



Physico-functional, Nutritional Composition, and Antioxidant Capacity of *Camelina Naheel*: A Newly Developed Cultivar of *Camelina sativa*

Zain ul Abideen, Nattira On-Nom, Rungtiwa Wongsagonsup, Aurawan Kringkasemsee Kettawan, Bangon Saowongjan, Kraingkrai Vasanachitt, Amornrat Aursalung, and Aikkarach Kettawan*

Institute of Nutrition, Mahidol University, Salaya, Phutthamonthon, Nakhon Pathom 73170, Thailand

*Corresponding author, E-mail: aikkarach.ket@mahidol.ac.th

Abstract

Oilseed species, including *Camelina sativa* (CS), are important for human consumption, providing dietary fiber, essential amino acids, polyunsaturated fatty acids, phytosterols, and antioxidants. Climatic variations in Europe and Asia prompted the development of a climate-resilient cultivar of CS, which can thrive in hotter conditions. Consequently, the Ayub Agriculture Research Institute (AARI) in Faisalabad, Pakistan, has introduced a new oilseed cultivar named *Camelina Naheel* (CN). The objective of this study was to explore the physico-functional properties, nutritional composition, and antioxidant capacity of this newly developed CN. Physical, functional, and nutritional properties were analyzed following standard protocols. Physical properties revealed that the seed is long, oval, and elongated with high pigments and carotenoids, suggesting a darker color. CN showed good water holding capacity (WHC) of 3.07 g/g sample, low oil holding capacity (OHC) and foaming capacity (FC) but good emulsifying capacity (45.28%). Proximate analysis revealed that it has 24.14 g/100g of protein, 40.18 g/100g of total fats, and 4.35 g/100g of ash content with a good amount of dietary fiber (13.75 g/100g) as well. Fatty acid composition revealed that total saturated fatty acids (SFA) were 9.98%, while monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) were 22.50% and 67.55% of total fatty acids, respectively. CN also showed high antioxidant capacity, especially in the ORAC assay, which revealed 18157.91 $\mu\text{mol TE}/100\text{g}$, while FRAP and DPPH showed 1069.29 $\mu\text{mol TE}/100\text{g}$ and 7856.84 $\text{mmol TE}/100\text{g}$, respectively, and high polyphenols (392.52 mg GAE/100g) were also determined. CN showed promising nutritional properties, and future research can be done on its incorporation in food product development.

Keywords: *Camelina Naheel*, functional properties, nutritional properties, oilseed, physical properties, sustainability

1. Introduction

Plant oilseed species fall in an important class of crop plants whose oil is edible and fit for human consumption. Plant-based foods produced from different oilseeds are an essential source of dietary fiber, essential amino acids, and lipids including mono and poly-unsaturated fatty acids, phytochemicals, and natural antioxidants and these oilseeds are consumed as whole seeds or as oil extracted from them (Gao et al., 2025).

Plant oils are necessary for human health since they are an easily digested supply of essential fatty acids with minimal cholesterol. Plant oils, which have several nutritional and industrial applications, are popular worldwide, notably from key oilseed crops like soybean, palm, and sunflower. Among the presently existing oilseeds, *Camelina sativa* (CS) is emerging as a promising alternative to minimize the burden on existing crops and contribute to food security for the fulfillment of the future needs because of its rich nutritional profile and other characteristics. Sustainable cultivation of this crop is critical to combat food insecurity, promote sustainable food systems, and meet the growing nutrition demand across the world.

CS, an oilseed flowering plant and a member of the Brassicaceae family, originated in Eastern and Central Europe, North America, Russia, and South Asia, and has a long history of cultivation in Europe and Asia (Bátrina et al., 2020). Sydor et al. (2022) stated that it is a highly branched plant, and the height of the plant ranges from 60-120 cm. It can be grown in a wide pH range of 5.5-8, contains summer and winter annual biotypes, has a short crop cycle/harvesting time of around 85-100 days (Hulbert et al., 2012), requires no/low fertilizer, is a drought-resistance crop, can be a good option for crop rotation, and can be grown on



barren and low-potential land, making it a good alternative for crop diversification (Montero-Muñoz et al., 2023).

Horn and Benning (2016) highlighted that it is mainly used as animal feed, and along with this, the higher proportion of oil makes it a perfect resource for biodiesel fuel production in aviation and industry while producing low carbon emissions to offset greenhouse gases in the atmosphere (Budin et al., 1995; Stamenković et al., 2023). Because of the above-mentioned characteristics, CS has the potential to be a promising alternative to traditional oilseed crops grown nowadays.

As CS is native to Europe, climatic differences have led to the development of climate-resilient cultivars that can adapt to comparatively hotter conditions. Therefore, the Ayub Agriculture Research Institute (AARI), Faisalabad, Pakistan, has developed a novel oilseed cultivar of CS called Camelina Naheel (CN), intended to improve yield performance and nutritional quality under local agroclimatic conditions (Gill et al., 2024). In feed technology, it can replace or supplement conventional oils in the diets of aquatic and poultry animals and can also be used to replace fat obtained from cow milk in functional food development.

CN was selected, bred, and stabilized by scientists to obtain desirable traits e.g., seed yield, seed quality, environmental adaptability. It was methodically developed through multi-location trials, progeny testing, and selection during the long period from 2013 to 2020. CS is the parent plant of CN, and extensive literature is available on the nutritional profile of CS; however, research exploring the nutritional profile of CN is limited because it is a newly developed oilseed crop. A detailed evaluation of physico-chemical and nutritional profiles is essential to establish the nutritional superiority or equivalence of CN relative to the standard CS and other oilseeds.

2. Objectives

Therefore, the objectives of the study were to analyze,

- 1) Physical properties of CN
- 2) Functional properties of CN
- 3) Nutritional composition of CN

Nutritional properties of CN were also compared with CS in this study using values reported in previously published reference papers. Physico-functional properties of CN were assessed to determine the potential of CN as a functional ingredient in future food product formulations.

3. Materials and Methods

3.1 Raw Material

CN was purchased from AARI, Faisalabad, Pakistan. A high-resolution digital image was captured under controlled lighting using a 64 MP sensor to show the appearance of the seed, as shown in figure 1. All the chemicals and reagents used were of analytical grade and stored according to the protocols provided by Sigma- Aldrich (Steinheim, Germany and St. Louis, MO, USA).



Figure 1 Camelina Naheel appearance



3.2 Physical Properties

3.2.1 Color Determination

Color was measured and recorded as L^* , a^* and b^* values using a ColorFlex EZ spectrophotometer (HunterLab, Reston, VA, USA) using the instructions of the manufacturer (Nourzad et al., 2024). Browning index was measured using the equation: $BI(x) = \frac{100(x'-0.31)}{0.17}$, where $x' = \frac{(a^*+1.75L^*)}{(5.645L^*+a^*-3.012b^*)}$ Chroma (C) and Hue (h°) were measured using the equations: $C = \sqrt{a^{*2} + b^{*2}}$ and $h^\circ = \tan^{-1}(b^*/a^*)$ respectively.

3.2.2 Seed Size

Seeds were sieved using mesh No. 18 (aperture size 1.00 mm) and separated into two different grades, e.g., large-sized seeds that did not pass the mesh and small-sized seeds that passed the mesh. Then a Vernier Caliper with a least count of 0.05 mm least count was used to measure the seed size of 20 different seeds randomly picked from both grades in three different dimensions, e.g., seed length, seed width, and seed thickness, as given below, and mean values were calculated for both grades separately.

a) Geometric Mean Diameter (D_g)

D_g values were measured according to Busari and Olaoye (2016) using the formula: $D_g = (a \cdot b \cdot c)^{1/3}$ where a represented longest diameter, b represented intermediate diameter, c represented shortest diameter along three perpendicular dimensions of the seed as measured by vernier caliper.

b) Arithmetic Mean Diameter (D_a)

D_a values were calculated according to Busari and Olaoye (2016) using the formula: $D_a = \frac{(a+b+c)}{3}$

c) Sphericity Determination (ϕ)

Sphericity values of the seed were measured according to Busari and Olaoye (2016) using the formula: $\phi = \frac{D_g}{a}$ where D_g is the geometric diameter, and a = major diameter

d) Surface Area (S)

Surface area of the seed was calculated according to Busari and Olaoye (2016) using the formula: $S = \pi(D_g)^2$ where $\pi = 3.14$

e) Aspect Ratio (R_a)

R_a was calculated according to Busari and Olaoye (2016) using the formula: $R_a = \frac{(b)}{(a)} \times 100$ where b = intermediate diameter, a = major diameter

3.3 Functional Properties

3.3.1 Water Holding Capacity (WHC)

WHC was measured according to Zielińska (2022) with minor modifications. Briefly, 1 g of powdered sample was added to 10 ml of distilled water and transferred into a 15ml test tube. Then the sample was vortexed to mix well and centrifuged at 1640 g for 10 minutes. The supernatant was carefully decanted, and the remaining sample was weighed again. WHC was calculated using the formula: $WHC = \left(\frac{g \text{ water}}{100g \text{ sample}} \right) \frac{W_2 - W_1}{W_0}$ where W_2 = total weight of test tube and hydrated sample after centrifugation, W_1 = test tube weight and dry sample, W_0 = weight of the sample

3.3.2 Oil Holding Capacity (OHC)

OHC was calculated in a similar way as WHC by replacing the water with sunflower oil.

3.3.3 Foaming Properties

Foaming capacity (FC) and foaming stability (FS) were measured according to the method described by Zielińska (2022) with minor modifications. For FC, 1 g sample was mixed with 99 ml of distilled water and the initial volume V_1 was recorded. The sample was transferred into a 250 ml beaker and homogenized with a high-speed homogenizer (IKA T18 basic, Jarosty, Poland) at 16000 rpm for 4 minutes and transferred into a 250 ml glass cylinder. The total volume of the sample was again recorded as V_2 immediately. FC was



calculated using the formula: $FC (\%) = \frac{V_2 - V_1}{V_1}$ where V_2 = volume of the sample after homogenization and V_1 = volume of the sample before homogenization. For FS, the volume of the foam was recorded after 30 minutes and calculated using the formula: $FS (\%) = \frac{V_{30}}{V_2}$ where V_{30} = volume of the foam after 30 minutes, V_2 = volume of the sample after homogenization.

3.3.4 Emulsifying Properties

Emulsifying capacity (EC) and emulsifying stability (ES) were measured according to the method described by Zielińska (2022) with minor modifications. For EC, 1 g of sample was dispersed into 100 ml of distilled water and mixed. Then 10 ml of sample of this dispersion and 10 ml of sunflower oil were taken in a test tube, and the volume was recorded as V_1 . The mixture was then homogenized with a high-speed homogenizer mixer (IKA T18 basic, Jarosty, Poland) at 16000 rpm for 5 minutes, and the volume of the emulsified layer was taken. EC was calculated by using the formula: $EC (\%) = \frac{V_2}{V_1} \times 100$ where V_2 = volume of the emulsified layer, V_1 = volume of the sample in the test tube. For ES, emulsion was heated in a water bath at 80°C for 30 minutes and centrifuged at 3000 g for 5 minutes, and the volume of the emulsified layer was recorded again. ES was calculated using the formula: $ES (\%) = \frac{V_{30}}{V_2} \times 100$ where V_{30} = volume of the emulsified layer after heating and centrifugation, V_2 = volume of the emulsified layer before heating and centrifugation.

3.4 Nutritional Properties

3.4.1 Proximate Composition

Proximate composition of the seed was calculated according to AOAC 2023 as mentioned by Medhe et al. (2023). Total carbohydrates (g/100g) were calculated by the difference method using the equation: $Total\ carbohydrates\ (g/100g) = 100 - [(Moisture + Fat + Protein + Ash)]$ and total energy (kcal/ 100g) was calculated using the equation: $Total\ energy\ (kcal/100g) = (\%carbs \times 4) + (\%protein \times 4) + (\%fat \times 9)$.

3.4.2 Dietary Fiber (DF)

Total Dietary Fiber (TDF), Soluble Dietary Fiber (SDF) and Insoluble Dietary Fiber (IDF) were calculated by following the method from AOAC 2023 (Medhe et al., 2023).

3.4.3 Fatty acid Profile

Fatty acid profile was measured by following Techaniyom et al. (2024). Briefly, five drops of Camelina Naheel oil were transferred into a clean glass tube and mixed with 1 mL of potassium hydroxide in methanol (KOH-MeOH). The mixture was heated in a water bath at 95-100°C for 5 min to saponify triglycerides. Subsequently, 600 μ L of boron trifluoride in methanol ($BF_3/MeOH$) was mixed thoroughly and reheated at the same temperature for 15 min so that free fatty acids are converted into fatty acid methyl esters. After completion of methylation, 1 mL of distilled water was added to stop the reaction and cool the mixture to room temperature. FAMES were extracted with 2.5 mL of petroleum ether, mixed immediately, and the upper organic phase was carefully collected into a fresh tube. The extract was incubated at 60°C overnight. An internal standard C17:0 (1 mg/mL) was then mixed and transferred into a GC vial. FAMES were analyzed using gas chromatography (HP 5890, Hewlett-Packard system) equipped with a flame ionization detector (FID). Retention periods were compared to known fatty acid methyl ester standards in order to quantify individual fatty acids. Results were expressed as percentages of total fatty acids.

3.4.4 Antioxidant Capacity

Antioxidant capacity was determined by following Plaitho et al. (2024) with some modifications, and three different assays were selected to assess antioxidant capacity.



a) Ferric reducing antioxidant power (FRAP)

In a 96-well microplate, 150 μL of fresh FRAP reagent with 20 μL of CN extract or iron (II) sulfate heptahydrate standard was combined. For eight minutes, the reaction mixture was allowed to sit at room temperature in the dark, and a microplate reader (Sunrise, Tecan Co.) was then used to measure the absorbance at 600 nm. A Trolox calibration curve was used to assess the antioxidant capacity, which was expressed as μmol Trolox equivalents (TE) per 100 g of material.

b) DPPH radical scavenging activity

In a 96-well microplate like FRAP, 200 μL of the newly made 150 μM DPPH solution was mixed with 22 μL of Trolox standard or CN extract. The reaction mixture was left in the dark at room temperature for 30 minutes. Absorbance at 517 nm was then measured using a microplate reader (Sunrise, Tecan Co., Grödi, Austria). Antioxidant activity was measured using a Trolox calibration curve and expressed as mmol Trolox equivalents (TE) per g of material.

c) Oxygen radical absorbance capacity (ORAC)

500 μL of sample extract, or 6.25-100 μmol Trolox, was mixed with 3 mL of 4.19 μM fluorescein. The mixture was incubated for eight minutes at room temperature before 0.5 mL of 153 mM 2,2'-azobis(2-amidino-propane) dihydrochloride (AAPH) was added. The absorbance at excitation $\lambda=495$ nm and emission $\lambda=515$ nm was measured using a luminescence spectrofluorometer (model LS 55; Perkin Elmer, Waltham, MA, USA). The antioxidant activity was expressed as μmol TE per g. A 75 mM phosphate buffer served as the blank (control).

3.4.5 Total Polyphenol Contents (TPC)

After mixing 0.5 mL of extract, 8.0 mL of Folin-Ciocalteu reagent, 0.5 mL of distilled water, and 1 mL of 20% Na_2CO_3 , the mixture was incubated in the dark. A UV/Vis spectrophotometer (model UV-1601; Shimadzu, Chiyoda-ku, Tokyo, Japan) was used to detect the absorbance at 750 nm. A gallic acid calibration curve was used to determine the total phenolic levels, which were then expressed as mg gallic acid equivalents (GAE) per 100g.

3.5 Statistical Analysis

Physico-functional properties of CN were reported as mean and SD of triplicate analyses, while nutritional properties of CN were reported as mean and SD of duplicate analyses. CS values were obtained from previously published literature. Data were presented for comparative purposes only, and no statistical inference was performed to compare the nutritional properties of CN with CS, making this a comparative literature-based analysis rather than a statistical comparison.

4. Results

4.1 Physical Properties

4.1.1 Color Determination

Table 1 shows the color properties of CN as 41.89, 16.16, and 28.36 for L^* , a^* and b^* respectively. The browning index (x) value was calculated as 132.42. Chroma and Hue values were 32.64 and 60.33° respectively.

Table 1 Color determination of *Camelina Naheel*

Parameter	<i>Camelina Naheel</i>
L^*	41.89 \pm 0.05
a^*	16.16 \pm 0.02
b^*	28.36 \pm 0.05
BI (x)	132.42 \pm 0.25
Chroma (C)	32.64 \pm 0.04
Hue (h°)	60.33 \pm 0.05

BI (x) represented the browning index.



4.1.2 Seed Size

D_g and D_a values of large-sized seeds and small-sized seeds were 1.27 mm, 1.37 mm, 1.12 mm, and 1.22 mm, respectively, as referred in Table 2. Sphericity, S , R_a values of large-sized seeds were 58.72%, 4.95 (mm)², and 48.97%, respectively, while the same values for small-sized seeds were 58.14%, 4.17 (mm)², and 48.08%, respectively.

Table 2 Physical properties of Camelina Naheel

Large-sized Seeds	
Parameter	Camelina Naheel
D_g (mm)	1.27±0.02
D_a (mm)	1.37±0.03
Sphericity (%)	58.72±0.02
S (mm) ²	4.95±0.04
R_a (%)	48.97±0.20
Small-Sized Seeds	
D_g (mm)	1.12±0.03
D_a (mm)	1.22±0.03
Sphericity (%)	58.14±0.05
S (mm) ²	4.17±0.04
R_a (%)	48.08±0.38

D_g and D_a represent geometric and arithmetic mean diameters, S represents surface area, R_a represents aspect ratio.

4.2 Functional Properties

WHC and OHC values were 3.07 (g water/g sample) and 1.38 (g oil/g sample), respectively. FC was 9.33% and FS was 96.93%. EC and ES were 45.28% and 50.13%, respectively.

Table 3 Functional properties of Camelina Naheel

Parameter	Camelina Naheel
WHC (g water/g sample)	3.07±0.16
OHC (g oil/g sample)	1.38±0.02
FC (%)	9.33±0.57
FS (%)	96.93±1.37
EC (%)	45.28±3.18
ES (%)	50.13±9.39

4.3 Nutritional Properties

Nutritional values of CN, e.g., proximate composition, dietary fiber, fatty acid composition, antioxidant capacity, and total polyphenol contents, were measured by following the protocols described in Materials and Methods section. However, the reported values of CS in the tables were taken as reference values from previously published papers to make a descriptive comparison only between CN and CS.

4.3.1 Proximate Composition

Proximate composition values of CN were measured and presented in Table 4, and these values were compared with CS. Moisture content in CN was reported as 3.11 g/100g. Protein, total fats, and ash were found to be 24.14 g/100g, 40.18 g/100g, 4.35 g/100g, respectively in CN. Total fats (27 g/100g) and ash (3.80 g/100g) in CS were comparatively lower than those in CN, but protein content (26.80 g/100g) in CS was relatively higher than in CN. Total carbohydrates in CN were 28.21 g/100g, which were lower than in CS 37.10 g/100g. The energy value was 571 kcal/100g in CN and 499 kcal/100g in CS.

**Table 4** Proximate composition of *Camelina Naheel* and *Camelina sativa* (CS values were from reference paper.)

Parameter (g/100g)	<i>Camelina Naheel</i>	<i>Camelina sativa</i> (Fraser et al., 2017)
Moisture	3.11±0.09	5.30
Protein	24.14±0.04	26.80
Total fats	40.18±0.10	27.00
Ash	4.35±0.03	3.80
Total carbs	28.21±0.06	37.10
Energy (kcal/100g)	571.00±0.99	499.00

4.3.2 Dietary Fiber

DF of CN was measured and presented in Table 5. No data on SDF and IDF of CS was found from the same study; therefore, no comparison was made for TDF and SDF. Only insoluble dietary fiber of CS was found and compared with CN. Total carbohydrates accounted for 28.21 g/100g, of which a considerable portion was dietary fiber (13.75 g/100g), predominantly insoluble fiber (12.59 g/100g). IDF in both oilseeds is comparable if we observe the IDF of CS, which is 12.02 g/100g.

Table 5 Dietary fiber of *Camelina Naheel* and *Camelina sativa* (CS values were from reference paper.)

Parameter	<i>Camelina Naheel</i>	<i>Camelina sativa</i> (Montero-Muñoz et al., 2023)
Total DF (g/100g)	13.75±0.16	-
Soluble DF (g/100g)	1.19±0.04	-
Insoluble DF (g/100g)	12.59±0.12	12.02

(-) indicates that no data was found in the literature.

4.3.3 Fatty Acid Composition

Fatty acid composition of CN was measured and presented in Table 6, and these values were compared with CS by taking reference values from previously published paper. According to Table 6, CN was found to have 6.72% palmitic acid and 3.26% stearic acids, which belong to saturated fatty acids. In CS, along with palmitic acid (6.10%) and stearic acid (2.80%), two additional fatty acids—arachidic acid (1.60%) and behenic acid 0.30%—were reported. In monounsaturated fatty acids (MUFA), CN had 0.59% palmitoleic acid, 20.34% oleic acid, and 1.57% eicosaenoic acid. In CS, five MUFA were reported: 0.10% palmitoleic acid, 17.70% oleic acid, 13.10% eicosaenoic acid, 2.30% erucic acid, and 0.60% nervonic acid. In polyunsaturated fatty acids (PUFA), CN had 19.42% linoleic acid, 15.24% g-linolenic acid, and 32.87% α -linolenic acid. In contrast, PUFA in CS contained 22.10% linoleic acid, 29.80% α -linolenic acid, 1.90% eicosadienoic, 1.10% eicosatrienoic, and 0.10% docosadienoic. Overall, CN had no trans fatty acids, no long-chain saturated fatty acids (C22-C24), and no erucic acid, whereas CS had a low amount (2.30%) of erucic acid. In CN, 32.87% total omega-3, 34.66% total omega-6, and 21.91% total omega-9 fatty acids were found. In comparison, CS contained 30.90% omega-3, 24.10% omega-6, and 33.70% omega-9 fatty acids. Lastly, total saturated fatty acids in CN were 9.98%, while CS contained 10.90% SFA, which is slightly higher than CN. Total MUFA were 22.50% in CNm whereas CS contained 33.80% MUFA, which is higher than CN. In contrast, total PUFA were 67.55% in CN, compared with 55% PUFA in CS, indicating a higher PUFA proportion in CN.

**Table 6** Fatty acid composition of *Camelina Naheel* and *Camelina sativa* (CS values were from reference paper)

Common Name	Symbol	Camelina Naheel (% of Total fatty acid)	<i>Camelina sativa</i> from ref paper (% of Total fatty acid) (Lopez et al., 2023)
Hexanoic (Caproic)	C 6:0	0.00	-
Octanoic (Caprylic)	C 8:0	0.00	-
Decanoic (Capric)	C 10:0	0.00	-
Dodecanoic (Lauric)	C 12: 0	0.00	-
Tetradecanoic (Myristic)	C 14: 0	0.00	0.1
cis-9-Tetradecenoic (Myristoleic)	C 14:1 n5	0.00	-
Hexadecanoic (Palmitic)	C 16:0	6.72	6.10
trans-9-Hexadecenoic (Palmitelaidic)	C 16:1 trans 9	0.00	-
cis-9-Hexadecenoic (Palmitoleic)	C 16:1 n7	0.59	0.10
Octadecanoic (Stearic)	C 18:0	3.26	2.80
trans-9-Octadecenoic (Elaidic)	C 18:1 n9 trans	0.00	-
trans-11-Octadecenoic (Vaccenic)	C 18:1 trans 11	0.00	-
cis-9-Octadecenoic (Oleic)	C 18:1 n9 cis	20.34	17.70
trans-9,12-Octadecadienoic (Linolenelaidic)	C 18:2 t9 t12	0.00	-
cis-9 trans-12-Octadecadienoic	C 18:2 c9 t12	0.00	-
trans-9 cis-12-Octadecadienoic	C 18:2 t9 c12	0.00	-
cis-9,12-Octadecadienoic (Linoleic)	C 18:2 n6 (c9 c12)	19.42	22.10
cis-6,9,12-Octadecatrienoic (g-Linolenic)	C 18:3 n6	15.24	0.00
cis-9,12,15-Octadecatrienoic (α -Linolenic)	C 18:3 n3	32.87	29.80
Icosanoic (Arachidic)	C 20:0	0.00	1.60
cis-11, -Eicosaenoic	C 20:1 n9	1.57	13.10
cis-11,14-Eicosadienoic	C 20:2 n6	0.00	1.90
cis-8,11,14-Eicosatrienoic	C 20:3 n6	0.00	-
cis-11,14,17-Eicosatrienoic	C 20:3 n3	0.00	1.10
cis-5,8,11,14-Eicosatetraenoic (Arachidonic)	C 20:4 n6	0.00	-
cis-5,8,11,14,17-Eicosapentaenoic	C 20:5 n3	0.00	-
Docosanoic (Behenic)	C 22:0	0.00	0.30
cis-13-Docosenoic (Erucic)	C 22:1 n9	0.00	2.30
cis-13,16-Docosadienoic	C 22:2 n6	0.00	0.10
cis-4,7,10,13,16,19-Docosahexaenoic	C 22:6 n3	0.00	-
Tetracosanoic (Lignoceric)	C 24:0	0.00	0.10
cis-15-Tetracosenoic (Nervonic)	C 24:1 n9	0.00	0.60
	Sum Trans-FA	0.00	0.00
	Total (Omega-3)	32.87	30.90
	Total (Omega-6)	34.66	24.10
	Total (Omega-9)	21.91	33.70
	Total SFA	9.98	10.90
	Total MUFA	22.50	33.80
	Total PUFA	67.55	55.00

(-) refers to no data was found from literature.

4.3.4 Antioxidant Capacity and Total Polyphenols

Antioxidant capacity and total polyphenol content of CN were measured and presented in Table 6, and these values were compared with CS by using reference values from previously published papers. According to Table 7, the FRAP assay value for CN was 1069.29 $\mu\text{mol TE}/100\text{g}$, which was lower than that of CS (6000 $\mu\text{mol TE}/100\text{g}$).

DPPH and ORAC assays of CN were found to be 7856.84 mmol TE/100g and 18157.91 $\mu\text{mol TE}/100\text{g}$, respectively, both of which were higher than the DPPH and ORAC values of CS, which were 175 mmol TE/100g and 350 $\mu\text{mol TE}/100\text{g}$, respectively. Total polyphenol content (TPC) in CN was found to be 392.52 mg GAE/100g, which was lower than that of CS (489 mg GAE/100g).

[322]



Table 7 Antioxidant capacity and total polyphenol content of *Camelina Naheel* and *Camelina sativa* (CS values were from reference paper.)

Parameter	<i>Camelina Naheel</i>	<i>Camelina sativa</i>
Antioxidant capacity (FRAP) ($\mu\text{mol TE}/100\text{g}$)	1069.29 \pm 55.23	6000 (Quezada & Cherian, 2012)
DPPH ($\text{mmol TE}/100\text{g}$)	7856.84 \pm 366.76	175
ORAC ($\mu\text{mol TE}/100\text{g}$)	18157.91 \pm 614.57	350
Total Polyphenol Contents ($\text{mg GAE}/100\text{g}$)	392.52 \pm 23.34	489 (Mierina et al., 2017)

5. Discussion

The color characteristics of CN indicate the presence of natural pigments. The seed's low lightness suggests a moderately dark surface, likely influenced by its seed coat composition and pigment density. The positive values of a^* and b^* point to red-yellow tones, attributable to carotenoids and phenolic compounds found in oilseeds. The vivid chroma value indicates a high intensity of these pigments, while the hue angle ($0^\circ = \text{red}$, $90^\circ = \text{yellow}$) was in the red-yellow region and more oriented toward the yellow region supported the prevalence of warm colors typical of carotenoid-rich plants (Abtahi et al., 2022). The browning index was very high and indicates the formation of brown pigments, potentially from non-enzymatic reactions or natural pigmentation. Overall, the color analysis reveals that CN has a highly pigmented seed profile, possibly related to its phytochemical composition and antioxidant potential (Abdelsalam & Fouda, 2023).

Physical properties are important to measure to know about the dimensions of oilseeds and to design the machinery, mechanical tools, and engineering processes accordingly. The results showed that CN oilseed has an oval or elongated geometry, indicating that the seed width is approximately half of its length and that the shape favors sliding behavior rather than rolling, and the compact size is reflected by the surface area value, which influences heat and mass transfer. Fouda et al. (2022) stated that these characteristics imply practical applications in industrial equipment, e.g., seed handling, conveying, and sieving operations, and oil extraction efficiency.

Functional qualities are critical performance aspects in food applications, impacting food texture and being governed by the formulation composition. The functional characteristics of CN imply efficient hydration, surface activity, and interfacial stability. Its high WHC indicates effective moisture retention and texture enhancement in food items, especially in baked products, through hydrogen bonding with water molecules and swelling behavior of protein matrices. Therefore, the functional profile of CN suggests a hydrophilic-dominant matrix contributing to high WHC (Joshi et al., 2015).

Low OHC indicates a preference for hydrophilic interactions over hydrophobic interactions. OHC of CN indicates limited lipid-binding ability, likely due to its compact protein structure and restricted exposure of hydrophobic sites capable of interacting with lipid molecules. This observation is consistent with previously reported ranges for different oilseeds, e.g., chia seeds, sesame seeds, and flaxseed, as reported by Miranda-Flores et al. (2025), confirming that the observed OHC falls within expected structural and compositional characteristics.

Low foaming capacity indicates limited air incorporation due to protein flexibility; however, the high foaming stability showed that the foam structure is durable once created. Zhang et al. (2023) confirmed that low FC can be enhanced by enzymatic hydrolysis while investigating for soybean protein. Both hydrophobic and hydrophilic residues were exposed because of partial proteolysis, which improved amphiphilic behavior and molecular flexibility. This structural alteration enhanced the proteins' foaming qualities by promoting improved interfacial adsorption and quicker diffusion of protein molecules to the air-water interface (Liang et al., 2020). Modest emulsifying ability and stable emulsions demonstrate CN's use as a functional component in semi-solid food systems.

The proximate composition of CN reflects a nutrient-dense profile with functional relevance. The low moisture content indicates good storage stability and reduced susceptibility to microbial spoilage. Its high total fat content explains its high energy value and potential for lipid-associated bioactives, while its high protein content supports its nutritional value and contribution to techno-functional qualities while ash content suggested a substantial mineral fraction. CN is appropriate for high-fiber and energy-rich food

[323]



formulations because dietary fiber supports bulking functionality and provides benefits for gastrointestinal health.

Fatty acid composition of CN showed favorable results, having low amount of SFA, which tends to increase the low-density lipoprotein (LDL) cholesterol and may cause inflammation and insulin resistance. In contrast, unsaturated fatty acids were high in CN, especially omega-3 and omega-6, while a considerable amount of omega-9 was also present. These fatty acids are associated not only with lowering LDL but also maintaining or increasing high-density lipoprotein (HDL), enhancing insulin resistance, exhibiting anti-inflammatory properties, and supporting cell membrane integrity. Omega-3 and omega-6 levels were high, and they play an important role in reducing triglyceride levels, supporting cardiovascular and metabolic health, and can therefore be used in the formulation of functional foods rich in unsaturated fatty acids.

Therefore, any oilseed that has a low amount of SFA and high unsaturated fatty acids can be utilized for food purposes (Czerwonka & Białek, 2023; Garbacz et al., 2023) and non-food applications (Delver & Smith, 2024; Riaz et al., 2022) as reported by different authors in various applications. A major nutritional and regulatory benefit of CN oil was its total lack of trans fatty acids and erucic acid, which increased its acceptability for human consumption, functional meals, and medicinal nutrition products. In research on animals, erucic acid is linked to myocardial lipidosis (fat deposits in heart muscle) and possible cardiac damage at high consumption levels but its cardiac adverse effects have not been confirmed in humans. Experimental studies by Ishinaga et al. (1982) indicated that erucic acid may interfere with cardiac phosphatidylcholine turnover and accumulate in heart tissue.

According to EFSA, a tolerable daily intake (TDI) for erucic acid was established at 7 mg/kg body weight per day (Galanty et al., 2023). CN usage as a heart-friendly functional oil is supported by the absence of very long-chain saturated fatty acids, which also improves nutritional safety and cardiovascular safety. Higher antioxidant activity is indicated by elevated FRAP, DPPH, and ORAC values, demonstrating the sample's capacity to counteract oxidative stress. FRAP and DPPH work via a single electron transfer (SET) mechanism, while ORAC works via the hydrogen atom transfer (HAT) mechanism.

CN showed higher antioxidant capacity in all three assays particularly ORAC. ORAC assesses hydrogen atom transfer (HAT)-based peroxyl radical scavenging, which is especially useful in lipid systems. Gill et al. (2024) reported 110 mg/100g of tocopherols in same CN used in this study. Tocopherols are lipid-soluble, chain-breaking antioxidants that act via the HAT mechanism, which likely contributed to the high ORAC antioxidant capacity observed (Skroza et al., 2022). In contrast, DPPH and FRAP tests focus on SET, which may underestimate lipophilic antioxidants and some bound phenolic chemicals found in CN. This showed that CN had a high lipid-phase antioxidant potential by showing superior quenching of peroxyl radicals. Previously published research showed that plant oilseeds are rich in natural antioxidants and can act as neuroprotectants, anti-inflammatory agents, and anti-cancer agents (Sławińska & Olas, 2025; Subrahmaniyan et al., 2024).

Although CN showed low polyphenol contents than CS but irrespective of this comparison, polyphenols in CN was still good enough to justify the high antioxidant capacity because high antioxidant capacity is attributed towards the presence of high polyphenol contents which can donate electrons or hydrogen, stabilize pro-oxidant metal ions and free radicals. As a result, CN's natural antioxidants may also contribute to the oil's increased storage stability. The structural diversity of polyphenols enhances their synergistic effects, underscoring the material's prospective use as a functional ingredient for health benefits related to oxidative stress (Amoah et al., 2025).

6. Conclusion

The outcomes of the study revealed that CN is an oilseed with good functional properties and a nutritionally rich profile, providing a good source of protein (24 g/100g) and most importantly, a favorable fatty acid composition comparable to many existing oilseed crops. Fatty acid composition revealed that CN is abundant in unsaturated fatty acids, especially in omega-3 (32.87%) and omega-6 (34.66%), and low in SFA (9.98%). Apart from this, overall CN also showed higher antioxidant activity in all three assays.



However, when compared with CS, the FRAP assay showed a significantly lower value than the CS reference. Total Polyphenols (392.52 mg GAE/100g) in CN were comparatively lower than CS reference.

Overall, CN showed higher ash content, omega-3 and omega-6 levels, lower SFA, higher PUFA, and higher DPPH and ORAC values as compared to CS. All the objectives of the study were fulfilled, and it can be suggested that CN is a valuable addition to the food system and can be grown commercially in future across the world to minimize the burden on other crops and contribute to SDGs, and its applications can be explored in food product development as a functional ingredient.

7. Acknowledgements

The authors acknowledge the Food Science for Nutrition program of Institute of Nutrition, Mahidol University, for providing research facilities and technical support throughout the study.

8. Conflict of interest

None

9. Data Availability

Data will be available on request.

10. Funding

Funding for this project was obtained from the Faculty of Graduate Studies, Mahidol University, Associate Prof. Dr. Aikkarach Kettawan (project supervisor), and the Institute of Nutrition, Mahidol University.

11. References

- Abdelsalam, A., & Fouda, T. (2023). Determination of color properties of some seeds. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 23(1), 15-20.
- Abtahi, M., Mirlohi, A., Sharif-Moghaddam, N., & Ataii, E. (2022). Revealing seed color variation and their possible association with yield and quality traits in a diversity panel of flax (*Linum Usitatissimum* L.). *Frontiers in Plant Science*, 13, Article 1038079. <https://doi.org/10.3389/fpls.2022.1038079>
- Amoah, I., Attakora, R., Arthur, M., Lombardo, M., Osei, E. O., Mohammed, A. Z., Adadi, P., Adukonu, E. K., Solomon, D., & Ackom, R. (2025). Sub-Saharan African oilseeds as functional ingredients: Nutritional profiles, bioactivities, and strategies for enhanced utilization in food and pharmaceutical systems. *Journal of Food Biochemistry*, 2025(1), Article 4087414. <https://doi.org/10.1155/jfbc/4087414>
- Bătrîna, Ș. L., Jurcoane, Ș., Popescu, I., Marin, F., Imbrea, I. M., Crista, F., Pop, G., & Imbrea, F. (2020). Camelina sativa: A study on amino acid content. *Romanian Biotechnological Letters*, 25(1), 1136-1142. <https://doi.org/10.25083/rbl/25.1/1136.1142>
- Budin, J. T., Breene, W. M., & Putnam, D. H. (1995). Some compositional properties of camelina (*Camelina sativa* L. Crantz) seeds and oils. *Journal of the American Oil Chemists' Society*, 72(3), 309-315. <https://doi.org/10.1007/BF02541088>
- Busari, R., & Olaoye, J. (2016). Selected physical properties of African pear seed for considering in design of mechanical expeller. *ARPN Journal of Engineering and Applied Sciences*, 11(8), 5463-5468.
- Czerwonka, M., & Białek, A. (2023). Fatty acid composition of pseudocereals and seeds used as functional food ingredients. *Life*, 13(1), Article 217. <https://doi.org/10.3390/life13010217>
- Delver, J. J., & Smith, Z. K. (2024). Opportunities for Camelina meal as a livestock feed ingredient. *Agriculture*, 14(1), Article 116. <https://doi.org/10.3390/agriculture14010116>
- Fouda, T., Abdelsalam, A., Swilam, A., & Didamony, M. E. (2022). Determination of physical properties of some seeds. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 22(3), 223-238.



- Fraser, J., Collins, S., Chen, Z., Tibbetts, S., Lall, S., & Anderson, D. (2017). Effects of dietary *Camelina sativa* products on digestible nutrient compositions for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition*, 23(5), 973-982. <https://doi.org/10.1111/anu.12465>
- Garbacz, K., Wawrzykowski, J., Czelej, M., Czernecki, T., & Waśko, A. (2023). Recent trends in the application of oilseed-derived protein hydrolysates as functional foods. *Foods*, 12(20), Article 3861. <https://doi.org/10.3390/foods12203861>
- Galanty, A., Grudzińska, M., Paździora, W., & Paśko, P. (2023). Erucic acid—both sides of the story: A concise review on its beneficial and toxic properties. *Molecules*, 28(4), Article 1924. <https://doi.org/10.3390/molecules28041924>
- Gao, G., Zhang, L., Tong, P., Yan, G., & Wu, X. (2025). Enhancing oil content in oilseed crops: Genetic insights, molecular mechanisms, and breeding approaches. *International Journal of Molecular Sciences*, 26(15), Article 7390. <https://doi.org/10.3390/ijms26157390>
- Gill, A. N., Athar, M. H., Khan, Q. A. T., & Waqar, M. (2024). *Camelina Naheel*: Development of climate resilient camelina cultivar enriched with omega-3 and vitamin e. *European Chemical Bulletin*, 13(06), 475-482. <https://doi.org/10.53555/ecb.v13:i6.17770>
- Horn, P. J., & Benning, C. (2016). The plant lipidome in human and environmental health. *Science*, 353(6305), 1228-1232. <https://doi.org/10.1126/science.aaf6206>
- Hulbert, S. H., Guy, S., Pan, W., Paulitz, T., Schillinger, W., Sowers, K., & Wysocki, D. (2012). *Camelina production in the dryland Pacific Northwest*. Washington State University Extension Pullman.
- Ishinaga, M., Sato, J., Kitagawa, Y., Sugimoto, E., & Kito, M. (1982). Perturbation of phospholipid metabolism by erucic acid in male Sprague-Dawley rat heart. *The Journal of Biochemistry*, 92(1), 253-263. <https://doi.org/10.1093/oxfordjournals.jbchem.a133921>
- Joshi, A. U., Liu, C., & Sathe, S. K. (2015). Functional properties of select seed flours. *LWT-Food Science and Technology*, 60(1), 325-331. <https://doi.org/10.1016/j.lwt.2014.08.038>
- Liang, G., Chen, W., Qie, X., Zeng, M., Qin, F., He, Z., & Chen, J. (2020). Modification of soy protein isolates using combined pre-heat treatment and controlled enzymatic hydrolysis for improving foaming properties. *Food Hydrocolloids*, 105, Article 105764. <https://doi.org/10.1016/j.foodhyd.2020.105764>
- Lopez, C., Sotin, H., Rabesona, H., Novales, B., Le Quéré, J.-M., Froissard, M., Faure, J.-D., Guyot, S., & Anton, M. (2023). Oil bodies from chia (*Salvia hispanica* L.) and camelina (*Camelina sativa* L.) seeds for innovative food applications: Microstructure, composition and physical stability. *Foods*, 12(1), Article 211. <https://doi.org/10.3390/foods12010211>
- Medhe, S. V., Kettawan, A. K., Kamble, M. T., Monboonpitak, N., Thompson, K. D., Kettawan, A., & Pirarat, N. (2023). Modification of physiochemical and techno-functional properties of stink bean (*Parkia speciosa*) by germination and hydrothermal cooking treatment. *Foods*, 12(24), Article 4480. <https://doi.org/10.3390/foods12244480>
- Mieriņa, I., Adere, L., Krasauska, K., Zoltnere, E., Dārta, Z. S., & Jure, M. (2017). Antioxidant properties of *Camelina sativa* oil and press-cakes. In *Proceedings of the Latvian Academy of Sciences* (Vol. 71, No. 6, p. 515). De Gruyter Poland. <https://doi.org/10.1515/prolas-2017-0089>
- Miranda-Flores, D., Castañeta, G., Loayza, E., & Peñarrieta, J. M. (2025). Assessment of functional and nutritional characteristics in Bolivians oilseed varieties. *Revista Boliviana de Química*, 42(2), 133-144. <https://doi.org/10.53287/kxwh6996bb57e>
- Montero-Muñoz, I., Mostaza-Colado, D., Capuano, A., & Mauri Ablanque, P. V. (2023). Seed and straw characterization of nine new varieties of *Camelina sativa* (L.) Crantz. *Land*, 12(2), Article 328. <https://doi.org/10.3390/land12020328>
- Nourzad, S., Naghdi Badi, H., Kalateh Jari, S., Mehrafarin, A., & Saeidi-Sar, S. (2024). Investigation of the qualitative and appearance characteristics of *Eryngium caeruleum* L. based on colorimetric and browning indices in storage conditions. *Food Science & Nutrition*, 12(9), 6690-6698. <https://doi.org/10.1002/fsn3.4243>



- Plaitho, Y., Kettawan, A., Sriprapai, H., Kettawan, A. K., & Kooprasertying, P. (2024). Antioxidant and anti-inflammatory activities of the extract and bioaccessible fraction of mango peel in muffins. *Food Technology and Biotechnology*, 62(2), 242-253. <https://doi.org/10.17113/ftb.62.02.24.8258>
- Quezada, N., & Cherian, G. (2012). Lipid characterization and antioxidant status of the seeds and meals of *Camelina sativa* and flax. *European Journal of Lipid Science and Technology*, 114(8), 974-982. <https://doi.org/10.1002/ejlt.201100298>
- Riaz, R., Ahmed, I., Sizmaz, O., & Ahsan, U. (2022). Use of *Camelina sativa* and by-products in diets for dairy cows: A Review. *Animals*, 12(9), Article 1082. <https://doi.org/10.3390/ani12091082>
- Skroza, D., Šimat, V., Vrdoljak, L., Jolić, N., Skelin, A., Čagalj, M., ... & Generalić Mekinić, I. (2022). Investigation of antioxidant synergisms and antagonisms among phenolic acids in the model matrices using FRAP and ORAC methods. *Antioxidants*, 11(9), Article 1784. <https://doi.org/10.3390/antiox11091784>
- Sławińska, N., & Olas, B. (2025). Effect of thermal processing on the antioxidant activity of oilseeds used in bakery products: A systematic review. *Industrial Crops and Products*, 233, Article 121459. <https://doi.org/10.1016/j.indcrop.2025.121459>
- Stamenković, O. S., Gautam, K., Singla-Pareek, S. L., Dhankher, O. P., Djalović, I. G., Kostić, M. D., Mitrović, P. M., Pareek, A., & Veljković, V. B. (2023). Biodiesel production from camelina oil: Present status and future perspectives. *Food and Energy Security*, 12(1), Article e340. <https://doi.org/10.1002/fes3.340>
- Subrahmaniyan, K., Veeramani, P., Mahalingam, A., Ranjith, R., Harishma, P. H., & Abarajitha, P. (2024). A comprehensive review on nutritional and antioxidant properties of Sesame (*Sesamum indicum* L.) seed oil with its therapeutic utilization as phytomedicine. *Annals of Phytomedicine*, 13(2), 273-281. <http://doi.org/10.54085/ap.2024.13.2.26>
- Sydor, M., Kurasiak-Popowska, D., Stuper-Szablewska, K., & Rogoziński, T. (2022). *Camelina sativa*. Status quo and future perspectives. *Industrial Crops and Products*, 187, Article 115531. <https://doi.org/10.1016/j.indcrop.2022.115531>
- Techaniyom, P., Korsirikoon, C., Rungruang, T., Pakaprot, N., Prombutara, P., Mukda, S., Kettawan, A. K., & Kettawan, A. (2024). Cold-pressed perilla seed oil: Investigating its protective influence on the gut-brain axis in mice with rotenone-induced Parkinson's disease. *Food Science & Nutrition*, 12(9), 6259-6283. <https://doi.org/10.1002/fsn3.4265>
- Zhang, M., Wang, O., Cai, S., Zhao, L., & Zhao, L. (2023). Composition, functional properties, health benefits and applications of oilseed proteins: A systematic review. *Food Research International*, 171, Article 113061. <https://doi.org/10.1016/j.foodres.2023.113061>
- Zielińska, E. (2022). Evaluating the functional characteristics of certain insect flours (non-defatted/defatted flour) and their protein preparations. *Molecules*, 27(19), Article 6339. <https://doi.org/10.3390/molecules27196339>