Research Article

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# Microwave-accelerated pretreatment technique in green extraction of oil and bioactive compounds from camelina seeds: Effectiveness and characterization

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**Abstract:** The effect of microwave pretreatment and moisture levels of *Camelina sativa* seeds on the quality of extracted oil by cold press was investigated. The seed moistures were adjusted to 2.5%, 5.0%, 7.5%, and 10.0% and pretreated with microwaves for 0, 1, 2, and 3 min. Microwave pretreatment (3 min) of the seeds with 2.5% moisture increased the oil extraction yield by ~11% compared to the control sample. The highest amount of acidity (0.564 g FFA·$g^{-1}$ oil), peroxide value (2.4 meq $O_2$·$kg^{-1}$ oil), carotenoid (5.26 mg·$kg^{-1}$ oil), and browning index (0.710) were found in the oil extracted from seeds with 10% moisture and 3 min microwave pretreatment. The total phenolic compound was increased by microwave pretreatment but was mitigated by the seed moisture content, and the highest amount (208.24 mg caffeic acid·100 $g^{-1}$ oil) was observed at 3 min microwave pretreatment of the seeds with 2.5% moisture. Chlorophyll content decreased by both microwave pretreatment and seed moisture content in camelina oil. Generally, the fatty acid composition of the extracted oils was not affected by the seed pretreatments. In conclusion, pretreatment of the camelina seeds before oil extraction is suggested to obtain a high oil extraction yield with a good quality oil.

**Keywords:** bioactive compounds, camelina seed, extraction yield, green oil extraction, microwave pretreatment

## 1 Introduction

Camelina (*Camelina sativa* [L.] Crtz.) belongs to the Brassicaceae family and is considered an ancient oilseed crop. It is native to Western Asia/Eastern Europe, but it has not been fully exploited [1]. It is known as a weed in many countries under different names such as false flax, gold of pleasure, and Dutch flax [2]. Camelina has several favorable agronomic properties including adaptation to various environmental conditions, the ability to grow in poor lands, and higher tolerance to weeds, pests, and diseases (compared to the other Brassicaceae), which make it an ideal oilseed crop [3–5]. The oil content of the camelina seed ranges from 30% to 49% [1]. Camelina oil has several features including a high level of polyunsaturated alpha-linolenic acid (30–43%), lower content of erucic acid (≤3%), 11–19% of eicosenoic acid, and less than 10% of saturated fatty acids (FAs), which distinguish it from other Brassicaceae oils [1,5]. Thus, camelina oil has a high potential for use in human and animal nutrition.

Oil extraction from oilseeds is conventionally performed by solvent extraction and pressing. The solvent extraction method is mostly used for seeds with low oil content (less than 20%), such as soybean [6], while pressing is applied to seeds with a high oil content such as rapeseed, sunflower, cottonseed, and sesame. Mechanical pressing is considered an easy, safe, and cost-effective method, but the oil recovery rate is low in this method [6,7]. In comparison

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to the mechanical pressing method, solvent extraction is more efficient with less oil residue in the cake. However, there are several concerns regarding its application in terms of human health, safety, and environmental pollution [7].

Mechanical pressing can be conducted by cold press (under 50°C) or hot press (80–105°C) conditions [8]. Generally, cold pressing sustains the natural compounds of the oil and the extracted oil does not need any refining. Thus, there is a high demand for cold-pressed oils in the markets. However, its oil extraction yield is lower than that of hot pressing. On the other hand, oil extracted with solvent and hot pressing has to be refined and, therefore, it has lower quality compared to the oil extracted by cold press. Therefore, there is a great necessity to employ novel pretreatments, rather than high-temperature treatment of the seeds, prior to cold pressing, to improve the oil extraction yield. Other reasons for using the cold press include the following: (1) it can be used in low capacities, i.e., less than 10 tons·day$^{-1}$. (2) Press extraction in low capacities requires a low investment cost compared to solvent extraction. (3) In remote areas, the cost of transportation can compensate for the high cost of the process and the low yield of oil in press extraction.

During the last two decades, new procedures such as microwave pretreatment of the seeds, to ameliorate oil extraction efficiency, have attracted much attention by the industry [9]. Microwave pretreatment is not only convenient and efficient but also is a time and energy-saver method with high-quality oil yield, which does not require the application of any chemicals and solvents [10]. The advantageous effects of microwave pretreatment on increasing the oil extraction yield, physicochemical features, as well as nutritional value have been proven [11]. A large body of evidence indicated that microwave pretreatment enhanced the oil extraction yield in various oilseeds such as rapeseed [6], black seed [12], chia seed [13], hazelnuts [9], and cotton seed [14]. When rapeseed seeds having 9% moisture content were pretreated with microwave for 3 min, up to 19% enhancement in oil extraction yield was obtained [15]. Regarding the physicochemical features of the oil, microwave pretreatment (for 10 min), increased the peroxide value of the rapeseed oil by around two-fold [16]. Furthermore, the acid value of the oil extracted from microwave-treated black seeds decreased by 1.82 mg KOH·g$^{-1}$, contrary to hazelnuts that exhibited 0.27 mg KOH·g$^{-1}$ enhancement [9,12].

In addition, microwave pretreatment reinforced the release of valuable nutraceuticals and desirable oil compounds as reported in pumpkin seeds [17], *Nigella sativa* [18], flaxseed [10], rapeseed [19,20], cashew nut [21], walnut [22], sunflower seed [23], black cumin seeds [24], milk thistle [25], and apricot kernel [26].

Despite several studies on oilseed crops, the utilization of new approaches to improve the oil extraction yield in camelina is poorly investigated. In the present work, the effect of microwave pretreatment and seed moisture levels on oil extraction efficiency and bioactive compounds of camelina oil was studied.

# 2 Materials and methods

## 2.1 Seed samples and microwave pretreatment

Camelina seeds were obtained from the Danesh Bonyan Bistun Shafa company (Kermanshah, Iran). For each microwave pretreatment, 500 g of the camelina seeds were used. The seeds were dried in an oven to remove the initial moisture. Then, 2.5%, 5.0%, 7.5%, and 10.0% water were added to the seed samples and then the moisturized seeds were stored in insulated dishes for moisture equilibration and distribution in the whole of the sample for 24 h at 4°C before microwave pretreatment. Then, seed samples were irradiated with a microwave (at 900 W) for 0, 1, 2, and 3 min according to the previously published methods [12,20]. For each microwave pretreatment, 500 g of camelina seeds was placed in four Pyrex Petri dishes inside a microwave. A non-irradiated sample (0 min) was used as a control sample. Each microwave treatment was done with three independent replicates.

## 2.2 Oil extraction by pressing

In order to determine the oil extraction yield, the amount of extracted oil by press was measured compared to the seed weight. Oil was extracted from the control and microwave-treated seeds by pressing with the screw pressing (Screw Press Model 85 mm, Kern Kraft, Wetro Gmbh, Aschaffenburg, Germany). The oil extraction efficiency was calculated as [24]:

$$\text{Oil extraction yield} = \frac{\text{Extracted oil by press (g)}}{\text{Seed weight (g)}} \times 100 \quad (1)$$

## 2.3 Acidity

The oil acidity was measured following the method stated earlier [27]. Briefly, 5 g of the extracted oil was weighed ($W$) and dissolved in 50 mL of ethanol/chloroform mixture (25:25) in the Erlenmeyer flask. Then, 3–4 drops of phenolphthalein

solution were added followed by the addition of 0.01 N NaOH reagent ($V$) until achieving a stable pink color of the final solution. The result was determined according to Eq. 2:

$$\text{free fatty acid \%(oleic acid 100 g}^{-1}\text{ sample)} = \left(\frac{282 \times N \times V}{100 \times W}\right) \times 100 \quad (2)$$

## 2.4 Peroxide value

The peroxide value was determined according to the method described by AOCS [27]. About 5 g of the extracted oil was mixed well with 30 mL of acetic acid/chloroform mixture (3:2 v/v). Then, 0.5 mL of saturated potassium iodide was added and the mixture was incubated in the dark for 1 min. Then, 30 mL of distilled water and 0.5 mL of starch solution were added. Afterward, 0.01 N sodium thiosulfate was added to the mixture and mixed vigorously until a change in the final solution to yellow color was observed. The peroxide value was calculated as

$$\text{peroxide value} = \left(\frac{(a - b) \times N \times 1{,}000}{P}\right) \quad (3)$$

where $a$ is the amount of sodium thiosulfate used for the sample (mL), $b$ is the amount of sodium thiosulfate used for the control sample (mL), and $P$ is the sample weight (g).

## 2.5 Fatty acid composition

Fatty acid methyl esters (FAMEs) were prepared by transesterification of oil samples using methanolic potassium hydroxide [28]. Then, FAMEs were analyzed by gas chromatography, equipped with a BPX70 capillary column (50 m × 0.22 mm, 0.25 µm film; Agilent Technologies), a flame ionization detector, and a split/splitless injector, helium was used as a carrier gas, and nitrogen as a make-up gas. The temperatures of the detector and injector were 230°C and 250°C, respectively. The oven temperature was maintained at 158°C for 5 min and then increased to 220°C at a rate of 2 °C·min$^{-1}$ [29]. FAMEs were identified by comparing their retention time with the corresponding standards. The integration software was used to calculate the peak areas and percentages of the individual FA.

## 2.6 Chlorophyll content

The amount of chlorophyll in edible oils was measured with a UV–Vis spectrophotometer [30]. The absorption of the oil sample was measured with a spectrophotometer at three wavelengths of 630, 670, and 710 nm, and then, it was calculated using Eq. 4:

$$C = \frac{345.3 \times (A_{670} - 0.5 \times A_{630} - 0.5 \times A_{710})}{L} \quad (4)$$

where $C$ is the content of the chlorophyll pigment (mg pheophytin·kg$^{-1}$ oil), $A$ is the absorption at the given wavelengths, and $L$ is the cell thickness of the spectrophotometer (mm).

## 2.7 Carotenoid content

In brief, 3 g of the extracted oil was weighed in a volumetric balloon and brought to a volume of 10 mL with cyclohexane. The absorption of oil samples was measured with a spectrophotometer at a wavelength of 470 nm [30]. The carotenoid content was calculated using Eq. 5:

$$C = \frac{A_{470} \times 10^6}{2{,}000 \times 100 \times d} \quad (5)$$

where $d$ is the cell thickness of the spectrophotometer.

## 2.8 Browning index (BI)

The BI of the microwave pretreatment for oil extraction was measured as previously described [18,30]. The extracted oil was dissolved in chloroform (1.2 w/v), and the absorbance was measured at 420 nm using a UV–Vis spectrophotometer to represent the non-enzymatic BI of oils.

## 2.9 Total phenolic compound content

About 2.5 mL of *n*-hexane was added to 2.5 g of oil and mixed by vortexing for 1 min. Afterward, 2.5 mL of methanol/water (80:20 v/v) was added and centrifuged at 5,000 rpm for 5 min. The aqueous phase was collected with a syringe and transferred to a 50 mL volumetric balloon.

The extraction from oil residues was repeated twice with the same solution and the obtained aqueous phases were combined and then smoothed. Then, 2.5 mL of Folin–Ciocalteu reagent was added and the mixture was incubated for 3 min. Eventually, 5 mL of saturated sodium carbonate was added to the aqueous phase and the mixture volume was adjusted to 50 mL with distilled water. The mixture was incubated for 1 h in the dark at room temperature, and its absorption was measured at 725 nm against the control sample [31]:

$$P = \frac{Y}{W} \times 1{,}000 \quad (6)$$

$$Y = 1.0071 \times x - 0.1612 \quad (7)$$

where $Y$ is the amount of phenolic compounds ($mg \cdot mL^{-1}$), $W$ is the weight of the oil sample, $P$ is the amount of phenolic compound ($mg \cdot kg^{-1}$), and $x$ is the absorption at a wavelength of 725 nm.

### 2.10 Statistical analysis

Each experiment was performed in triplicate, and the results are expressed as the mean value of replications ± standard deviation. Data analysis was conducted by one-way analysis of variance (ANOVA) using SPSS software 20.0 (SPSS Inc., Chicago, IL USA). The difference between the mean values was determined by Duncan's test ($P \leq 0.05$).

## 3 Results and discussion

### 3.1 Effect of microwave pretreatment on the oil extraction yield

Microwave pretreatment improved the oil extraction yield in camelina seeds (Table 1). At constant moisture levels, with increasing the duration of exposure to microwave radiation, the amount of oil extracted from camelina seeds increased, which is ascribed to the enhancement in rupture of cell membranes and permanent pores. Moreover, in all the microwave pretreatments, with decreasing the initial moisture of the seeds, the amount of extracted oil increased. Overall, the results showed that the best conditions to reach the high oil extraction yield were microwave pretreatment for 3 min and 2.5% seed moisture. Camelina oil is a rich source of alpha-linolenic acid (ALA, 18:3n-3) and low unsaturated fatty acid. Pretreatment for more than 3 min caused smoking of the seeds; therefore, to preserve bioactive compounds and not require purification, pretreatment was done for <3 min. The results of our experiment are consistent with the findings of other studies in which microwave pretreatment improved the oil extraction efficiency in rapeseed, black cumin seeds, Chilean hazelnuts, *Moringa oleifera*, and canola [9,20,24,32,33]. The yield of cold pressed-extracted oil was increased (from 39% to 54%) when rapeseed with 10.5% moisture pre-treated for 2–10 min by microwave [34]. Moreover, exposure to microwave irradiation for 3.5 min ameliorated the solvent-extracted oil efficiency by about 33% in cottonseed [14]. Microwave-induced amino acid denaturation leads to lipoprotein cell membrane loss, which in turn boosts the oil transport from the cell membrane and consequently increases the oil extraction efficiency [9,32,33].

**Table 1:** Oil extraction yield (%) from microwave-pretreated camelina seeds with different moisture levels

| Seed moisture (%) | Microwave time (min) | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| 2.5 | $27.6^{de*}$ | $31.2^{c}$ | $35.5^{b}$ | $38.4^{a}$ |
| 5.0 | $25^{e}$ | $28.6^{d}$ | $32.6^{c}$ | $35.8^{b}$ |
| 7.5 | $18^{i}$ | $21.6^{f}$ | $26^{e}$ | $29.6^{d}$ |
| 10.0 | $11.6^{k}$ | $15^{j}$ | $19.2^{h}$ | $22.4^{f}$ |

*Different letters indicate a significant difference in the 5% probability level.

### 3.2 Acidity

The results showed that the microwave pretreatment had a significant effect ($P < 0.05$) on the acidity of the seed oil. At all moisture levels, increasing the duration of exposure to microwave radiation enhanced the acidity (Table 2). Similarly, the initial moisture content of the seeds positively affects the acidity and the highest acidity value was observed at 10% moisture level. Acidity value is considered as an index of the free FA content in oil and can be used for estimation of oil freshness. Similar to our results, in peanut oil extracted after 5 min of microwave treatment, the acid value was significantly increased [35]. As the microwave pretreatment enhanced free FA content [36], the increased acidity value by microwave pretreatment in camelina oil can be attributed to the triacylglycerol hydrolysis [9,23,37]. The higher limit for acid value in the Codex Alimentarius standard for cold press vegetable oil is 4 mg $KOH \cdot g^{-1}$ oil, which shows that all the extracted oil samples have acidity at acceptable levels (Table 2).

### 3.3 Peroxide values

As shown in Table 3, at constant humidity levels, the oil peroxide extracted from camelina seeds is increased by increasing the duration of microwave exposure. A similar trend was also observed at constant microwave radiation levels so that the peroxide value was increased by

**Table 2:** Acidity (g FFA/g oil) of oil extracted from microwave-pretreated camelina seeds with different moisture levels

| Seed moisture (%) | Microwave time (min) | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| 2.5 | $0.169^{g*} \pm 0.02$ | $0.214^{gf} \pm 0.02$ | $0.282^{defg} \pm 0.02$ | $0.451^{abcd} \pm 0.02$ |
| 5.0 | $0.169^{g} \pm 0.02$ | $0.225^{gf} \pm 0.02$ | $0.293^{cdefg} \pm 0.02$ | $0.479^{abc} \pm 0.02$ |
| 7.5 | $0.174^{gf} \pm 0.02$ | $0.338^{bcdefg} \pm 0.02$ | $0.338^{bcdefg} \pm 0.02$ | $0.507^{ab} \pm 0.02$ |
| 10.0 | $0.180^{gf} \pm 0.02$ | $0.366^{bcdef} \pm 0.02$ | $0.406^{abcde} \pm 0.02$ | $0.564^{a} \pm 0.02$ |

*Different letters indicate a significant difference in the 5% probability level.

**Table 3:** Effect of pretreatments on peroxide values (meq $O_2 \cdot kg^{-1}$ oil) of the extracted camelina oil

| Seed moisture (%) | Microwave time (min) | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| 2.5 | $0.2^{k*} \pm 0.1$ | $1.0^{h} \pm 0.1$ | $1.6^{e} \pm 0.1$ | $2.0^{c} \pm 0.1$ |
| 5.0 | $0.2^{k} \pm 0.1$ | $1.2^{g} \pm 0.1$ | $1.8^{d} \pm 0.1$ | $2.0^{c} \pm 0.1$ |
| 7.5 | $0.4^{j} \pm 0.1$ | $1.4^{f} \pm 0.1$ | $2.0^{c} \pm 0.1$ | $2.2^{b} \pm 0.1$ |
| 10.0 | $0.6^{i} \pm 0.1$ | $1.4^{f} \pm 0.1$ | $2.0^{c} \pm 0.1$ | $2.4^{a} \pm 0.1$ |

*Different letters indicate a significant difference in the 5% probability level.

increasing the moisture levels of the seeds. In oil samples extracted from camelina seeds, the highest amount of peroxide was obtained at a 10% moisture level and 3 min exposure to microwave irradiation, while the lowest one was observed at a 10% moisture level without exposure to microwave irradiation (0 min).

The peroxide value represents the oxidation states of the oil. The findings of this study are in good agreement with the results of the previous studies in which the black cumin oil extracted from microwave-treated seeds exhibited an upward trend in peroxide number [24,38]. Furthermore, the results of this study are consistent with the research conducted on sunflower, Chilean hazelnuts, and rapeseed oils [9,23,34]. The higher limit for peroxide value in the Codex Alimentarius standard for cold press vegetable oil is 15 (meq $O_2 \cdot kg^{-1}$ oil), which shows that all the extracted oil samples have acceptable levels of PV (Table 3).

## 3.4 Fatty acid composition

Table 4 shows the effect of pretreatments on the FA composition of camelina oil. The FA composition of camelina is close to that of rapeseed oil. Camelina seed oil is

**Table 4:** Effect of pretreatments on fatty acid composition (%) of the extracted camelina oil

| Microwave time (min) | Seed moisture (%) | C16:0 | C18:0 | C18:1 | C18:2 | C18:3 | C20:1 |
|---|---|---|---|---|---|---|---|
| 0 | 2.5 | $6.01^{d*}$ | $3.5^{d}$ | $20.1^{f}$ | $18.3^{a}$ | $30.7^{a}$ | $12.8^{a}$ |
| | 5 | $6.0^{d}$ | $3.4^{d}$ | $20.0^{f}$ | $18.1^{ab}$ | $30.3^{a}$ | $12.7^{ab}$ |
| | 7.5 | $6.2^{d}$ | $3.5^{d}$ | $20.2^{f}$ | $18.2^{a}$ | $30.9^{a}$ | $12.8^{a}$ |
| | 10 | $6.2^{d}$ | $3.4^{d}$ | $20.4^{f}$ | $18.5^{a}$ | $31.0^{a}$ | $13.0^{a}$ |
| 1 | 2.5 | $6.1^{d}$ | $3.3^{d}$ | $20.7^{ef}$ | $18.1^{ab}$ | $30.4^{a}$ | $13.0^{a}$ |
| | 5 | $6.1^{d}$ | $3.5^{d}$ | $22.0^{de}$ | $17.2^{c}$ | $29.0^{b}$ | $12.8^{a}$ |
| | 7.5 | $6.5^{c}$ | $3.7^{cd}$ | $22.1^{de}$ | $17.5^{bc}$ | $28.2^{bc}$ | $12.4^{b}$ |
| | 10 | $6.1^{d}$ | $3.0^{e}$ | $21.5^{e}$ | $17.9^{b}$ | $28.7^{b}$ | $12.5^{b}$ |
| 2 | 2.5 | $6.5^{c}$ | $3.5^{d}$ | $22.1^{de}$ | $16.8^{cd}$ | $27.7^{d}$ | $12.7^{ab}$ |
| | 5 | $6.5^{c}$ | $3.7^{cd}$ | $22.4^{d}$ | $16.3^{de}$ | $28.0^{c}$ | $12.5^{b}$ |
| | 7.5 | $6.4^{c}$ | $3.8^{c}$ | $22.0^{de}$ | $16.5^{d}$ | $27.9^{cd}$ | $12.6^{ab}$ |
| | 10 | $6.7^{bc}$ | $3.6^{cd}$ | $23.5^{cd}$ | $16.4^{d}$ | $27.4^{d}$ | $12.8^{a}$ |
| 3 | 2.5 | $7.4^{b}$ | $4.2^{ab}$ | $24.0^{c}$ | $17.0^{c}$ | $25.2^{e}$ | $12.7^{ab}$ |
| | 5 | $8.0^{a}$ | $4.1^{b}$ | $25.1^{b}$ | $15.8^{e}$ | $24.0^{f}$ | $11.8^{c}$ |
| | 7.5 | $7.9^{a}$ | $4.5^{a}$ | $25.2^{b}$ | $15.8^{e}$ | $24.0^{f}$ | $11.5^{c}$ |
| | 10 | $8.1^{a}$ | $4.2^{ab}$ | $26.0^{a}$ | $15.5^{e}$ | $23.7^{f}$ | $11.5^{c}$ |

*Different letters indicate a significant difference in the 5% probability level.

considered one of the richest oils owing to its high amount of about 50–60% of unsaturated FA (35–40% of omega-3 and 15–20% of omega-6) and the high percentage of omega-3 [39]. Thus, because of its high omega-3 and -6 fatty acid contents, it could replace fish food in fish production farms. Results show that camelina oil has a high percentage of unsaturated FA, especially linoleic acid. The high quality of the oil, its health effects, stability, and aromatic taste similar to almonds, make camelina an important edible oil source in the future.

Camelina meal has low glycosinolates and can be used for animal feed. Camelina meal is similar to soybean meal exhibiting higher performance with 45–47% protein [40]. Another unique feature of camellia oil is the high level of omega-9. Nevertheless, polyunsaturated fatty acids (PUFA) make up about 50% of the total FA in camellia oil [39,41]. Like many PUFA-containing oils, camellia oil contains many different molecules with antioxidant capacity. Camelina oil is rich in tocopherols; in general, the tocopherol content is reported to be between 700 and 800 mg·kg$^{-1}$ seeds, of which 90% of the total is gamma-tocopherol (vitamin E), which acts as an antioxidant increasing the stability of camelina oil leading to long shelf life compared to other omega-3 oils [42]. Linolenic acid (18:3) was the most reported FA, followed by linoleic acid (18:2), oleic acid (18:1), palmitic acid (16:0), stearic acid (18:0), and eicosenoic acid (20:1) with 30.7%, 18.3%, 20.1%, 6.01%, 3.5%, and 12.8%, respectively (Table 4). Camelina seed oil is a rich source of the critical n-3 and n-6 FAs, which confirms earlier reports by Murphy et al. [39]. It is also unique among seeds containing omega-3 FA because the ratio of omega-3/omega-6 in camellia oil is more balanced and this ratio varies between 1.3 and 2.0. Otherwise, this ratio in rapeseed oil (0.52), soybean oil (0.15), safflower oil (0.013), sunflower oil (0.014), and corn oil (0.018) is significantly lower, whereas it is significantly higher (4.2) in linseed oil (calculated from data provided by the Canola Council of Canada).

The FA contents of all samples were similar, which suggests that the initial moisture of the seeds did not affect the composition of the oil FAs. Also, these results are in agreement with previously published data on the common ash seed oil [43], Nigella seed oil [12], and Balangu oil [44]. PUFAs have generally been linked to improved health in early and late life stages. The use of linolenic acid (n-3) and linoleic acid (n-6) includes health benefits such as anti-oxidative and anti-carcinogenic effects as well as decreasing atherosclerosis, inflammation, and obesity.

## 3.5 Chlorophyll

The chlorophyll content of the oil extracted from camelina seed decreased by increasing the duration of microwave exposure (Table 5). It is known that the longer duration of seed exposure to microwave radiation increases the temperature and yields higher energy absorption. Chlorophyll is sensitive to discoloration in hot environments, and the reduced chlorophyll content of the oil can be attributed to the increased temperature by microwave treatment. Furthermore, at constant microwave radiation levels, chlorophyll content decreased by increasing the seed moisture levels. In an oil sample extracted from camelina seeds, the highest

**Table 5:** Mean and standard deviation of chlorophyll (mg pheophytin·kg$^{-1}$ oil), carotenoids (mg·kg$^{-1}$ oil), and browning in camelina seed oil

| Microwave time (min) | Seed moisture (%) | Chlorophyll | Carotenoids | Browning |
|---|---|---|---|---|
| 0 | 2.5 | $7.3^{a*} \pm 0.28$ | $2.26^{k} \pm 0.11$ | $0.120^{g} \pm 0.018$ |
| | 5 | $5.175^{b} \pm 0.28$ | $2.91^{i} \pm 0.11$ | $0.122^{g} \pm 0.018$ |
| | 7.5 | $4.315^{c} \pm 0.28$ | $3.35^{hj} \pm 0.11$ | $0.251^{e} \pm 0.018$ |
| | 10 | $4.14^{cd} \pm 0.28$ | $3.8^{e} \pm 0.11$ | $0.445^{c} \pm 0.018$ |
| 1 | 2.5 | $3.71^{d} \pm 0.28$ | $2.45^{j} \pm 0.11$ | $0.126^{g} \pm 0.018$ |
| | 5 | $2.845^{e} \pm 0.28$ | $3.45^{fg} \pm 0.11$ | $0.138^{g} \pm 0.018$ |
| | 7.5 | $2.155^{hg} \pm 0.28$ | $3.56^{f} \pm 0.11$ | $0.254^{e} \pm 0.018$ |
| | 10 | $2.07^{hg} \pm 0.28$ | $4.08^{d} \pm 0.11$ | $0.548^{b} \pm 0.018$ |
| 2 | 2.5 | $2.675^{ef} \pm 0.28$ | $3.21^{h} \pm 0.11$ | $0.178^{f} \pm 0.018$ |
| | 5 | $2.155^{hg} \pm 0.28$ | $3.61^{f} \pm 0.11$ | $0.263^{de} \pm 0.018$ |
| | 7.5 | $1.64^{hij} \pm 0.28$ | $4.57^{c} \pm 0.11$ | $0.265^{de} \pm 0.018$ |
| | 10 | $1.205^{kj} \pm 0.28$ | $5.11^{a} \pm 0.11$ | $0.690^{a} \pm 0.018$ |
| 3 | 2.5 | $2.24^{fg} \pm 0.28$ | $4.52^{c} \pm 0.11$ | $0.201^{f} \pm 0.018$ |
| | 5 | $1.81^{hij} \pm 0.28$ | $4.87^{b} \pm 0.11$ | $0.288^{d} \pm 0.018$ |
| | 7.5 | $1.55^{ij} \pm 0.28$ | $5.12^{a} \pm 0.11$ | $0.295^{d} \pm 0.018$ |
| | 10 | $1.035^{k} \pm 0.28$ | $5.26^{a} \pm 0.11$ | $0.710^{a} \pm 0.018$ |

*Different letters indicate a significant difference in the 5% probability level.

**Table 6:** Mean and standard deviation of phenolic compounds (mg caffeic acid·100 $g^{-1}$ oil) in camelina seed oil

| Seed moisture (%) | Microwave time (min) | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| 2.5 | $132.91^{e*} \pm 2.4$ | $149.02^{d} \pm 2.4$ | $182.86^{b} \pm 2.4$ | $208.24^{a} \pm 2.4$ |
| 5.0 | $101.09^{g} \pm 2.4$ | $125.25^{f} \pm 2.4$ | $136.94^{e} \pm 2.4$ | $155.87^{c} \pm 2.4$ |
| 7.5 | $78.52^{j} \pm 2.4$ | $89.40^{h} \pm 2.4$ | $102.69^{g} \pm 2.4$ | $136.13^{e} \pm 2.4$ |
| 10.0 | $44.28^{m} \pm 2.4$ | $50.32^{l} \pm 2.4$ | $62.01^{k} \pm 2.4$ | $85.37^{i} \pm 2.4$ |

*Different letters indicate a significant difference in the 5% probability level.

chlorophyll content was recorded at a 2.5% moisture level without exposure to microwave irradiation (0 min), whereas the lowest one was observed at a 10% moisture level and 3 min exposure to microwave irradiation. Contrary to our results, in a study on black cumin seed oil, the chlorophyll content was enhanced by increasing the duration of exposure to microwave radiation [24,25].

### 3.6 Carotenoid value

The carotenoid content of the oil extracted from camelina seeds increased with increasing duration of microwave exposure (Table 5). At constant humidity levels, the highest carotenoid content was observed after 3 min of seed exposure to microwave irradiation. In addition, the moisture level of the seeds had a positive effect on the carotenoid content of the camelina seed oil so that at constant microwave exposure time, the maximum carotenoid content was obtained at a 10% moisture level. This can be explained by the observed fact that the stability of the carotenoid decreases in the drying process but the oxidation and discoloration increase; as a result, the carotenoid content is lower at low moisture levels.

### 3.7 Browning value

The microwave pretreatment had a significant effect ($P < 0.05$) on the number of brown pigments of the seed oil (Table 5). Therefore, increasing the duration of exposure to microwave radiation enhanced the number of brown pigments at all moisture levels. Seed moisture levels affect the number of brown pigments of the seed oil. In seed oil, the rate of browning was enhanced by increasing the humidity of the seeds so that the maximum rate of browning was observed at 10% moisture level and 3 min exposure to microwave irradiation, and the minimum one was recorded at a 2.5% moisture level without microwave irradiation treatment (0 min). As well known, color is one of the major sensory characteristics of the oil. In support of our results, oil extracted from roasted seeds also exhibited color change toward darkening in other studies [19,23,36]. Moreover, the BI and darkening of the oil were enhanced by microwave pretreatment [19]. The oil color alteration by increasing the temperature can be ascribed to the variety of non-enzymatic browning reactions such as Mylard, caramelization, and degradation of phospholipids [45].

### 3.8 Phenolic compound content

The microwave pretreatment significantly affects ($P < 0.05$) the polyphenol content of seed oil. Therefore, increasing the duration of exposure to microwave radiation enhanced the phenolic compound content at all moisture levels (Table 6). In contrast, polyphenol content decreased by increasing the seed humidity level in seed oil. For seed oil, the highest polyphenol content was obtained at a 2.5% moisture level and 3 min exposure to microwave irradiation, and the lowest one was recorded at a 10% moisture level without microwave irradiation treatment (0 min). The increase in the total phenolic content might be due to the decomposition of complex phenolic compounds and the production of simple phenolic compounds that can react with the Folin–Ciocalteu reagent and result in higher adsorption in spectrophotometry. In a study on rapeseed oil, it was observed that the amount of total phenolic content increased by increasing the duration of the microwave irradiation treatment, which is in line with the results of this study [20].

## 4 Conclusion

In the present work, the effects of microwave pretreatment and seed moisture levels on oil extraction yield and physicochemical properties of camelina oil have been studied. The results showed that microwave pretreatment is effective in enhancement of the camelina oil extraction yield.

Furthermore, by increasing the microwave exposure time and seed moisture level, some physicochemical properties of camelina oil including acidity, peroxide value, carotenoid, and BI were enhanced. Moreover, the total phenolic content was increased by microwave pretreatment but decreased with an increase in the seed moisture content. In conclusion, to achieve the maximum oil extraction yield from camelina seeds, 3 min microwave pretreatment of the seeds with 2.5% humidity can be recommended.

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