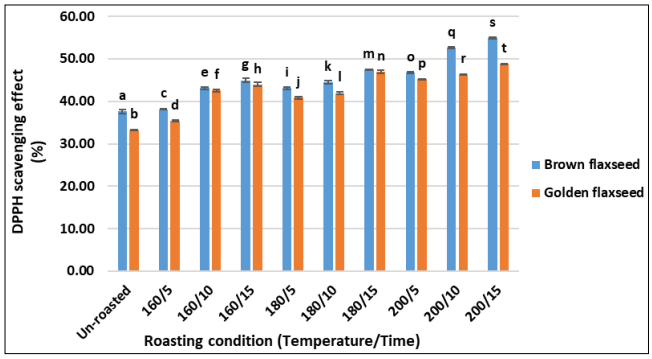

Fig 7: Effects of different roasting conditions on antioxidant capacities (AC) of two different varieties of flaxseeds. The values are mean ± SD. Means sharing different letters are significantly different (p<0.05).

(Juntachote & Berghofer, 2005) [39]. The results from this study were in consistent with the research of Rizki (Rizki *et al*., 2015) [37] about the increase in antioxidant activity was due to the effect of roasting treatment. The same phenomenon was also reported in another research of Ali (Ali, Islam, & Pal, 2016) [40]. This study demonstrated that roasted samples of peanuts produced significantly higher DPPH radical-scavenging activity than that of un-roasted ones.

Difference in antioxidant capacities of two different varieties of flaxseeds

The antioxidant capacities obtained from brown flaxseeds at different conditions were reported to be higher than that of golden flaxseeds. The same phenomenon was also reported in a research done by Sargi (Sargi *et al*., 2013) [27] showed that there was no significant difference in the antioxidant capacities of two different varieties of flaxseeds. They also claimed that brown flaxseeds (1.56 ± 0.01) contained higher antioxidant capacity than that of golden flaxseeds (1.16 ± 0.04).

Conclusions

In this study, the effects of roasting on nutritional compositions, total phenolic contents, total flavonoid contents and antioxidant capacity of brown and golden

flaxseeds (*Linum usitatissimum L.*) were thoroughly and successfully investigated.

- Roasting conditions that produced high number of bioactive compounds and antioxidant capacity were 180/15, 200/10 and 200/15 (temperature/time).
- Among these three conditions, roasted flaxseed meals from 180/15 condition contained the highest lipid content, protein content and carbohydrate/fiber content which indicated that roasting flaxseed at 180ºC for around 15 minutes was suitable and beneficial for consumption.
- The nutritional differences between brown and golden flaxseeds were small which was likely due to the differences in growing conditions.
- Roasting process not only helps break down the hard seed coat, of which is very difficult to break while chewing but also makes the nutrients contained within the seed become easier for digestion. Therefore, it may suggest that applying roasting process for flaxseed could make it become a more suitable and acceptable kind of functional food to many consumers, especially for people who suffer from constipation, diabetes, high cholesterol, heart disease and cancer.

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