Saadellaoui W *et al.* (2025)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 53, Issue 1, Article number 14175
DOI:10.15835/nbha53114175
Research Article

Valorization of wild species *Cardaria draba* (L.) Desv.: primary metabolites, mineral content, and fatty acid profile

Wissal SAADELLAOUI[1], Yassine MRABET[2], Mohamed Ali BENABDERRAHIM[3], Abir HADDADA[1], Nourhen HAMMAMI[4], Khaled NASRI[5], Abdelaziz SEBEI[5], Fethia HARZALLAH-SKHIRI[6], Karim HOSNI[2], Sondes STAMBOULI-ESSASSI[1]*

[1] *University of Tunis El Manar, Faculty of Sciences of Tunis, Laboratory of Biodiversity, Biotechnology and Climate Change (LR11-ES09), 1060 Tunis, Tunisia; wissal.saadellaoui@etudiant-fst.utm.tn; abir.haddada@etudiant-fst.utm.tn; sondes.stambouli@fst.utm.tn (*corresponding author)*

[2] *National Institute for Research and Physicochemical Analysis, Laboratory of Natural Substances, Technological Center of Sidi Thabet, 2020 Tunis, Tunisia; yassine.mrabet@gmail.com; karim.hosni@inrap.rnrt.tn*

[3] *Institute of Arid Land, Laboratory of Arid and Oases Cropping, Medenine 4119, Tunisia; medali_abderrahim@hotmail.com*

[4] *University of Tunis El Manar, Faculty of Sciences, Department of Biology (LR18-ES04), Laboratory of Plant Productivity and Environmental Constraint, 1060 Tunis, Tunisia; nourhen.hammami@etudiant-fst.utm.tn*

[5] *University of Tunis El Manar, Department of Geology, Faculty of Science of Tunis, Laboratory of Mineral Resources and Environment (LR01-ES06), Geology 1060 Tunis, Tunisia; nasri.khaled201@gmail.com; abdelaziz.sebei@fst.utm.tn*

[6] *University of Monastir, High Institute of Biotechnology of Monastir, Laboratory of Bioresources: Integrative Biology and Valorization (LR14-ES06), 5000 Monastir, Tunisia; fethiaprosopis@yahoo.fr*

Abstract

The aim of this research was to assess the proximate (ash, organic matter, fiber, protein, sugars, starch, and carbohydrates) and minerals (K, Ca, Mg, P, Na, S, Fe, Zn, Cu, Mn, Cd, Co, Cr, Pb, and Ni) compositions of Tunisian wild *Cardaria draba* (L.) Desv. organs (roots, stems, leaves, flowers, and fruits) using standard methods. The profile of fatty acids was assessed through gas chromatography with flame ionization detection (GC-FID) with lipid quality evaluation. Results show that leaves have the highest ash (19.20 g/100 g dw) and protein (38.90 g/100 g dw) contents, while roots are richest in fiber (32.80 g/100 g dw) and soluble sugars (9.68 g/100 g dw). Flowers and fruits contain the most starch contents (56.96 and 51.22 g/100 g dw, respectively). Leaves also have the highest concentrations of K, Ca, Mg, Na, and P, while fruits and flowers have the highest sulfur content (478.98 and 432.50 mg/100 g dw, respectively). Fe is primarily found in leaves and stems (37.50 and 36.98 mg/100 g dw), Mn in stems (5.35 mg/100 g dw), and Zn in leaves (4.21 mg/100 g dw). Roots accumulate the most trace elements, remaining below toxicity limits. Fruits have the highest oil content (12.50%). Unsaturated fatty acids (UFA) dominate, with oleic acid (29.38%) as the main in roots, α-linolenic acid (12.98%) in aerial parts, and linoleic acid (7.94%) in fruits oils. Erucic acid is highest in fruits (7.70%) but undetectable in aerial parts. Palmitic and stearic acids, are highest in roots (22.05% and 23.18%, respectively). The oils demonstrate high nutritional quality, with favorable hypocholesterolemic properties (h/H ratio of 1.67 to 2.30) and low atherogenic (0.50-0.62) and thrombogenic (0.22-1.00) indices. These results indicate

---

Received: 02 Oct 2024. Received in revised form: 13 Nov 2024. Accepted: 21 Mar 2025. Published online: 25 Mar 2025.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

that *C. draba* organs are a valuable source of essential nutrients and fats, with potential applications in diet, health, cosmetics, and biodiesel.

Keywords: *Cardaria draba* (L.) Desv.; fatty acids; GC-FID analysis; lipid quality indices; nutritional composition

Introduction

Wild plant species play a crucial role in human life, particularly in terms of diet and medicine uses (Batool *et al*., 2023; Kumar *et al*., 2024). Interest in these species has significantly increased due to their promising health improvements given their richness in beneficial nutrients, particularly mineral content, dietary fiber, carbohydrates, fats, and proteins (García-Herrera *et al.*, 2014). These nutrients provide numerous advantages for human consumption and constitute an alternative food source (Duguma, 2020). Additionally, Baydoun *et al*. (2017) demonstrated the economic importance of wild plants of Lebanon based on the commercial value of these species and their relationship to industrial crops. Brassicaceae family (syn. Cruciferae), includes various cultivated species having agronomic and economic importance. They are consumed as vegetables, fodder, condiments, and oilseed due to their richness in vitamins, minerals, and secondary metabolites (Raza *et al.*, 2020; Jabeen, 2020). Scientific evidence indicates that including cruciferous vegetables in the human diet can yield positive effects on health and well-being (Šamec *et al*., 2019). *Cardaria draba* (L.) Desv., a spontaneous perennial herbaceous plant, belonging to this family, is known for its richness in bioactive molecules such as phenolic, alkaloid, terpenoid, and volatile organic compounds with anti-inflammatory, antioxidant, and antimicrobial activities, which have contributed to its use in treating various illnesses (Roshanak *et al*., 2021; Fathi *et al*., 2023; Saadellaoui *et al*., 2024). It is also recognized as a wild edible plant of significant nutritive value (Bensaid *et al*., 2018). Young leaves and shoots are typically added raw to salads and the seeds can serve as a substitute for pepper in seasoning mixes (Francis and Warwick, 2008). Furthermore, it is an excellent fodder species for ruminants characterized by high levels of neutral and acid detergent fibers (Sasoli *et al*., 2022). The reason that many wild Brassicaceae species have not been widely cultivated may be attributed to the lack of detailed information on their nutritional value (Guil-Guerrero *et al*., 1999). For *C. draba,* previous studies on its mineral composition have primarily focused on assessing trace element content of this species growing wild in Iraq, Iran, Turkey, and Bulgaria. They examined the entire plant for Mn, Fe, Zn, Cu, Pb, Co, Cd, Li, Hg, Ni, Se, Al, V, As, and Cr (Targan *et al.*, 2018) and for Fe, Mn, Co, and Ni (Kılıç *et al*., 2019); the aerial parts for Cd, Cu, Pb, Ni, and Zn (Hosseini *et al.*, 2020) and for As, Co, Cr, Fe, and Mn (Hosseini *et al.*, 2022); the shoots and leaves for Cd, Pb, Fe, Ni, Zn, and Cu (Mohsenzadeh and Rad, 2012); the leaves for Fe, Cd, Cr, Co, Pb, Mn, Ni, and Zn (Hussein, 2016) and for Pb and Zn (Ghaderian *et al.*, 2007); as well as in shoots for Zn, Cu, Pb and Cd (Georgieva *et al*., 2015). However, few publications have focused on its macroelement content. Targan *et al.* (2018) confirmed the richness of its aerial parts and roots mixture in Ca (6469 μg/g dry matter), Na (3451 μg/g dry matter), and Mg (3364 μg/g dry matter). For Guil-Guerrero *et al.* (1999), the tender leaves of *C. draba* growing wild in Spain contain 667, 168, and 131 mg/100 g fresh biomass of K, Ca, and Mg, respectively. According to Hussein (2016), the Ca and Mg content of the leaves of Iraqi species were 4.02 and 27.30 mg/kg dry weight, respectively. In addition, research on the nutritive value of this species examined protein, ash, fiber and fatty acid contents in leaves (Guil-Guerrero *et al.*, 1999), protein, soluble sugars, and fatty acids in seeds (Tonguç and Erbaş, 2012), and the aerial parts fatty acid profile (Sarikurkcu *et al.*, 2017). In contrast, the compositions of roots and fruits have not been studied before.

In this context, to the best of our knowledge, there has been no prior research assessing the primary metabolites and mineral content of wild *C. draba* in Tunisia. Therefore, this study focused on the evaluation of the proximate composition (moisture, ash, organic matter, soluble sugars, starch, crude fiber, crude protein, and carbohydrate) and mineral elements (Ca, K, Mg, P, Na, S, Cu, Fe, Mn, Zn, Cd, Co, Cr, Ni, and Pb) of *C. draba* organs (roots, leaves, stems, flowers, and fruits). Moreover, it investigated the lipid content of the roots, aerial parts mixture, and fruits, as well as, fatty acid profiles and related nutritional indices. Our aim was to evaluate the nutritional value and explore the potential applications of the different organs of *C. draba* in commercial industries, thus supporting their consumption and wider uses.

Materials and Methods

Plant material

Cardaria draba samples, including roots, stems, leaves, and flowers, were gathered in spring (April 2023), during full flowering. Fruits were harvested two months later, in June 2023. The collection site was located at the Ksour-Essaf area (35°25′.02 North, 10°59′.694 East, 15 m), situated approximately 17 km away from Mahdia in the Central-Eastern region of Tunisia. The average annual precipitation is 353.7 mm, with a mean annual temperature of 19.4 °C and a moisture content of 85%. The soil is calcareous, notably rich in calcium, potassium, and iron. Voucher specimens (N°124*Cd2*-5), authenticated by botanist Professor Fethia Harzallah-Skhiri, are preserved in the Laboratory of Bioresources: Integrative Biology and Valorization (LR14-ES06) at the High Institute of Biotechnology of Monastir, Tunisia herbarium. In the laboratory, the harvested material was thoroughly cleaned with tap water. It was then oven-dried at 20 °C until reaching a stable dry weight, finely ground into a homogeneous powder using a Duronic CG 250 Premium 250 W electric grinder, and then weighed. The obtained powders from the five different organs were stored in glass bottles until analyses.

Proximate composition

Proximate analysis of the powdered *C. draba* organs included estimation of moisture, ash, organic matter, protein, crude fiber, soluble sugars, starch, crude fat, carbohydrate contents and energy value.

Moisture content (MC)

The content of the moisture of each sample was assessed using the standard AOAC (2005) method. Samples were oven-dried (103 °C) until a stable weight was reached. The MC was expressed in %.

Ash content (AC) and organic matter content (OMC)

The ash content was measured as described by the ISO 5984:2022 method. Five grams (5 g, w2) of each sample was set in a crucible which has been already washed, dried at 180 °C for 30 min, cooled and then weighed (w1). The crucible was transferred into a muffle oven set at 550 °C for 12-18 hours, until the content became white after which the crucible was cooled in a desiccator and weighed (w3). The ash percentage was then determined using the relation below:

$$\text{Ash (\%)} = \text{weight of ash /weight of sample} \times 100 = \text{w3-w2/w2-w1} \times 100 \quad (1)$$

$$\text{Organic matter (\%)} = 100 - \text{ash (\%)} \quad (2)$$

Protein content (PC)

The protein contents were calculated by elemental microanalysis as percentage nitrogen content multiplied by 6.25 using a Leco CHNS-932 analyser (St. Joseph, MI, USA).

Crude fiber content (CF)

The crude fiber analysis was carried out according to the enzymatic-gravimetric AOCS Ba 6a-05 (2005) method. Briefly, 0.5 g of each sample was weighed (w3) and then boiled in 1.25% H_2SO_4 solution in a beaker for 30 min. It was subsequently hydrolysed for an additional 30 min with 1.25% NaOH. After rinsing the sample with hot water and acetone, it was dried at 105 °C for 1h until a stable weight was reached (w1). The remaining residue was reignited in a muffle oven at 55 °C for 3 h, then cooled in a desiccator and weighed again (w2). The crude fiber content was calculated using the following equation:

$$\text{Crude fiber} = (w1 - w2)/w3 \times 100 \quad (3)$$

Soluble sugar (SS) and starch (ST) contents

The soluble sugar levels in the five samples were assessed using the sulfuric acid anthrone method (Chen *et al.*, 2016). Briefly, 10 mg of each powder sample was combined with 1 ml of 80% ethanol. This mixture was heated in a water bath (70 °C, 30 min), with regular stirring. Once cooled in an ice bath, it was centrifuged (9,000 rpm, 4 °C, 15 min). The residue was reserved for starch analysis, while the supernatant was used to quantify sugar content. A volume of 50 µl of the supernatant were mixed with 2 ml of anthrone ($C_{14}H_{10}O$) solution prepared in a fume hood, by combining 5 ml H_2SO_4 with 10 mg anthrone, and 1200 µl 80% ethanol. This mixture was subsequently heated during 10 min, in a boiling water bath, until a greenish colour was obtained, then rapidly cooled in an ice bath. A control was prepared by mixing 2.5 ml anthrone with 1250 µl 80% ethanol. Sugar concentrations were determined on the basis of a standard curve prepared using glucose solutions. The residue was hydrolysed with 150 µl of 35% perchloric acid in an ice bath (15 min). The mixture is centrifuged and the s1 supernatant (s1) is collected. The residue was re-hydrolysed for 30 min, centrifuged and the s2 (s2) supernatant was recovered. The two supernatants s1 and s2 were combined, and the total volume obtained was adjusted to 5 ml with distilled water. The starch content was determined using anthrone in the presence of perchloric acid (21%). The starch standard was established with pure glucose diluted in perchloric acid (21%). Finally, optical density was measured at 640 nm using a V-1100 D spectrophotometer. Soluble sugar and starch contents are reported in g/100 g dry weight (dw).

Oil content (OC)

Given that oil extraction from *C. draba* leaves, stems, and flowers did not yield oil, we combined the dried powders of the aerial parts. Then, 20 g of roots, a mixture of the aerial parts, and fruits dry powders were extracted, each one apart, using hexane in an appropriate Soxhlet apparatus (8 hours, 18–22 cycles/h). Extractions were conducted three times. Hexane was eliminated with a rotary vacuum evaporator in a water bath (40 °C). The obtained oil yield (g/100 g dw) was determined to calculate the lipid content of each sample.

Total Carbohydrate Content (CC) and Energy Value (EV)

Carbohydrates and energy value were calculated using the following equations (Food and Agriculture Organization, 1998):

$$\text{Carbohydrate content (\%)} = 100 - (\text{moisture} + \text{ash} + \text{protein} + \text{lipid}) \quad (4)$$

$$\text{EV (Kcal/100 g dw)} = 4 \times (\text{protein} + \text{carbohydrate}) + 9 \times (\text{lipid}) \quad (5)$$

Mineral composition

Mineral composition (Ca, K, Na, S, Mg, Zn, Fe, Cu, Mn, Cd, Ni, Pb, Cr, and Co) was determined using the AOAC 985.35 (2000) official method for atomic absorption spectroscopy. Briefly, mineralization was conducted on 0.2 g of each sample. The samples were digested with a mixture of nitric and perchloric acids (2:1 v/v), heated for 3 hours at 90 °C, and then diluted with 20 ml of 2% nitric acid. Analyses were performed using a Thermo SOLAR atomic absorption spectrometer (AAS). The concentration of phosphorus was determined using a UV spectrophotometer, measuring absorption at 430 nm. For each sample, 2.5 g was added to 1 g of calcium carbonate, followed by incineration in a muffle oven (550 °C, 4 hours). Subsequently, 10 ml of 6N hydrochloric acid was added and heated to boiling, filtered, rinsed with distilled water, and then subjected to spectrophotometric analysis. Results are expressed as mg/100 g dw.

Fatty acid composition and lipid indices quality

Fatty acid methyl esters (FAMEs) and chromatographic analysis (GC/FID)

Fatty acid methyl-esters (FAMEs) from the total lipids were obtained using 3% sodium methoxide in methanol (Cecchi *et al*., 1985). The FAMEs were analyzed using gas chromatography with a Hewlett-Packard 6890 gas chromatograph series II (Agilent Technologies, Palo Alto, California, USA) fitted with a flame ionization detector (FID). Individual FAMEs were separated on an Rtx-2330 capillary column (90% biscyanopropyl/10% phenyl cyanopropyl polysiloxane, 30 m × 0.32 mm, 0.20 µm film thickness). The temperatures of the injector and the FID detector were maintained at 240 °C and 260 °C, respectively. The oven temperature was set to rise from 100 to 230 °C at a rate of 4 °C/min and held for 16 min. Nitrogen served as the carrier gas at a flow rate of 1.2 ml/min. Then, 1 µl of the sample was injected in split mode with ratio of 1/100. Peak identification was conducted by referencing to the retention times of a standard pure mixture FAMEs (Ref: CRM47885, Supelco 37 Component FAME Mix). The percentages of FAMEs were determined based on the total fatty acids.

Lipid quality indices

Lipid quality indices, including saturated fatty acids (SFA), unsaturated fatty acids (UFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), UFA/SFA ratio, omega-3 (ω3)/omega-6 (ω6) ratio, atherogenic index (AI) (Ulbrich and Southgate,1991), thrombogenic index (TI) (Ulbrich and Southgate,1991), hypocholesterolemic fatty acid/hypercholesterolemic fatty acid ratio (h/H) (Santos-Silva *et al.,* 2002), calculated oxidizability value (Cox) (Fatemi and Hammond, 1980), and oxidative susceptibility (OS) (Cecchi *et al*., 2011) were calculated as follows:

$$AI = [(4 \times C14{:}0) + C16{:}0 + C18{:}0)]/[\sum UFA + \sum \omega6\ PUFA + \sum \omega3\ PUFA]\ (6)$$

$$TI = [C14{:}0 + C16{:}0 + C18{:}0]/[0.5 \times MUFA + 0.5 \times \omega6\ PUFA + 3 \times \omega3\ PUFA + \omega3/\omega6 \times PUFA]\ (7)$$

$$h/H = [C18{:}1\ n\text{-}9 + C18{:}2\ n\text{-}6 + C20{:}4n\text{-}6 + C18{:}3\ n\text{-}3 + C20{:}5\ n\text{-}3 + C22{:}5\ n\text{-}3 + C22{:}6n\text{-}6]/[C14{:}0 + C16{:}0]\ (8)$$

$$Cox = [C18{:}1 + 10.3 \times C18{:}2 + 21.6 \times C18{:}3]/100\ (9)$$

$$OS = MUFA + 45 \times C18{:}2 + 100 \times C18{:}3\ (10)$$

Statistical analyses

All the analyses were conducted in triplicate, and the results are expressed as mean ± standard deviation (SD). Analysis of variance (ANOVA) was conducted using XLSTAT 2019 to compare the means. The differences were found to be significant when $p < 0.05$ using Duncan's multiple range test. Heat map dendrogram was generated using Metabo Analyst 5.0 (*http://www.metaboanalyst.ca/*, accessed on May 22, 2023) to evaluate the combination of proximate and mineral contents characterizing *C. draba* organs.

Results and Discussion

Proximate and elemental composition

Proximate composition

The proximate composition results are provided in Table 1. The highest moisture contents (MC) were registered in stems, followed by leaves, and flowers (73.72%, 73.61%, and 70.25%, respectively). Fruits exhibited a lower MC (68.05%), while roots had the lowest value (46.85%). The results, particularly regarding the MC of the aerial parts, are comparable to those noted by Afzal *et al.* (2016) for the total plant growing wild in Pakistan (72.71%). This high MC is crucial for food quality and preservation, as it is essential for maintaining the turgidity of vegetable cells and keeping them fresh (Galindo *et al.*, 2004). It also confirms the species' ability to thrive in harsh environments (Husen, 2021).

Table 1. Proximate composition of *Cardaria draba* roots, stems, leaves, flowers, and fruits

Component	Content				
	Roots	Stems	Leaves	Flowers	Fruits
Moisture (%)	46.85 ± 1.4^{b}	73.72 ± 1.1^{a}	73.61 ± 1.2^{a}	70.25 ± 1.0^{a}	68.05 ± 1.8^{a}
Ash (%)	8.70 ± 0.3^{c}	11.20 ± 0.1^{b}	19.20 ± 0.4^{a}	10.10 ± 0.1^{b}	8.80 ± 0.3^{c}
Organic matter (%)	91.30 ± 2.0^{a}	88.80 ± 1.3^{b}	80.80 ± 2.1^{c}	89.90 ± 3.2^{b}	91.20 ± 3.1^{a}
Crude protein (g/100 g dw)	14.90 ± 0.4^{b}	16.00 ± 0.2^{b}	32.30 ± 0.3^{a}	38.90 ± 0.2^{a}	14.10 ± 0.4^{b}
Crude fiber (g/100 g dw)	32.80 ± 1.6^{a}	27.90 ± 1.4^{b}	13.90 ± 1.2^{d}	12.00 ± 1.1^{d}	18.50 ± 1.4^{c}
Soluble sugar (g/100 g dw)	9.68 ± 5.8^{a}	8.99 ± 3.9^{a}	7.93 ± 3.8^{b}	9.20 ± 5.0^{a}	7.86 ± 0.5^{b}
Starch (g/100 g dw)	44.39 ± 5.9^{cd}	38.43 ± 4.5^{d}	42.06 ± 2.1^{c}	56.96 ± 3.7^{a}	51.22 ± 1.8^{b}

*Note: Data represents the mean of three replicates. The means ± the standard deviations followed by the same letter within the same line are significantly different (Duncan test, $p < 0.05$), dw; dry weight.

The ash content (AC) exhibits significant variation ($p < 0.05$) among the organs. Specifically, leaves show the highest AC (19.20%), followed by stems and flowers (11.20 and 10.10%, respectively), and then by roots and fruits (8.70 and 8.80%, respectively). The AC of *C. draba* leaves exceeds the previously value of 15.72 g/100 g dw reported for the whole plant of this species growing wild in Iran (Hoseini Nejad *et al.*, 2012), and that for the leaves of other edible Brassicaceae species, such as *Lepidium sativum* L. (15.38 g/100 g dw) (Hassan *et al.*, 2011), *Brassica oleracea* L. (10.42 g/100 g dw) (Martinez *et al.*, 2010) and *B. rapa* L. (7.31 g/100 g dw) (Sun *et al.*, 2022).

The highest average contents in protein (PC) are found in flowers, followed by leaves (38.90 and 32.30 g/100 g dw, respectively) (Table 1). These values are significantly greater than those recorded by Tonguç and Erbaş (2012) (23.50%) for the seeds, and Sasoli *et al.* (2022) (18.58%) for the leaves of *C. draba* growing wild in Turkey and Pakistan, respectively. For Kittani and Alousy (2003), among six species of palatable herbs collected from two sites in Iraq, *C. draba* whole plant shows the highest percentages of crude protein (17.75 and 10.68%). Moreover, the PC in *C. draba* leaves and flowers from Tunisia was higher than that reported by Malhotra and Sontakke (2023) (22.73%) and Hassan *et al.* (2011) (18.25%) in *L. sativum* seeds and leaves, respectively. It was also higher than the PC in *B. oleracea* flowers (26.44-31.28%) and leaves (21.63-27.49%) (Dufoo-Hurtado *et al.*, 2020), confirming that *C. draba* is an excellent source of protein.

Regarding crude fiber content (CF), the roots followed by the stems exhibit the highest values (32.80 and 27.90 g/100 g dw, respectively). This aligns with the findings reported by Kittani and Alousy (2003) for Iraqi species across two sites (26.34 and 29.83 g/100 g dw). Compared to the CF levels of some Brassicaceae edible species; *B. oleracea* var. *acephala* leaves (7.80 g/100g dw, Agarwal *et al.*, 2017), *B. oleracea* var. *capitata* leaves (3.77%, Ogbede *et al.*, 2015), and *L. sativum* leaves (9.31%, Hassan *et al.*, 2011), the stems and roots of *C. draba* could be considered highly favorable sources of crude fiber.

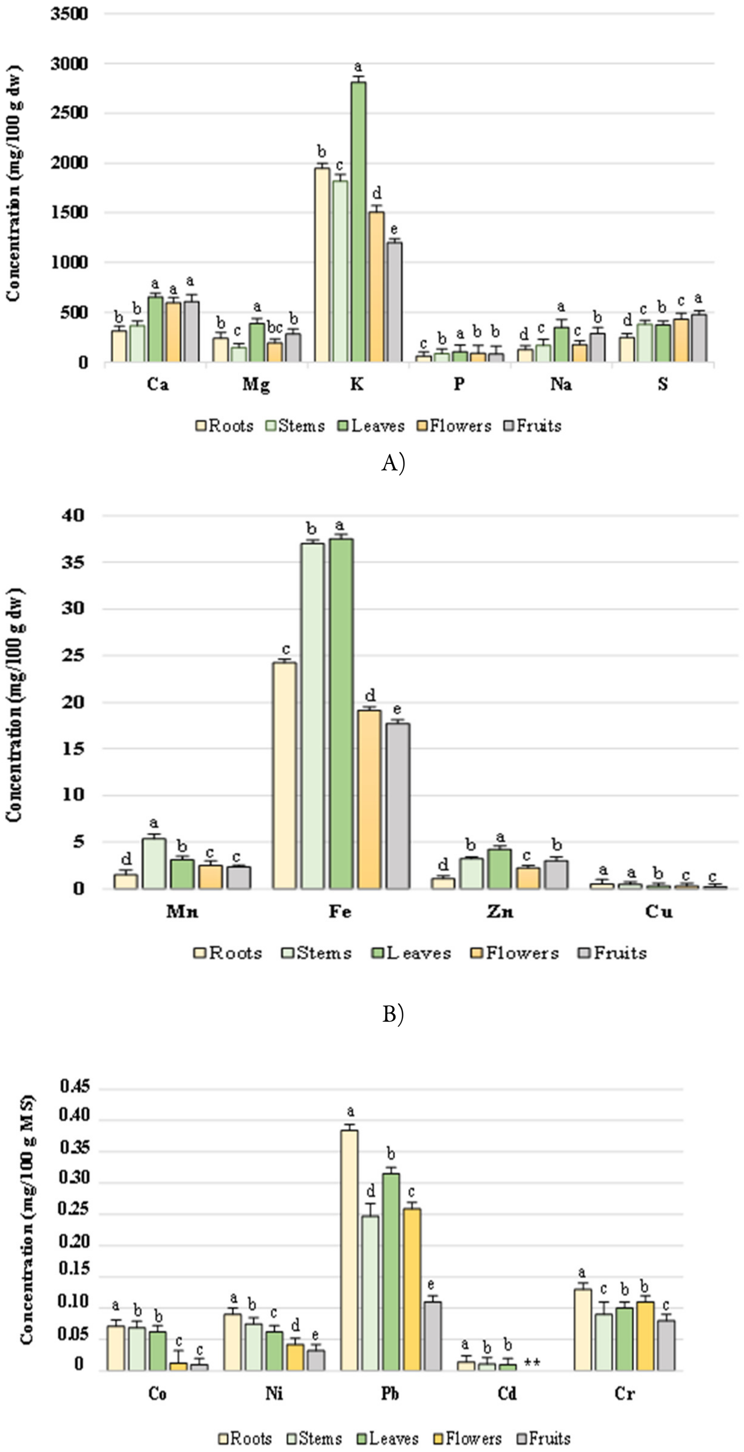
On the other hand, *C. draba* roots were found to have the highest content of soluble sugars (9.68 g/100g dw), succeeded by the flowers (9.20 g/100 g dw). Indeed, *C. draba* is known for its capacity to accumulate substantial sugar reserves in its root system (Mulligan and Findlay, 1974). These values largely exceed those recorded by Tonguç and Erbaş (2012) for the seeds of *C. draba* of Turkey (26.65 mg/g dw). Moreover, reproductive organs are the richest in starch (56.96 and 51.22 g/100 g dw, in flowers and fruits, respectively), followed by roots, leaves, and stems (44.39, 42.06, and 38.43 g/100 g dw, respectively). In fact, according to Karthika *et al.* (2020), for Brassicaceae, the potassium enhances fruit quality by converting their high starch content into sugars. Windsor *et al.* (2000) also found that starch formation in fruits and seeds of *Lepidium* L. species provides carbon and energy for mucilage production. On the other hand, the oil contents of roots, aerial parts (a mixture of leaves, stems and flowers), and fruits (containing seeds) exhibit considerable variability. Fruits have the highest oil content (12.50±0.02 g/100 g dw), followed by the aerial parts (7.50±0.01 g/100 g dw), and roots 5.00±0.01 g/100 g dw. Furthermore, roots have the highest carbohydrates content (75.40 against 64.60 and 55.93%, in fruits and aerial parts, respectively). Fruits exhibit the highest energy value (427.30, against 376.20 and 353.50 kcal/100 g dw in roots and aerial parts, respectively).

Mineral nutrient composition

The micro- and macronutrient average contents of roots, stems, leaves, flowers, and fruits of *C. draba* are presented in Figure 1 A-C.

Macroelements content

All organs exhibited high levels of potassium (K), especially the leaves (2813.2 mg/100 g dw), followed by roots (1950.70 mg/100 g dw) and stems (1820.00 mg/100 g dw) (Figure 1A). The two major elements after K are calcium (Ca) and sulfur (S), followed by magnesium (Mg), sodium (Na), and phosphorus (P) (K >Ca>S >Mg >Na >P). Leaves, fruits, and flowers exhibited the highest amounts of Ca (653.96, 610.11, and 598.30 mg/100 g dw, respectively). The S content was higher in fruits, followed by flowers (478.98 and 432.50 mg/100 g dw, respectively). Regarding Mg, Na, and P, they are significantly more abundant in the leaves compared to the other organs (390.10, 350.12, and 102.51 mg/100 g dw, respectively). The elevated level of K and low level of Na, resulting in a low Na/K ratio (<1) in all organs of *C. draba*, supports health recommendations to lower sodium intake and increase potassium intake (Drewnowski *et al.*, 2012). An increase in dietary potassium is crucial for disease prevention, particularly hypertension (Perez and Chang, 2014). Our results are in agreement with those conducted by Kittani and Alouzy (2003) and Guil-Guerrero *et al.* (1999), who reported that K was the predominant mineral in leaves of *C. draba* from Spain and Iraq (2.44-3.11% and 667 mg/100 g fresh biomass, respectively). Potassium content, ranging in our study from 1200 to 2813.2 mg/100 g dw, is higher than recorded values in some edible Brassicaceae; such as the leaves of *B. oleracea* var. *acephala* (23.62 mg/g dw) (Martinez *et al.*, 2010) and *L. sativum* (1850 mg/100 g dw) (Hassan *et al.*, 2011).



A)

B)

C)

Figure 1. Mineral composition of different plant parts (roots, stems, leaves, flowers, and fruits) of Tunisian wild *Cardaria draba* (mg/100 g dw); (A) Macroelements; (B) and (C) Trace elements

Below the detection limit; dw Dry weight; The letters a, b, c, d and e correspond to significantly different values (Duncan test, $p < 0.05$)

All organs of *C. draba* growing in Tunisia appear to be richer in Ca, ranging from 314.52 to 653.96 mg/100 g dw, compared to the results reported for *C. draba* leaves by Hussein (2016), Guil-Guerrero *et al.* (1999) and Kittani and Alouzi (2003), the aerial parts by Targan *et al.* (2018) (4.02 ppm, 168 mg/100 g fresh biomass, 2.29-2.06%, and 6469 µg/g dw, respectively), as well as for *B. oleracea* var. *botrytis* floret (2.5 g/kg dw) (Collado-Gonzalez *et al.*, 2021) and *B. oleracea* var. *gemmifera* (2219.2 mg/kg dw) (Doniec *et al.*, 2022). The Mg content of the leaves (390.10 mg/100 g dw) also exceeds that of *B. oleracea* var. *acephala* leaves (2.85 mg/g dw) (Martinez *et al.*, 2010), and *B. oleracea* var. *botrytis* entire plant (2.1 g/kg dw) (Collado-Gonzalez *et al.*, 2021). Previous studies on *C. draba* have not investigated the S content of this species. The highest value, recorded in the fruits (478.98 mg/100 g dw), is very close to that reported in *L. sativum* aerial parts (4651-4751 mg/kg dw) by Sat *et al.* (2013). In fact, Brassicaceae species are known for their high sulfur content compared to other vegetable families (Fusari *et al.*, 2020). The P content of *C. draba* leaves reported by Guil-Guerrero *et al.* (1999) from Spain (28.6 mg/100 g dw) and by Kittani and Alouzi (2003) from Iraq (59 mg/100 g dw) is lower than the levels recorded in our study, which range from 63.52 to 102.51 mg/100 g dw. These values are considerably lower than those found in *B. oleracea* var. *acephala* leaves (5.73 mg/g dw) (Ayaz *et al.*, 2006), *B. oleracea* var. *italica* aerial parts (5.98 mg/g dw) (Montaner *et al.*, 2023), and *B. oleracea* var. *botrytis* floret (5.7 mg/kg dw) (Collado-González *et al.*, 2021), but higher than the levels in *L. sativum* (1478 mg/kg dw) (Sat *et al.*, 2013) and *B. rapa* leaves (33.1 mg/kg dw) (Sun *et al.*, 2022).

Trace elements content

Iron (Fe) is the most abundant essential trace element in all the organs. It was followed by manganese (Mn), zinc (Zn), and copper (Cu) (Fe>Mn>Zn>Cu), particularly in leaves and in stems (37.50 and 36.98 mg/100 g dw, respectively) (Figure 1B).

The amount of Mn ranged from 1.50 to 5.35 mg/100 g dw. The maximum concentrations were found in stems (5.35 mg/100 g dw) and leaves (3.10 mg/100 g dw). Leaves also recorded the highest amount of Zn (4.210 mg/100 g dw), while roots had the highest amount of Cu (0.279 mg/100 g dw). For the toxic trace metals, they are mainly concentrated in the roots with a clear predominance of lead (Pb) (0.38 mg/100 g dw) followed by chromium (Cr) (0.13 mg/100 g dw) (Pb>Cr >Ni>Co>Cd). The amounts of Pb in the other organs ranged from 0.11 to 0.31 mg/100 g dw, and Cr from 0.08 to 0.11 mg/100 g dw. The optimal concentration of Ni in the roots is 0.09 mg/100 g dw, followed by 0.075 mg/100 g dw in the stems, and does not exceed 0.062 mg/100 g dw in the other organs. The highest concentration of cobalt (Co) is found in the roots (0.071 mg/100 g dw), while the lowest were recorded in the reproductive organs; flowers (0.012 mg/100 g dw) and fruits (0.010 mg/100 g dw). Cadmium was the least represented in the organs (0.014, 0.011 and 0.010 in roots, stems, and leaves, respectively). It was not detected in flowers and fruits (Figure 1C). Trace elements also called heavy metals are notable environmental pollutants, posing problems due to their toxicity, which affects environmental, ecological, and nutritional aspects (Zaynab *et al.*, 2022). They are required in very low amounts and their excess can pose a threat to organism (Asati *et al.*, 2016). For Pantola and Alam (2014), around quarter of hyperaccumulators plants belong to the Brassicaceae family, highlighting their significant potential in both phytoremediation and biofumigation. Indeed, *C. draba* is a highly effective phytoremediation and bioindicator plant due to its capacity to hyper accumulate heavy metals (Sobhan Ardakani and Hosseini, 2024). Moreover, it tolerates various environmental factors and can be encountered in diverse habitats such as roadsides, farmland, and pastures (Francis and Warwick, 2008). It is frequently subjected to emissions from traffic and absorbs varying levels of heavy metals from both soil and atmosphere (Hosseini *et al.*, 2020). We compared the trace metals concentrations in the five organs of *C. draba* with their corresponding limit amounts in dry raw plant material provided by the World Health Organization (2007). Thus, amounts of Cu (0,094-0.297 mg/100 g dw) and Zn (1.104-4.210 mg/100 g dw) are significantly below the set limits of 15 mg/100 g dw and 0.1-10 mg/100 g, respectively. Likewise, concentrations of Pb (0.110-0.384 mg/100 g dw), Cd (0.010-

0.014 mg/100 g dw), Cr (0.08-0.13 mg/100 g dw), and Ni (0.032-0.090 mg/100 g dw) are also below the toxicity limits which are defined as 1.0 mg/100 g dw for Pb, 0.03 mg/100 g dw for Cd, 0.2 mg/100 g dw for Cr, and 0.10-5 mg/100 g dw for Ni, respectively. The World Health Organization (2007) does not specify a specific limit for Co. It is considered a trace element required in small amounts for human health. However, excessive intake of Co could potentially lead to adverse health effects (European Food Safety Authority, 2015).

When comparing our results with those published on *C. draba* growing wild in other countries and under different environmental conditions, as well as with those for consumed Brassicaceae species, differences emerged. For Fe, the most abundant trace element in our samples, high levels were found in the roots and shoots of the Iranian species; 272.67 and 148.18 mg/kg dw, respectively (Hosseini *et al.*, 2022), and in the leaves of the Iraqi species (40.00 ppm) (Hussein, 2016). The aerial parts of *C. draba* growing in Turkey contain 352.00 µg/g dw of Fe (Targan *et al.*, 2018). Our results are almost close for the roots (24.25 mg/100 g dw) but higher for stems (36.98 mg/100 g dw) and leaves (37.50 mg/100 g dw). The composition of flowers and fruits of *C. draba* has not been studied previously. The Fe concentrations are higher than those in *B. oleracea* var. *italica* (broccoli) (0.135-0.106 mg/g dw) (Montaner *et al.*, 2023) and *B. oleracea* var. *botrytis* (cauliflower) (60.47 mg/kg dw) (Collado-Gonzalez *et al.*, 2021). Kılıç *et al.* (2019) confirmed that the average amount of Mn accumulation in *C. draba* from Turkey is lower than that of Fe. In our study, the highest recorded concentration of Mn, in the stems of *C. draba* (5.35 mg/100 g dw) is slightly higher than that noted by Hosseini *et al.* (2022) for this organ in the Iranian species (44.14 mg/kg dw). Stems of Tunisian *C. draba* appear to be as rich in Mn as the leaves of *L. sativum* (5.74 mg/100 g dw) recorded by Hassan *et al.* (2011). The highest concentrations of Zn in the leaves (4.21 mg/100 g dw), followed by stems (3.21 mg/100 g dw), and fruits (3.02 mg/100 g dw) are very close to those in the *C. draba* aerial parts from Iran (31.29 mg/kg dw) (Hosseini *et al.*, 2020) and exceeding those in the leaves of *C. draba* from Turkey (24.3 µg/g dw) (Targan *et al.*, 2018) and Iraq (7.19 ppm) (Hussein, 2016). Regarding Cu, Co, Ni, Pb, Cr, and Cd contents, our values are close to, or slightly lower than those reported for this species by Hussein (2016) in Iraq, Hosseini *et al.* (2020) in Iran, and Targan *et al.* (2018) in Turkey. These values cannot be compared to those reported by Ghaderian *et al.* (2007), Mohsenzadeh and Rad (2012), and Georgieva *et al.* (2015). Their studies focused on Iranian and Bulgarian species growing in metal mining and highly polluted areas, which are characterized by high levels of contamination, in order to assess their phytoextraction potential.

Therefore, to evaluate the variation in the richness of proximate, micro-, and macroelement contents among the roots, leaves, stems, flowers, and fruits of *C. draba* organs, a heatmap was generated (Figure 2). The results of the Hierarchical Cluster Analysis (HCA) revealed a clear separation among the clusters of these organs. Group 1 (G1), corresponding to the roots, is characterized by its richness in crude fiber and by the highest percentages of trace elements (Cu, Pb, Ni, Cr, Co, and Cd). In contrast, group 2 (G2) comprises stems and leaves. Stems are characterized by their richness in Fe, Mn, and Zn microelements, moisture, crude fiber, and soluble sugars, whereas leaves contain high levels in K, Mg, Ca, P, and Na macroelements, as well as Fe, Zn, ash, moisture, and crude protein. The third group (G3) corresponds to the reproductive organs; flowers and fruits. Flowers are particularly rich in P, Ca, and S macroelements, as well as moisture, crude protein, soluble sugars, and starch. However, fruits are rich in Mg, Ca, S, Na, Zn, and starch.

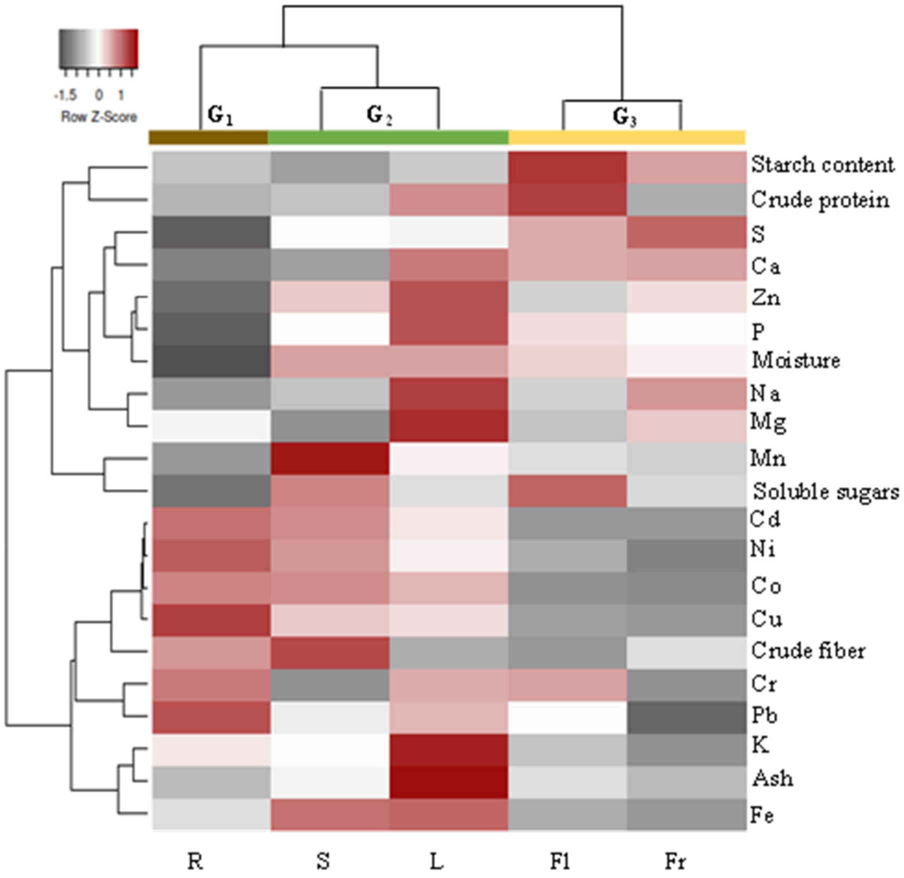


Figure 2. Heatmap along with Hierarchical Cluster Analysis (HCA) of *C. draba* organs based on proximate and mineral nutrients contents

The rows in the heatmap diagram indicate proximate/minerals, and the columns represent organs (roots, stems, leaves, flowers, and fruits). Dark red corresponds to high values, and dark gray corresponds to the lowest values. R Roots; S Stems; L Leaves; Fl Flowers; Fr Fruits; G_1 Group 1; G_2 Group 2; G_3 Group 3

Fatty acid profile and related nutritional indices

Fatty acid profile

GC analysis of FAMEs showed the detection of 14 saturated, monounsaturated, and polyunsaturated fatty acids. The highest number of fatty acids was detected in the fruits (13), followed by the roots (7), and the aerial parts (5) (Table 2).

Table 2. Composition of fatty acids (% of total fatty acids) from fruits, aerial parts (leaves, stems, flowers) and roots of wild Tunisian *Cardaria draba* and their nutritional quality indices

	Fatty acid	**RT (min)***	**Fatty acid area (%)**		
			Roots	Aerial Parts	Fruits
Saturated					
1	Myristic (C14:0)	21.68	Nd	2.03 ± 0.10^{fgh}	Nd
2	Palmitic (C16:0)	25.05	22.05 ± 1.20^{ef}	7.05 ± 0.30^{e}	18.22 ± 0.24^{f}
3	Margaric (C17:0)	26.71	Nd	Nd	0.24 ± 0.08^{l}
4	Stearic (C18:0)	28.60	23.18 ± 1.10^{e}	1.32 ± 0.01^{ghij}	18.29 ± 0.20^{f}
5	Arachidic (C20:0)	31.88	Nd	Nd	1.53 ± 0.01^{ijkl}
6	Behenic (C22:0)	35.29	Nd	Nd	2.81 ± 0.12^{hij}
7	Lignoceric (C24:0)	39.59	Nd	Nd	1.25 ± 0.02^{ijkl}
Monounsaturated					
8	Palmitoleic (C16:1 n-7)	25.51	Nd	Nd	0.29 ± 0.01^{l}
9	Oleic (C18:1 n-9)	28.94	29.38 ± 1.05^{d}	Nd	25.22 ± 0.90^{e}
10	11-Eicosenoic (C20:1 n-9)	32.89	Nd	Nd	3.93 ± 0.14^{h}
11	Erucic (C22:1 n-9)	35.84	2.64 ± 0.14^{h}	Nd	7.70 ± 0.32^{g}
Polyunsaturated					
12	Linoleic (C18:2 n-6)	29.71	7.30 ± 0.24^{g}	2.19 ± 0.10^{fg}	7.94 ± 0.34^{g}
13	*α*-Linolenic (C18:3 n-3)	30.79	7.33 ± 0.20^{g}	12.98 ± 0.32^{c}	9.29 ± 0.42^{g}
14	Eicosatrienoic (C20:3 n-6)	34.35	5.57 ± 0.16^{g}	Nd	0.61 ± 0.01^{kl}
Lipid quality					
	SFA		45.23 ± 1.20^{c}	10.40 ± 0.30^{d}	42.34 ± 1.10^{c}
	MUFA		32.02 ± 1.05^{d}	Nd	37.14 ± 1.06^{d}
	PUFA		20.20 ± 0.30^{f}	15.17 ± 0.10^{b}	17.84 ± 0.10^{f}
	UFA		52.22 ± 1.65^{b}	15.17 ± 0.10^{b}	54.98 ± 1.30^{b}
	UFA/SFA		1.15 ± 0.01^{h}	1.45 ± 0.01^{ghij}	1.29 ± 0.01^{ijkl}
	ω3/ω6		0.57 ± 0.01^{h}	5.92 ± 0.10^{e}	1.07 ± 0.01^{jkl}
	AI		0.62 ± 0.01^{h}	0.61 ± 0.01^{hij}	0.50 ± 0.01^{kl}
	TI		1.00 ± 0.01^{h}	0.22 ± 0.02^{ij}	0.70 ± 0.02^{kl}
	h/H		2.25 ± 0.02^{h}	1.67 ± 0.01^{fghi}	2.30 ± 0.02^{hijk}
	Cox		2.63 ± 0.01^{h}	3.03 ± 0.01^{f}	3.07 ± 0.01^{hi}
	OS		1093.52 ± 3.20^{a}	1396.55 ± 2.30^{a}	1323.44 ± 2.10^{a}

* Note: Means ± SD with the same letter (s) in the same column are significantly different (Duncan test, $p < 0.05$)
Nd; not detected, *; retention time on Rtx-2330 capillary column, SFA; saturated fatty acids, UFA; unsaturated fatty acids, MUFA; monounsaturated fatty acids, PUFA; polyunsaturated fatty acids, AI; atherogenic index, TI; thrombogenic index, h/H; hypocholesterolemic ratio, Cox; calculated oxidizability value, OS; oxidative susceptibility.

Fruits, roots, and aerial parts are characterized by a slightly higher fraction of unsaturated fatty acids (UFA) (54.98, 52.22, and 15.17%, respectively) compared to saturated ones (SFA) (42.34, 45.02, and 10.40, respectively). In roots and fruits, monounsaturated fatty acids (MUFA) are more abundant than polyunsaturated fatty acids (PUFA) (32.02 and 37.14% against 20.20 and 17.84%, respectively). In contrast, MUFA were not detected in the aerial parts, where only 15.17% of PUFA was identified. The UFA fraction was predominantly composed of oleic acid, reaching high concentrations in roots (29.38%) and fruits (25.22%). It was not detected in the aerial parts. It was followed by *α*-Linolenic acid, which reached maximum amounts (12.98%) in the aerial parts, and 9.29% and 7.33% in fruits and roots, respectively. Linoleic acid is the third most abundant UFA, particularly in fruits and roots (7.94 and 7.30%, respectively). The SFA fraction was primarily composed of stearic and palmitic acids, particularly in roots (23.18% and 22.05%, respectively) and in fruits (18.29% and 18.22%, respectively). Erucic acid was not detected in the aerial parts oil, but was present at concentrations of 7.70 and 2.64% in fruits and roots oils, respectively. It is a characteristic fatty acid of the Brassicaceae family, and is often used as a distinguishing marker for this plant family (Vetter *et al.*, 2020). The main fatty acid; oleic acid, identified in the roots and fruits of *C. draba*, is associated with various health benefits (Farràs *et al.*, 2021). It is the most abundant MUFA in the human diet (Schwingshack and Hoffmann, 2012). Oleic acid is characterized by its high anticancer effects and play a critical role in reducing inflammation, lowering cholesterol, and improving metabolic health, making it a valuable component in managing chronic diseases (Pravst, 2014). *α*-Linolenic, the sole omega-3 fatty acid identified in the samples, plays a vital role in cardiovascular health by enhancing lipid profiles. It also supports cognitive function and reduces depression symptoms, highlighting its role in overall mental and physical health (Sala-Vila *et al.*, 2022). Linoleic acid is vital for skin health and immune function. It modulates inflammation and managing metabolic syndrome, highlighting its importance for overall metabolic health (Viladomiu *et al.*, 2016). On the other hand, stearic and palmitic acids, which are major saturated fatty acids in roots and fruits oils, are integral to the cosmetics industry due to their emulsifying, thickening, and conditioning properties (Rabasco Álvarez and González Rodríguez, 2000). Erucic acid concentrations in fruits and roots oils exceed the safe levels which are typically below 2% for oils intended for human consumption. Plants with high levels of erucic acid, whether cultivated or wild, are exclusively designated for non-food applications and are specifically grown to meet the needs of the oleochemical industry (Knutsen *et al.*, 2016). Erucic acid is used in the manufacture of lubricants, plastics, and coatings (Jadhav *et al.*, 2024), as well as in the neuropharmacological sector (Kumar and Sharma, 2022).

Nutritional indices

Nutritional indices for the lipidic fraction of *C. draba* indicate that the UFA/SFA ratio ranges from 1.15 to 1.45, with the highest value recorded in the aerial parts oil. A higher UFA/SFA ratio, is generally considered indicative of good nutritional quality and is associated with a reduced risk of cardiovascular diseases (Chiofalo *et al.*, 2012; Gheorghe *et al.*, 2022). The aerial parts oil shows also the highest ω-3/ω-6 ratio (5.92), compared to fruits (1.07) and roots (0.57), indicating its high nutritional quality. D'Angelo *et al.* (2020) highlight that a high ω-3/ω-6 ratio is essential for achieving a balanced diet. This ratio affects energy balance, nutrient requirements and absorption, and plays a role in producing lipid mediators. Additionally, it may offer health benefits by helping prevent chronic disorders, including cancer, and cardiovascular and inflammatory diseases. Furthermore, *C. draba* oils seem to have cholesterol-lowering properties, as indicated by their elevated hypo/hypercholesterolemic ratio (h/H), particularly in fruits, followed by roots and aerial parts (2.3, 2.25, and 1.67, respectively). Even more interestingly, their high nutritional quality is confirmed by their low atherogenic (AI) (0.50-0.62) and thrombogenic (TI) (0.22-1.00) indices. The lowest AI (0.50) and TI (0.22) values are recorded in fruits and aerial parts oils. Indeed, these indices reflect the relationship between major saturated fatty acids (stearic, myristic, and palmitic), which are known as pro-atherogenic, and unsaturated ones that are anti-atherogenic (Tilami and Kouřimská, 2022). In contrast, these oils have a tendency to oxidize as indicated by their high values of oxidative susceptibility (OS) and oxidizability (Cox). These indices are inversely proportional to the PUFA content of oil (Anwar *et al.*, 2007). The highest values of Cox and OS are recorded in the fruits (3.07 and 1323.24, respectively) and the aerial parts oils (3.03 and 1396.55, respectively), due to their richness in linoleic and α-linolenic acids. The lower recorded value of α-linolenic acid in the roots, compared to those in fruits and aerial parts oils, reduce their susceptibility to oxidation, as shown by the lower Cox and OS values (2.63 and 1093.52, respectively). For Mao *et al.* (2020), α-linolenic acid is the only main fatty acid needing replenishment, as oils rich in it are highly susceptible to oxidation and degrade quickly with exposure to air, light, and heat.

Published studies on the fatty acid profile of *C. draba* have previously focused exclusively on the leaves of the Spanish species (Guil-Guerrero *et al.*, 1999), and on the seeds (Tonguc and Erbaş, 2012; Özcan *et al.*, 2014) and aerial parts (Sarikurkcu *et al.*, 2017) of the Turkish one. Roots and fruits oils composition have not been studied before. Our results revealed differences in both lipid content, fatty acids composition, and lipid quality compared to previous studies conducted on *C. draba* growing wild in other natural biotopes. Indeed, variation in the content of the components of the fatty acid composition in wild plants can be significantly attributed to provenance, genetic factors, geographical origin; including edaphic and climatic factors, and the year of harvest (Muthai *et al*., 2019). The seed oil contents, 6.97% and 6.39%, reported by Tonguc and Erbaş (2012) and Özcan *et al.* (2014) respectively, are much lower than the oil yield from the fruits (containing seeds) in our study (12.50%) which could highlights that the pericarp of *C. draba* silicles is also rich in oil. The SFA fractions in the leaves of the Spanish *C. draba* (Guil-Guerrero *et al.*, 1999) and in the above ground parts of the Turkish species (Sarikurkcu *et al*., 2017) are predominantly composed of palmitic acid, accounting for 24.50% and 19.68%, respectively. These percentages are significantly higher than the 7.05% of palmitic acid found in the Tunisian aerial parts species. However, similar contents were recorded in roots and fruits oils (22.05 and 18.22%, respectively). For Tonguc and Erbaş (2012), palmitic (17.10%) and stearic (9.24%) acids have the highest percentages in seed oil, implying a higher energy storage capacity for germination. These results are aligned with ours, where these two SFA dominate the fruits oil (18.22% and 18.29%, respectively). Regarding the content of UFA, our results are consistent with the literature, which identifies oleic, α-linolenic, and linoleic acids as the major UFA, although there are differences in their percentages. Oleic acid, which was not identified in the aerial parts of the Tunisian species, was detected at 10.14% (Sarikurkcu *et al.*, 2017) and 7.80% (Guil-Guerrero *et al*., 1999) in the leaves and aerial parts of the Turkish *C. draba*. It is also the main UFA in the roots in our study (29.38%). For Tonguc and Erbaş (2012), its content did not exceed 12.29% in the seeds of this species, whereas it reached higher levels (25.22%), in the fruits oil of the Tunisian species. In contrast, the contents of α-linolenic (39.03, 36.92, and 38.93%) and linoleic (9.98%, 15.95%, and 18.93%) acids in the leaves, aerial parts, and seeds of *C. draba*, recorded by these authors, are higher than those registered in our study, where α-linolenic acid was 7.33, 12.98, and 9.29%, and linoleic acid was 7.30, 2.19, and 7.94% in the roots, aerial parts, and fruits oils, respectively. Regarding erucic acid, both differences and similarities emerged compared to previous studies. As our finding, Sarikurkcu *et al.* (2017) confirmed the absence of this MUF in the aerial parts oil of *C. draba* growing wild in Turkey. While, Guil-Guerrero *et al.* (1999), confirmed its occurrence in leaves of Spanish species at very low levels (1.55%). However, our results (7.7% erucic acid in the oil from fruits with seeds) contradict those of Tonguc and Erbaş (2012), who reported that the seeds of this species from Turkey did not contain erucic acid. Additionally, it is significantly lower than the erucic acid content found in the oil from *Cakile maritima* fruits (with seeds), which is 22.04% according to Stambouli-Essassi *et al.* (2020). In the roots of *C. draba*, no previous studies have reported the presence of erucic acid, which we estimated to be 2.64%. Thus, oils from the fruits and roots could be considered non-edible and may serve as promising substitutes for traditional edible food crops in biodiesel production (Atabani *et al*., 2013). In fact, erucic acid, a key component in mustard biodiesel, positively affects fuel properties, enhances engine performance, and improves exhaust emissions (Aslan, 2023). Due to its hydrophobic properties and water resistance, erucic acid is an essential oleochemical used in machinery, rubber, metallurgy, and various other industries (Wang *et al*., 2022).

Conclusions

This investigation demonstrates that the organs of Tunisian *C. draba* exhibit significant nutritional and industrial potential. The aerial parts, particularly the leaves and stems, are noted for their high levels of essential minerals such as potassium, magnesium, calcium, and iron, as well in proteins, low levels of saturated fatty acids, a significant ω-3/ω-6 ratio, and the absence of erucic acid. These features make them suitable for dietary purposes and nutritional applications. Additionally, the roots, which are rich in crude fiber and starch, could be ideal for digestive health supplements. The high content of palmitic and stearic acids in roots, followed by fruits oils makes them valuable for the cosmetics industry. Furthermore, their richness in oleic acid makes them highly beneficial for cardiovascular health and cholesterol-lowering. On the other hand, fruits oil could be useful for biodiesel production due to its erucic acid content.

Authors' Contributions

WS provided the plant material, performed the experiments, and wrote the draft of the manuscript; YM conducted the extraction and the GC/FID analysis of the fatty acids; MAB performed the analysis of the protein content, AH statistically analysed the data ; NH analysed the soluble sugars and starch; KN and AS performed the mineral elements contents; KH provided the results of the fatty acids composition and the lipid quality indices; SSE supervised the experiments, wrote and discussed results, and FHS revised the final version of the manuscript. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Afzal M, Ali MI, Munir MA, Zeeshan MA, Sharif MN, Aslam M (2016). Genetic association among morphological traits of *Lepidium draba*. Bulletin of Biological and Allied Sciences Research 1(1):1-5. *https://doi.org/10.54112/bbasr.v2016i1.1*.

Agarwal A, Raj N, Chaturvedi N (2017). A comparative study on proximate and antioxidant activity of *Brassica oleracea* (Kale) and *Spinacea oleracea* (Spinach) leaves. International Journal of Advanced Research in Biological Sciences 4(4):22-29. *http://dx.doi.org/10.22192/ijarbs.2017.04.04.004*

Anwar F, Hussain AI, Iqbal S, Bhanger MI (2007). Enhancement of the oxidative stability of some vegetable oils by blending with *Moringa oleifera* oil. Food Chemistry 103:1181-1191. *https://doi.org/10.1016/j.foodchem.2006.10.023*.

AOAC (2005). Association of Officiating Analytical Chemists. Washington DC, (18th ed), Washington, USA.

AOAC (2020). Association of Officiating Analytical Chemists. Official Methods of Analysis of AOAC International, (20th ed), Rockville, MD, USA.

AOCS Ba 6a-05 (2005). The American Oil Chemists' Society. Official Methods and Recommended Practices of the AOCS, Champaign, IL.

Asati A, Pichhode M, Nikhil K (2016). Effect of heavy metals on plants: an overview. International Journal of Application or Innovation in Engineering and Management 5(3):56-66.

Aslan V (2023). Fuel characterization, engine performance characteristics and emissions analysis of different mustard seed biodiesel: An overview. Journal of Biotechnology 370:12-30. *https://doi.org/10.1016/j.jbiotec.2023.05.006*.

Atabani AE, Silitonga AS, Ong HC, Mahlia TMI, Masjuki HH, Badruddin IA, Fayaz H (2013). Non-edible vegetable oils: a critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. Renewable and Sustainable Energy Reviews 18:211-245. *https://doi.org/10.1016/j.rser.2012.10.013*.

Ayaz FA, Glew RH, Millson M, Huang HS, Chuang LT, Sanz C, Hayırlıoglu-Ayaz S (2006). Nutrient contents of kale (*Brassica oleraceae* L. var. *acephala* DC.). Food Chemistry 572-579. *https://doi.org/10.1016/j.foodchem.2005.03.011*.

Batool W, Hussain W, Hassan R, Tasleem T, Ullah S, Ali A (2023). A study of wild vegetables: proximate and mineral analysis of selected wild edible vegetables of parachinar, district kurramkp, Pakistan. Pakistan Journal of Botany 55(1):291-298. *http://doi.org/10.30848/PJB2023-1(21)*

Baydoun SA, Kanj D, Raafat K, Aboul Ela M, Chalak L, Arnold-Apostolides N (2017). Ethnobotanical and economic importance of wild plant species of Jabal Moussa Bioreserve, Lebanon. Journal of Ecosystem and Ecography 7(3):1-10. *http://doi.org/10.4172/2157-7625.1000245*

Bensaid SO, Bicha S, Benmekhebi L, Rebbas K, Bensouici C, Demirtas I, ..., Benayache F (2018). HPLC analysis and antioxidant properties of Algerian *Lepidium draba* ethyl acetate extract. Journal of Biologically Active Products from Nature 8(4):265-271. *http://doi.org/10.1080/22311866.2018.1511381*.

Cecchi G, Biasini S, Castano J (1985). Note de laboratoire [Laboratory note]. Revue Française des Corps Gras 4:163-164.

Cecchi T, Passamonti P, Alfei B, Cecchi P (2011). Monovarietal extra virgin olive oils from the Marche region, Italy: analytical and sensory characterization. International Journal of Food Properties 14(3):483-495. *https://doi.org/10.1080/10942910903254811*.

Chen XL, Xue XZ, Guo WZ, Wang LC, Qiao XJ (2016). Growth and nutritional properties of lettuce affected by mixed irradiation of white and supplemental light provided by light-emitting diode. Scientia Horticulturae 200:111-118. *https://doi.org/10.1016/j.scienta.2016.01.007*.

Chiofalo B, Presti VL, Chiofalo V, Gresta F (2012). The productive traits, fatty acid profile and nutritional indices of three lupin (*Lupinus* spp.) species cultivated in a Mediterranean environment for the livestock. Animal Feed Science and Technology 171(2-4):230-239. *https://doi.org/10.1016/j.anifeedsci.2011.11.005*.

Collado-González J, Piñero MC, Otálora G, López-Marín J, del Amor FM (2021). Exogenous spermidine modifies nutritional and bioactive constituents of cauliflower (*Brassica oleracea* var. *botrytis* L.) florets under heat stress. Scientia Horticulturae 277:e109818. *https://doi.org/10.1016/j.scienta.2020.109818*.

D'Angelo S, Motti ML, Meccariello R (2020). ω-3 and ω-6 polyunsaturated fatty acids, obesity and cancer. Nutrients 12(9):2751. *https://doi.org/10.3390/nu12092751*.

Doniec J, Florkiewicz A, Duliński R, Filipiak-Florkiewicz A (2022). Impact of hydrothermal treatments on nutritional value and mineral bioaccessibility of Brussels sprouts (*Brassica oleracea* var. *gemmifera*). Molecules 27(6):1861. *https://doi.org/10.3390/molecules27061861*.

Drewnowski A, Maillot M, Rehm C (2012). Reducing the sodium-potassium ratio in the US diet: a challenge for public health. The American journal of clinical nutrition 96(2):439-444. *https://doi.org/10.3945/ajcn.111.025353*.

Dufoo-Hurtado MD, Vazquez-Barrios ME, Ramirez-Gonzalez E, Vazquez Celestino D, Rivera-Pastrana DM, Mercado-Silva E (2020). Nutritional, nutraceutical and functional properties of flours obtained from broccoli waste material dried at different temperatures. Acta Horticulturae 1292:137-144. *https://doi.org/10.17660/ActaHortic.2020.1292.18*

Duguma HF (2020). Wild edible plant nutritional contribution and consumer perception in Ethiopia. International Journal of Food Science (1):2958623. *https://doi.org/10.1155/2020/2958623*

European Food Safety Authority (EFSA) (2015). Scientific Opinion on the tolerable upper intake level of cobalt. EFSA Journal 13(1):e3978.

Farràs M, Almanza-Aguilera E, Hernáez Á, Agustí N, Julve J, Fitó M, Castañer O (2021). Beneficial effects of olive oil and Mediterranean diet on cancer physio-pathology and incidence. Seminars in Cancer Biology 73:178-195. *https://doi.org/10.1016/j.semcancer.2020.11.011*.

Fatemi SH, Hammond EG (1980). Analysis of oleate, linoleate and linolenate hydroperoxides in oxidized ester mixtures. Lipids 15(5):379-385.

Fathi H, Ebrahimzadeh MA, Ahanjan M, Shokri F, Jafari H, Eslami S, …, Rostamnezhad M (2023). Antioxidant capacity, chromatographic analysis of phenolic compounds and anti-microbial effects of *Cardaria draba* growing in Iran. International Journal of Pharmaceutical Sciences and Research 14(1):373-380. *https://doi.org/10.13040/IJPSR.0975-8232.14(1).373-80*

Food and Agriculture Organization (FAO) (1998). Carbohydrates in human nutrition. Food and Nutrition Paper.

Francis A, Warwick SI. (2008). The biology of Canadian weeds. *Lepidium draba* L., *L. chalepense* L., *L. appelianum* Al Shehbaz (updated). Canadian Journal of Plant Science 88(2):379-401. *https://doi.org/10.4141/CJPS07100*.

Fusari CM, Nazareno MA, Locatelli DA, Fontana A, Beretta V, Camargo AB (2020). Phytochemical profile and functionality of Brassicaceae species. Food Bioscience 36:e100606. *https://doi.org/10.1016/j.fbio.2020.100606*.

Galindo FG, Herppich W, Gekas V, Sjöholm I (2004). Factors affecting quality and postharvest properties of vegetables: Integration of water relations and metabolism. Critical Reviews in Food Science and Nutrition 44(3):139-154. *https://doi.org/10.1080/10408690490424649*.

García-Herrera P, Sánchez-Mata MC, Cámara M, Fernández-Ruiz V, Díez-Marqués C, Molina M, Tardío J (2014). Nutrient composition of six wild edible Mediterranean Asteraceae plants of dietary interest. Journal of Food Composition and Analysis 34(2):163-170. *https://doi.org/10.1016/j.jfca.2014.02.009*.

Georgieva S, Atanassova J, Dinev N (2015). Metal hyperaccumulation in *Cardaria draba* (L.) Desv. (Brassicaceae) and heavy metal effects on the nematodes and a weevil associated with the plant roots in sites near a non-ferrous metal smelter in Bulgaria. Soil Science Agrochemistry Ecology 49:55-64.

Ghaderian SM, Hemmat GR, Reeves RD, Baker AJM (2007). Accumulation of lead and zinc by plants colonizing a metal mining area in Central Iran. Journal of Applied Botany and Food Quality 81(2):145-150.

Gheorghe A, Habeanu M, Ciurescu G, Lefter NA, Ropota M, Custura I, Tudorache M (2022). Effects of dietary mixture enriched in polyunsaturated fatty acids and probiotic on performance, biochemical response, breast meat fatty acids, and lipid indices in broiler chickens. Agriculture 12(8):e1120. *https://doi.org/10.3390/agriculture12081120*.

Guil-Guerrero JL, Giménez-Martínez JJ, Torija-Isasa ME (1999). Nutritional composition of wild edible crucifer species. Journal of Food Biochemistry 23(3):283-294. *https://doi.org/10.1111/j.1745-4514.1999.tb00020.x*.

Hassan LG, Hassan SW, Hashim T, Umar KJ, Sani NA (2011). Determination of nutritive values of garden cress (*Lepidium sativum* L.) Leaves. Bayero Journal of Pure and Applied Sciences 4(2):18-23. *https://doi.org/10.4314/bajopas.v4i2.4*

Hoseini Nejad Z, Yoosefollahi M, Fazayeli H (2012). Nutritive value of five halophytes determined in Sistan Area. Iranian Journal of Animal Science 43(1):1-10. *https://doi.org/10.22059/ijas.2012.24904*

Hosseini NS, Sobhanardakani S, Cheraghi M, Lorestani B, Merrikhpour H (2020). Heavy metal concentrations in roadside plants (*Achillea wilhelmsii* and *Cardaria draba*) and soils along some highways in Hamedan, west of Iran. Environmental Science and Pollution Research 27:13301-13314. *https://doi.org/10.1007/s11356-020-07874-6*

Hosseini NS, Sobhanardakani S, Cheraghi M, Lorestani B, Merrikhpour H (2022). Expansive herbaceous species as bio-tools for elements detection in the vicinity of major roads of Hamedan, Iran. International Journal of Environmental Science and Technology 19(3):1611-1624. *https://doi.org/10.1007/s13762-021-03183-8*

Husen A (2021). The harsh environment and resilient plants: an overview. In: Husen A (Eds). Harsh Environment and Plant Resilience, Springer, Cham, pp 2-14. *https://doi.org/10.1007/978-3-030-65912-7_1*.

Hussein HM (2016). Determination of phytochemical composition and ten elements content (Cd, Ca, Cr, Co, Fe, Pb, Mg, Mn, Ni, and Zn) of *Cardaria draba* by GC-MS, FT-IR and as techniques. International Journal of Pharma and Bio Sciences 7(3):1009-1017.

ISO 5984:2022 (2022). Animal feeding stuffs-determination of crude ash. International Organization for Standardization, Geneva, Switzerland.

Jabeen N (2020). Agricultural, economic and societal importance of Brassicaceae plants. In: Hasanuzzaman M (Ed). The Plant Family Brassicaceae. Springer, Singapore, pp 45-128. *https://doi.org/10.1007/978-981-15-6345-4_2*.

Jadhav PD, Girase CD, Kulkarni RD, Patwardhan AV, Unnithan UR (2024). Synthesis and properties of a bio-based plasticizer derived from fatty acid methyl ester of erucic acid. Journal of Polymers and the Environment 32:4371-4384. *https://doi.org/10.1007/s10924-024-03231-7*

Karthika KS, Philip PS, Neenu S (2020). Brassicaceae plants response and tolerance to nutrient deficiencies. In: Hasanuzzaman M (Ed). The plant family Brassicaceae biology and physiological responses to environmental stresses. Springer, Singapore, pp 337-362. *https://doi.org/10.1007/978-981-15-6345-4_11*

Kılıç DD, Sürmen B, Kutbay HG, Tuna EE (2019). Naturally distributed species *Lepidium draba* L. investigation of usability in phytoremediation method. European Journal of Science and Technology 17:491-499. *https://doi.org/10.31590/ejosat.624424*.

Kittani MM, Alousy YMA (2003). The effect of site and samples date collection on the nutritional content for pastoral plants in Ninevah and Namrood forests. Mesopotamia Journal of Agriculture 4(3):68-76.

Knutsen HK, Alexander J, Barregård L, Bignami M, Brüschweiler B, Ceccatelli S, …, Vleminckx C (2016). Erucic acid in feed and food. EFSA Journal 14(11):4593. *https://doi.org/10.2903/j.efsa.2016.4593*.

Kumar JS, Sharma B (2022). A review on neuropharmacological role of erucic acid: An omega-9 fatty acid from edible oils. Nutritional Neuroscience 25(5):1041-1055. *https://doi.org/10.1080/1028415X.2020.1831262*.

Kumar R, Sharma V, Kumar S (2024). Biotechnological tools for conservation and sustainable utilization of medicinal plants. In: Role of Science and Technology for Sustainable Future, Vol.1, Sustainable Development: A Primary Goal Singapore, Springer Nature Singapore, pp 303-319. *https://doi.org/10.1007/978-981-97-0710-2_18*

Malhotra U, Sontakke M (2023). Potential effect of pre-treatments on antinutritional and mineral composition of garden cress seed (*Lepidium sativum*). Preprint. Research Square. *https://doi:10.21203/rs.3.rs-2650799/v1*.

Mao X, Chen W, Huyan Z, Hussain Sherazi ST, Yu X (2020). Impact of linolenic acid on oxidative stability of rapeseed oils. Journal of Food Science and Technology 57(9):3184-3192.

Martinez S, Losada P, Franco I, Carballo J (2010). Protein, amino acid, ash and mineral contents in *Brassica* spp. grown in Northwest Spain. International Journal of Food Science and Technology 46:146-153. *https://doi.org/10.1111/j.1365-2621.2010.02463.x*.

Mohsenzadeh F, Rad AC (2012). Bioremediation of heavy metal pollution by nano-particles of *Noaea mucronata*. International Journal of Bioscience, Biochemistry and Bioinformatics 2(2):85.

Montaner C, Mallor C, Laguna S, Zufiaurre R (2023). Bioactive compounds, antioxidant activity, and mineral content of bróquil: A traditional crop of *Brassica oleracea* var. *italica*. Frontiers in Nutrition 9:e1006012. *https://doi.org/10.3389/fnut.2022.1006012*

Mulligan GA, Findlay JN (1974). The biology of Canadian weeds *Cardaria draba*, *C. chalepensis*, and *C. pubescens*. Canadian Journal of Plant Science 54(1):149-160. *https://doi.org/10.4141/cjps74-024*.

Muthai UK, Indieka AS, Muchugi A, Karori SM, Mng'omba S, Ky-Dembele C, Jamnadass R (2019). Quantitative variation of fatty acid composition in seed oil from baobab (*Adansonia digitata* L.) wild populations in sub-Sahara Africa. South African Journal of Botany 123:1-8. *https://doi.org/10.1016/j.sajb.2019.01.026*.

Ogbede SC, Saidu AN, Kabiru AY, Busari MB (2015). Nutrient and anti-nutrient compositions of *Brassica oleracae* var. *capitata* L. IOSR Journal of Pharmacy 5(3):19-25.

Özcan T (2014). Fatty acid composition of seed oils in some sand dune vegetation species from Turkey. Chemistry of Natural Compounds 50(5):699-703.

Pantola RC, Alam A (2014). Potential of Brassicaceae Burnett (Mustard family; Angiosperms) in phytoremediation of heavy metals. International Journal of Scientific Research in Environmental Sciences 2:120-138. *http://dx.doi.org/10.12983/ijsres-2014-p0120-0138*

Perez V, Chang ET (2014). Sodium-to-potassium ratio and blood pressure, hypertension, and related factors. Advances in Nutrition 5(6):712-741. *https://doi.org/10.3945/an.114.006783*

Pravst I (2014). Oleic acid and its potential health effects. In: Oleic acid: production, uses and potential health effects. Nova Science Publishers, Lynette Whelan Inc, pp 35-54.

Rabasco Álvarez AM, González Rodríguez ML (2000). Lipids in pharmaceutical and cosmetic preparations. Grasas y Aceites 51(1-2):74-96. *https://doi.org/10.3989/gya.2000.v51.i1-2.409*.

Raza A, Hafeez MB, Zahra N, Shaukat K, Umbreen S, Tabassum J, …, Hasanuzzaman M (2020). The Plant Family Brassicaceae: Introduction, Biology, and Importance. In: Hasanuzzaman M (Ed). Springer, Singapore pp 1-43. *https://doi.org/10.1007/978-981-15-6345-4_1*

Roshanak S, Alizadeh Behbahani B, Shahidi F, Tabatabaei Yazdi F, Vasiee AR, Norouzi N (2021). Evaluation of antioxidant potential and antimicrobial activity of Mocheh (*Lepidium draba*) extract *in vitro*. Iranian Food Science and Technology 17-24. *https://doi.org/10.22067/ifstrj.v17i3.86954*.

Saadellaoui W, Kahlaoui S, Hcini K, Haddada A, Sleimi N, Ascrizzi R, …, Stambouli-Essassi S (2024). Profiles of the headspace volatile organic and essential oil compounds from the Tunisian *Cardaria draba* (L.) Desv. and its leaf and stem epidermal micromorphology. Phyton-International Journal of Experimental Botany 93(4):725-744. *https://doi.org/10.32604/phyton.2024.048110*.

Sala-Vila A, Fleming J, Kris-Etherton P, Ros E (2022). Impact of α-linolenic acid, the vegetable ω-3 fatty acid, on cardio vascular disease and cognition. Advances in Nutrition 13(5):1584-1602. *https://doi.org/10.1093/advances/nmac016*.

Šamec D, Urlić B, Salopek-Sondi B (2019). Kale (*Brassica oleracea* var. *acephala*) as a superfood: Review of the scientific evidence behind the statement. Critical Reviews in Food Science and Nutrition 59(15):2411-2422. *https://doi.org/10.1080/10408398.2018.1454400*.

Santos-Silva J, Bessa RJB, Santos-Silva F (2002). Effect of genotype, feeding system and slaughter weight on the quality of light lambs: II. Fatty acid composition of meat. Livestock Production Science 77:187-194. *https://doi.org/10.1016/S0301-6226(02)00059-3*.

Sarikurkcu C, Targan S, Ozer MS, Tepe B (2017). Fatty acid composition, enzyme inhibitory, and antioxidant activities of the ethanol extracts of selected wild edible plants consumed as vegetables in the Aegean region of Turkey. International Journal of Food Properties 20(3):560-572. *https://doi.org/10.1080/10942912.2016.1168837*.

Sasoli MA, Abro R, Marghazani IB, Mughal GA, Reki MY, Khaskheli AK, …, Qadir A (2022). Identification and nutrients composition of different rangeland species (grasses, herbs, shrubs, and trees) grazed by small and large ruminants in Balochistan: Kharan region. Pure and Applied Biology 11(3):823-834. *http://dx.doi.org/10.19045/bspab.2022.110083*

Sat IG, Yildirim E, Turan M, Demirbas M (2013). Antioxidant and nutritional characteristics of garden cress (*Lepidium sativum*). Acta Scientiarum Polonorum Hortorum Cultus 12(4):173-179.

Schwingshackl L, Hoffmann G (2012). Monounsaturated fatty acids and risk of cardiovascular disease: synopsis of the evidence available from systematic reviews and meta-analyses. Nutrients 4:1989-2007. *https://doi.org/10.3390/nu4121989*.

Sobhan Ardakani S, Hosseini NS (2024). Evaluating the ability of *Cardaria draba* (L.) Desv. and *Achillea wilhelmsii* C. Koch as biomonitors and bioremediators of potentially toxic elements in the roadside environment. Journal of Natural Environment 77:61-76. *https://doi.org/10.22059/jne.2023.353266.2511*

Stambouli-Essassi S, Mejri F, Dhoueibi M, Mrabet Y, Harzallah-Skhiri F, Hosni K (2020). Anatomical features, fatty acid profile and tocopherol content of the Tunisian *Cakile maritima* subsp. *maritima* Scop. fruit. Journal of Animal and Plant Sciences 43(1):7366-7379. *https://doi.org/10.35759/JAnmPlSci.v43-1.3*

Sun X, wang W, paerhati M, song Z, Li J, Zhu J (2022). Phytochemical composition and nutritional characterization of qamgur (*Brassica rapa* L.) in different forms. Journal of Food Science and Technology, 42:e35722. *https://doi.org/10.1590/fst.35722*.

Targan Ş, Yelboğa EG, Cittan M (2018). Macro and trace element contents of some wild plants consumed as vegetable in Manisa district, Turkey. Journal of the Turkish Chemical Society Section A: Chemistry 5(2):751-762. *http://doi.org/10.18596/jotcsa.363151*

Tilami SK, Kouřimská L (2022). Assessment of the nutritional quality of plant lipids using atherogenicity and thrombogenicity indices. Nutrients 14(18):3795. *https://doi.org/10.3390/nu14183795*.

Tonguç M, Erbaş S (2012). Evaluation of fatty acid compositions and some seed characters of common wild plant species of Turkey. Turkish Journal of Agriculture and Forestry 36(6):673-679. *http://doi.org/10.3906/tar-1201-22*

Ulbrich TL, Southgate DA (1991). Coronary heart disease: seven dietary factors. Lancet 338 (8773):985-992. *https://doi.org/10.1016/0140-6736(91)91846-M*.

Vetter W, Darwisch V, Lehnert K (2020). Erucic acid in Brassicaceae and salmon-An evaluation of the new proposed limits of erucic acid in food. Nutrition and Food Science 19:9-15. *https://doi.org/10.1016/j.nfs.2020.03.002*.

Viladomiu M, Hontecillas R, Bassaganya-Riera J (2016). Modulation of inflammation and immunity by dietary conjugated linoleic acid. European Journal of Pharmacology 785:87-95. *https://doi.org/10.1016/j.ejphar.2015.03.095*

Wang P, Xiong X, Zhang X, Wu G, Liu F (2022). A review of erucic acid production in Brassicaceae oil seeds: Progress and prospects for the genetic engineering of high and low-erucic acid rape seeds (*Brassica napus*). Frontiers in Plant Science 13:e899076. *https://doi.org/10.3389/fpls.2022.899076*.

Windsor JB, Symonds VV, Mendenhall J, Lloyd AL (2000). *Arabidopsis* seed coat development: Morphological differentiation of the outer integument. Plant Journal 22:483-493. *https://doi.org/10.1046/j.1365-313x.2000.00756.x.*

World Health Organization (2007). WHO guidelines for assessing quality of herbal medicines with reference to contaminants and residues. Retrieved 2007 June 5th from: *https://www.who.int/publications/i/item/9789241594448*

Zaynab M, Al-Yahyai R, Ameen A, Sharif Y, Ali L, Fatima M, …, Li S (2022). Health and environmental effects of heavy metals. Journal of King Saud University-Science 34(1):101653. *https://doi.org/10.1016/j.jksus.2021.101653*.

The journal offers free, immediate, and unrestricted access to peer-reviewed research and scholarly work. Users are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles, or use them for any other lawful purpose, without asking prior permission from the publisher or the author.

License - Articles published in ***Notulae Botanicae Horti Agrobotanici Cluj-Napoca*** are Open-Access, distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) License.
© Articles by the authors; Licensee UASVM and SHST, Cluj-Napoca, Romania. The journal allows the author(s) to hold the copyright/to retain publishing rights without restriction.

Notes:

- Material disclaimer: The authors are fully responsible for their work and they hold sole responsibility for the articles published in the journal.
- Maps and affiliations: The publisher stay neutral with regard to jurisdictional claims in published maps and institutional affiliations.
- Responsibilities: The editors, editorial board and publisher do not assume any responsibility for the article's contents and for the authors' views expressed in their contributions. The statements and opinions published represent the views of the authors or persons to whom they are credited. Publication of research information does not constitute a recommendation or endorsement of products involved.