

<https://doi.org/10.48047/AFJBS.6.16.2024.38-61>



African Journal of Biological Sciences

Journal homepage: <http://www.afjbs.com>



Research Paper

Open Access

Effects of Germination on the Physicochemical, Functional, and Nutritional Properties of Garden Cress Seeds (*Lepidium sativum* L.)

Kaissa Boudieb^{1,2*}, Djamila Aroune^{1,3}, Nabila Hamza^{1,4}, Yasmina Ouzid^{1,5}, Imane Boudiab¹ & Nabila Badi¹

¹ University of M'hamed Bougara of Boumerdes, Faculty of Sciences, 35000, Boumerdes, Algeria

² University of M'hamed Bougara of Boumerdes, Faculty of Sciences, Laboratory of Soft Technology, Valorization, Physical-Chemistry of Biological Materials and Biodiversity, 35000, Boumerdes, Algeria

³ University of Science and Technology Houari Boumediene, Faculty of Biological Sciences, Laboratory of Biology and Physiology of Organisms, Nutrition and Metabolism Alger, Algeria

⁴ University of M'hamed Bougara of Boumerdes, Faculty of Sciences, Laboratory of Valorization and Conservation of Biological Resources, 35000, Boumerdes, Algeria

⁵ Mouloud Mammeri University, Faculty of Biological and Agronomic Sciences, Department of Biochemistry and Microbiology, Laboratory of Analytic Biochemistry and Biotechnology, Tizi-Ouzou, 1500, Algeria

*Corresponding author: k.boudieb@univ-boumerdes.dz

Volume 6, Issue 16, Dec 2024

Received: 15 Oct 2024

Accepted: 20 Nov 2024

Published: 02 Dec 2024

[doi: 10.48047/AFJBS.6.16.2024.38-61](https://doi.org/10.48047/AFJBS.6.16.2024.38-61)

Abstract

This study investigated the physicochemical and phytochemical transformations occurring in *Lepidium sativum* L. seeds following an eight-day germination period. A comprehensive analysis was conducted on both non-germinated and germinated seeds, encompassing germination kinetics, physicochemical properties, particle size distribution, microstructure using scanning electron microscopy (SEM), Fourier-transform infrared (FTIR) spectroscopy, and gas chromatography-mass spectrometry (GC-MS). The results demonstrated a high germination rate and notable metabolic alterations during the germination process. The germinated seeds exhibited increased moisture content, acidity, and mineral levels, which were statistically significant ($p < 0.05$). Microscopic analysis revealed notable microstructural alterations, while FTIR confirmed modifications in functional groups, particularly an increase in the intensity of the O-H stretching band. Notably, GC-MS analysis demonstrated a substantial increase in linoleic acid within the lipid profile of germinated seeds. These findings underscore the considerable biochemical and structural changes induced by germination in *L. sativum* seeds and highlight their potential as a rich source of bioactive compounds for food and pharmaceutical applications.

Keywords: *Lepidium sativum*, seed germination, FTIR spectroscopy, GC-MS, lipid profile, microstructure analysis

Introduction

Garden cress (*Lepidium sativum* L.), a member of the Brassicaceae family, is a fast-growing annual herb that is widely cultivated for its nutritional and medicinal properties (Ramadan and Oraby, 2020). Historically, cress seeds have been employed for their therapeutic benefits, exhibiting a high nutritional profile comprising proteins, lipids, vitamins, and minerals, including calcium, iron, magnesium, and phosphorus. These nutritional attributes render them indispensable for a balanced diet and for the prevention of conditions such as osteoporosis and anemia (Raj et al., 2020; Syeda Kaniz et al., 2022; Bhatia and Bhasin, 2023).

In addition to their nutritional value, cress seeds have been demonstrated to possess a range of pharmacological properties, including antidiabetic, hypocholesterolemic, antihypertensive, anti-inflammatory, and antioxidant activities. The therapeutic effects of *L. sativum* are attributed to the bioactive compounds present in the plant, making it a particularly attractive subject for investigation by the pharmaceutical and food industries (Baregama & Goyal, 2019; Sharma, 2020; Shah et al., 2021; Waheeb and Makki, 2023).

Additionally, cress seeds are distinguished by their high concentration of essential fatty acids, including linolenic acid and oleic acid, along with phytosterols such as β -sitosterol and campesterol, and tocopherols. These components contribute to the antioxidant and anti-inflammatory properties of the seed oil, thereby conferring benefits for cardiovascular health and cholesterol regulation (Rezig et al., 2022). The increasing consumer demand for natural and health-promoting foods has led to a growing interest in cress seeds due to their versatile medicinal and nutritional properties (Bhatia and Bhasin, 2023).

While the nutritional composition of cress seeds has been extensively studied (Singh et al., 2015; Al-Sayed et al., 2019; Kanabur & Sharavathi, 2022; Tufail et al., 2024), the effects of germination on their physicochemical and biological properties remain relatively unexplored. Germination is a complex physiological process that activates key enzymes, leading to the breakdown of macromolecules and the synthesis of new bioactive compounds, including phenols, flavonoids, and antioxidants (Rahate et al., 2021; Ramos-Pacheco et al., 2024).

These biochemical transformations enhance the digestibility of nutrients, the bioavailability of minerals, and reduce antinutritional factors such as phytates (Malhotra et al., 2023; Ramos-Pacheco et al., 2024). Furthermore, germination alters the lipid profile of seeds,

enriching them with antioxidants and thereby enhancing their potential for preventing chronic diseases such as cardiovascular disease and diabetes (Bhatia and Bhasin, 2023).

Prior research on the germination of diverse seeds, including quinoa, sesame, rapeseed, and mustard, has revealed enhancements in physicochemical attributes and augmented concentrations of bioactive compounds (Atlaw et al., 2018; Belt et al., 2023; Ramos-Pacheco et al., 2024).

Based on these findings, the present study aims to investigate the impact of germination on the composition of oils, mineral content, functional groups, microstructure, and particle size distribution in *Lepidium sativum* powders, both before and after an 8-day germination period. The specific modifications induced by germination will be examined with the aid of spectroscopic (FTIR), chromatographic (GC-MS), and particle size analysis techniques, with a particular focus on essential fatty acids. A deeper understanding of these germination-driven transformations could enhance the potential of *Lepidium sativum* as a functional ingredient in food and therapeutic applications

Materials and Methods

Garden cress (*Lepidium sativum* L.) seeds were obtained from a local herbalist in Boumerdès. The seeds were divided into two groups: a control group (non-germinated) and an experimental group subjected to germination. Dry seeds were ground into a fine powder using an electric grinder and stored under airtight conditions to preserve sample integrity.

For the experimental group, seeds were germinated. After an eight-day germination period, the sprouted seeds were dried at room temperature and then ground into a fine powder.

The powders from both groups were then subjected to a comprehensive analytical protocol.

Germination Experiments

Standard germination tests were conducted following the guidelines of the International Seed Testing Association (ISTA, 2000). A total of 120 seeds were evenly distributed across three Petri dishes (40 seeds per dish), each lined with moistened filter paper. The Petri dishes were incubated at a constant temperature of 23–25°C, with regular moisture replenishment. Germination was monitored daily for eight days, with radicle emergence used as the criterion for germination, as described by Baskin and Baskin (1998).

To assess germination kinetics, the total germination rate (TGR), mean germination time (MGT), and coefficient of velocity (CV) were calculated according to methods outlined by Bewley and Black (1994), Maguire (1962), and Kotowski (1926).

Physicochemical Characterization

The physicochemical properties of both non-germinated and germinated seed powders were determined. Moisture content was assessed using the ISTA method (ISTA, 2007). Ash content was determined through incineration, following the AOAC standard method (AOAC, 2016). The pH was measured using a pH meter, a standard electrochemical technique for determining solution acidity.

Scanning Electron Microscopy (SEM)

The morphological characteristics of *Lepidium sativum* seed powders, both non-germinated and germinated, were examined using scanning electron microscopy (SEM). A Quanta 650 field emission scanning electron microscope was employed to capture high-resolution images at magnifications up to 1,000,000x. Samples were prepared according to standard protocols involving fixation, dehydration, and gold coating to ensure optimal image quality. SEM analysis provided detailed topographical information on the surface structure of the seed powders (Bortoluzzi et al., 2012).

Fourier-Transform Infrared Spectroscopy (FTIR)

Fourier-transform infrared (FTIR) spectroscopy was employed to characterize the functional groups present in the *Lepidium sativum* seed powders. Approximately 3 mg of powdered sample was mixed with 300 mg of spectroscopic-grade potassium bromide (KBr) and pressed into a translucent pellet under vacuum. The FTIR spectra were recorded in the mid-infrared region (4000-400 cm^{-1}) to identify characteristic functional groups.

Atomic Absorption Spectrometry (AAS)

Elemental composition of the seed powders was determined by atomic absorption spectrometry (AAS) using an Analytik Jena spectrometer. Samples were subjected to dry ashing at 800°C for 8 hours to mineralize organic matter. The resulting ash was dissolved in

concentrated hydrochloric acid, filtered, and diluted with distilled water prior to analysis. The concentrations of zinc, iron, potassium, magnesium, and calcium were quantified by measuring the absorbance of specific wavelengths corresponding to each element.

Laser Particle Size Analysis

Particle size distribution of the seed powders was determined using a LA-950 laser particle size analyzer. The instrument operates on the principle of laser diffraction, measuring particle size by analyzing the diffraction pattern generated as a laser beam interacts with the sample. The system was equipped with two analysis modules to accommodate both dry powders (range: 0.1-3000 μm) and liquid suspensions (range: 0.01-3000 μm). Data analysis was performed using OPEXCEL software to obtain particle size distribution parameters.

Lipid Extraction and GC-MS Analysis

Approximately 20 grams of *Lepidium sativum* seed or sprout powder was accurately weighed and placed in a Soxhlet thimble. The sample was extracted with 200 mL of n-hexane for 6 hours. The resulting extract was concentrated under reduced pressure using a rotary evaporator and stored at 4°C in a sealed container until further analysis.

Gas chromatography-mass spectrometry (GC-MS) was employed to characterize the lipid profile. The GC-MS analysis was performed on a Shimadzu GC-MS-QP2010 Ultra system equipped with an RTX-5MS capillary column (30 m \times 0.25 mm internal diameter, 0.25 μm film thickness). Helium was used as the carrier gas at a flow rate of 1 mL/min. The GC oven temperature program was as follows: initial temperature of 50°C held for 2 min, ramped at 10°C/min to 280°C, and held for 10 min. 1 μl of sample was injected in splitless mode at an injector temperature of 300°C. Mass spectra were acquired in electron impact ionization mode at 70 eV over a mass range of 50-500 m/z. Compound identification was achieved by comparing mass spectra with authentic standards.

Statistic Analysis

Analyses of moisture, ash, pH, and mineral content were performed in triplicate, and results are expressed as mean values with standard deviation (\pm SD). Analysis of variance

(one-way ANOVA), followed by Tukey's HSD test, was conducted to determine significant differences between group means ($p < 0.05$) using Statistica 7.1 (StatSoft Inc, France).

Results and discussions

Germination results

Table 1. Germination rate and related parameters of garden cress seeds

Parameters	TGR (1d)	TGR (2d)	TGR (3d)	MGT (d)	CV
Results	75%	86.66%	100%	1.36	73.14

TGR: Total Germination Rate, MGT: Mean Germination Time (in days), CV: Coefficient of Variation

The present study demonstrated that the seeds of *Lepidium sativum* exhibited rapid and uniform germination (Table 1), with a germination rate of 75% as early as the first day, increasing to 86.66% by the second day, and achieving complete germination (100%) by the third day. The mean germination time (MGT) of 1.36 days and the coefficient of variation (CV) of 73.14% indicate that germination occurred rapidly and synchronously. These findings are in accordance with the observations made by Demir et al. (2019), who similarly reported high and rapid germination rates for a range of cress cultivars. The high seed vigour observed in our study, characterized by a final germination rate of 100% and a short mean germination time, serves to highlight the agronomic potential of cress. These results have direct implications for microgreen production, where rapid and uniform germination is essential for achieving high-quality products.

Physicochemical Characterization

Table 2. Moisture, ash, and pH content of cress seeds and seedlings

Parameters	Dry cress seeds		Seedlings cress seeds		P
	Means	\pm SD	Means	\pm SD	
Moisture (%)	8.31 ^b	0.11	13.70 ^a	0.52	<0.05
Ash (%)	3.98 ^b	0.17	5.36 ^a	0.47	<0.05
pH	5.67 ^a	0.05	5.26 ^b	0.02	<0.05

Data are presented as mean \pm SD: standard deviation. Different letters (a, b) indicate significant differences between means within the same row with unlike superscripts differ at $P < 0.05$

As demonstrated in Table 2, the chemical composition analysis of cress seeds revealed notable alterations following germination. The moisture content increased significantly, from 8.31% to 13.70% ($p < 0.05$), which is in line with the findings of Gnanwa et al. (2021) on

peanut seeds. This increase is of great significance, as it activates the metabolic processes that occur during germination. Concurrently, the ash content, which serves as an indicator of mineral richness, increased by 1.38%, thereby suggesting a significant mobilisation of mineral reserves. This finding is consistent with those reported by Tok and Ertas (2020) and Gnanwa et al. (2021).

It should be noted, however, that the moisture content and ash content of cress seeds can vary significantly. Zia-Ul-Haq et al. (2011) reported a moisture content of 2.9% and an ash content of 7.1% in garden cress seeds. A lower moisture content is typically associated with enhanced stability, elevated nutritional value, and an extended shelf life (Alsadee and Agbashee, 2021; Bathish et al., 2021).

The observed decrease in pH ($p < 0.05$) is likely attributed to the activation of hydrolytic enzymes, as previously noted by Gnanwa et al. (2021). This acidification may potentially influence the stability of bioactive compounds and the microbiological quality of the product. In conclusion, these results highlight the profound biochemical transformations induced by germination in cress seeds, with direct implications for their nutritional value and stability.

Morphological Analysis of *Lepidium sativum* Seeds and powders

As illustrated in Figure 1a, the seeds of *Lepidium sativum* typically exhibit an oval shape with slight flattening, measuring approximately 3-4 mm in length and 1-2 mm in width. This observation was previously documented by Doke and Guha (2014). These dimensions are consistent with the typical morphology of seeds in the Brassicaceae family, which is characterized by small, reddish-brown seeds with a reticulated integument (Kreitschitz and Gorb, 2018).

A scanning electron microscope (SEM) analysis has revealed a complex morphology comprising a range of specialized structures (Figure 1b). The epidermal cells, which feature thickened walls and punctations, collectively form a protective network. Moreover, the presence of waxy deposits on the seed surface endows it with hydrophobic properties, which facilitate dispersion and resist desiccation. This hydrophobicity represents a significant adaptation, corroborating the findings of Patat et al. (2022) regarding genetic diversity within the species.

The presence of pores and microstructures, such as papillae (Figure 1bd), suggests potential adsorbent properties, thereby enhancing the seeds' ability to interact with their environment (Hashem et al., 2022). Additionally notable features include a groove, a wing-like extension (Figure 1c), and a mucilaginous envelope, all of which are specialized for adhesion and germination. These structural adaptations demonstrate that *Lepidium sativum* has evolved effective dispersal, protection, and germination strategies.

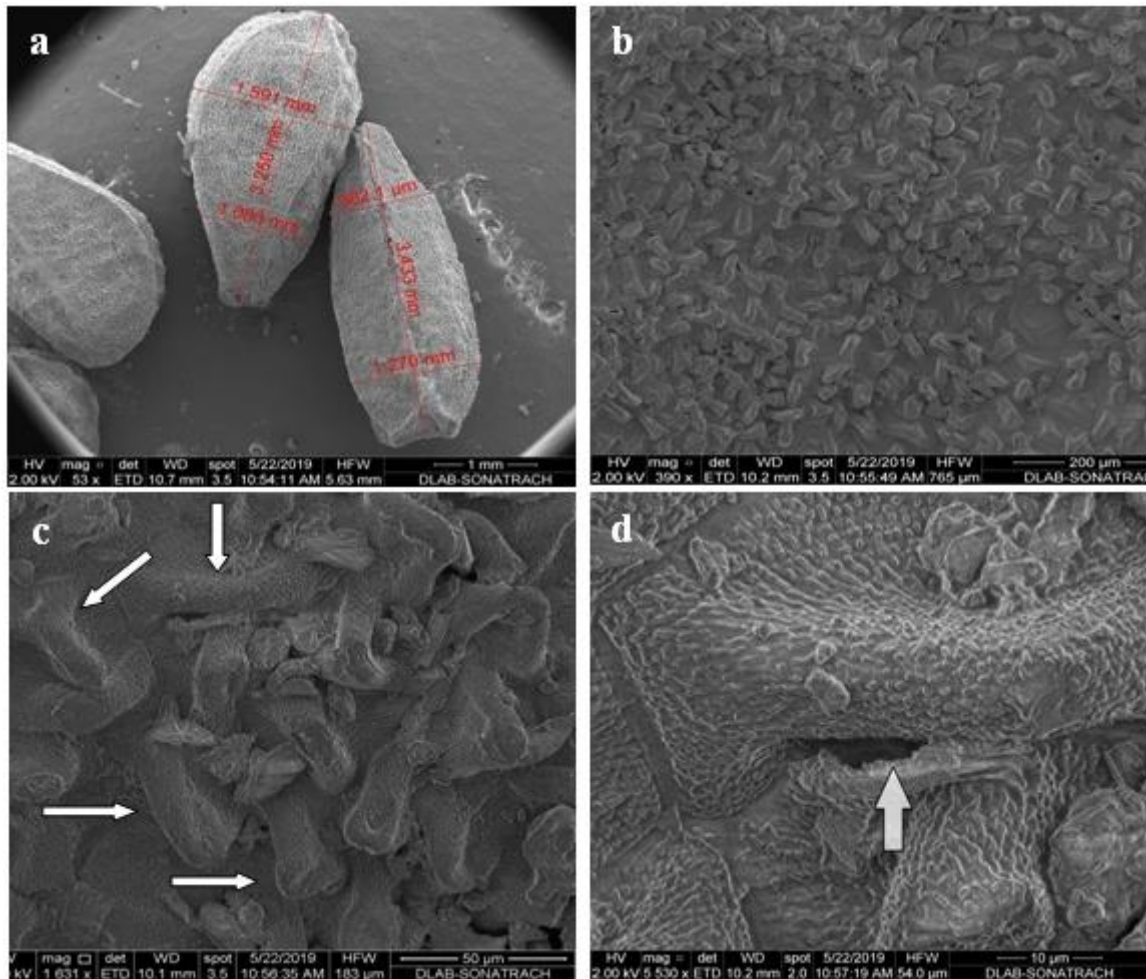


Figure 1. Scanning electron microscopy (SEM) of *Lepidium sativum* seeds (a) Seeds of *Lepidium sativum* ($\times 53$), (b) Seed surface morphology ($\times 390$), (c) Seed surface morphology showing a groove and a wing-like extension ($\times 1631$), (d) Seed surface morphology showing pores and microstructures ($\times 5530$)

A comparative analysis of scanning electron microscopy (SEM) micrographs revealed significant alterations in structure following the eight-day germination of cress seeds (Figure 2). The dry seeds displayed a textured surface and intact cellular structures, indicative of the presence of stored nutrients (Figure 2a). The process of germination resulted in the degradation of these structures, leading to the formation of a finer and more homogeneous texture. The presence of radicle and stem fragments, particularly evident in Figure 2b,

indicates the activation of growth processes, marking the transition from dormancy to active growth. This disruption of cellular structures facilitates the release of bioactive compounds. These morphological changes have direct implications for the functional properties of the resulting powders. A reduction in particle size and an increase in porosity enhance the solubility, bioavailability, and bioactivity of the compounds of interest. These characteristics make powders from germinated seeds particularly attractive for the food and pharmaceutical industries, opening new avenues for the development of high-value products such as functional food supplements and cosmetic ingredients.

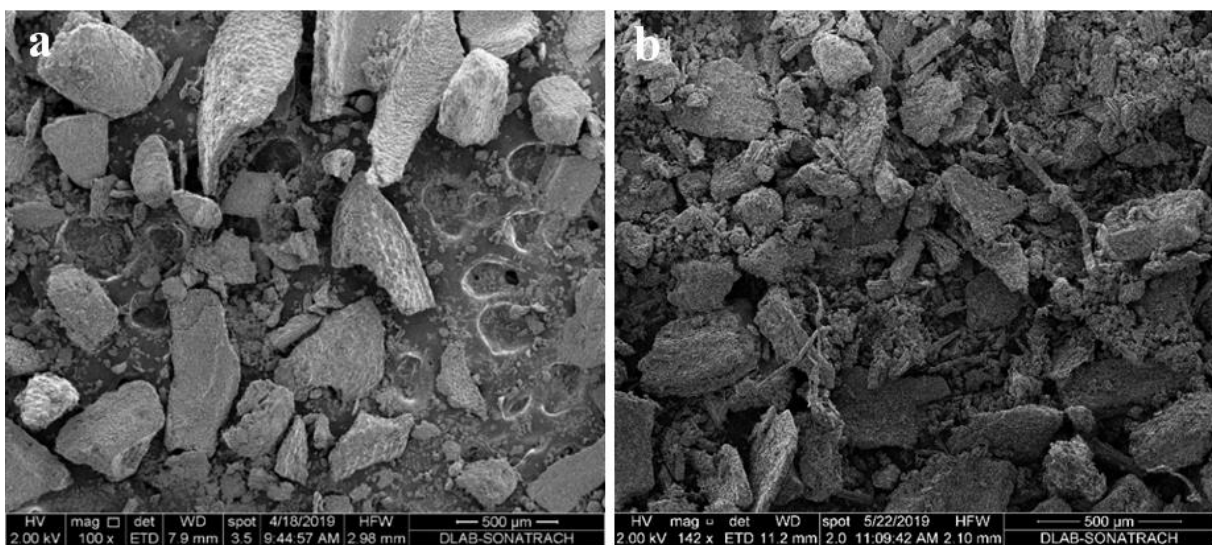


Figure 2. Scanning electron microscopy (SEM) micrographs of both powders
(a) dry cress seeds powder (x 100), (b) seedling cress seeds powder (x 142)

Fourier-Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy is a valuable tool for studying the biochemical changes that occur during germination. It can identify functional groups in biological samples based on their characteristic absorption bands. This technique was used to characterize the molecular composition of *Lepidium sativum* L. seeds and seedlings.

The FTIR spectra of both samples are presented in Figure 3 a-b. They exhibited characteristic absorption bands indicative of the various functional groups present in plant tissues. A broad and intense band observed between 3700 and 3000 cm^{-1} is attributed to O-H stretching vibrations, predominantly from alcohols and phenolic compounds. The higher transmittance observed in the seedlings compared to the seeds suggests the potential for differences in hydration or the presence of hydroxyl-containing compounds.

Chumroenphat et al. (2021) indicate that the absorption peaks were observed throughout the wavenumbers, including those of the phenolic compounds, which exhibited their characteristic peaks at 3291 cm^{-1} (phenolic O-H stretching vibration), 2930 cm^{-1} (C-H stretching), 1639 cm^{-1} (aromatic moiety C=C stretching), 1539 cm^{-1} (C-O-C stretching), and 1050 cm^{-1} (C-O-C stretching).

The presence of phenolic acids was confirmed in pigeon pea (*Cajanus cajan* (L.) Huth) seeds. This finding aligns with the observation that prolonged germination periods may enhance the concentration of phenolic acids (Papayrata et al., 2024).

The spectral region between 3000 and 2600 cm^{-1} exhibited C-H stretching vibrations, which are characteristic of aldehydes. A broad, weak band between 2600 and 1800 cm^{-1} was attributed to S-H stretching vibrations, indicating the presence of sulfur-containing compounds, particularly in seeds. The presence of a $\text{C}\equiv\text{C}$ stretching band in the seed spectrum indicates a higher content of alkyne-containing compounds in comparison to the seedlings. The region between 1800 and 1200 cm^{-1} exhibited a variety of carbonyl stretching vibrations, including C=O stretching of carboxylic acids, esters, and potentially alcohols or phenols. The band between 1200 and 900 cm^{-1} is attributable to C-C stretching and bending vibrations of alkanes (Table 3).

FTIR spectroscopy analysis of *Lepidium sativum* seeds and seedlings revealed notable molecular modifications during germination. The observed increase in the intensity of the O-H stretching band at 3300 cm^{-1} in seedlings relative to seeds indicates a significant enhancement in hydration, a common phenomenon during germination (Djordjević et al., 2023). The presence of sulfur-containing compounds and alkynes indicates the diversity of molecular modifications that are induced by germination. These findings corroborate the intricate nature of the biochemical processes underlying germination and underscore the significance of these molecular modifications for the nutritional and functional attributes of germinated seeds, as observed in other species, including cereals (Kaur et al., 2021), Bambara groundnut (Chinma et al., 2021), mung bean (Sofi et al., 2023), and chickpea (Mao et al., 2024).

Infrared spectroscopy was employed to elucidate the structural changes that occur during the germination process. The study conducted by Ramos-Pacheco et al. (2024) on *Chenopodium quinoa* Willd. revealed a change in color and an increase in protein, fiber, mineral, phenolic compound, flavonoid, and antioxidant capacity after 72 hours of

germination. This phenomenon was attributed to the activation of enzymatic pathways. Germination represents a promising avenue for the development of functional ingredients derived from germinated quinoa flour, exhibiting enhanced nutritional and functional attributes.

Our identification corroborated the presence of the detected phytochemicals, thereby underscoring the role of germination in enhancing the antioxidant capacity of *Lepidium sativum* L.

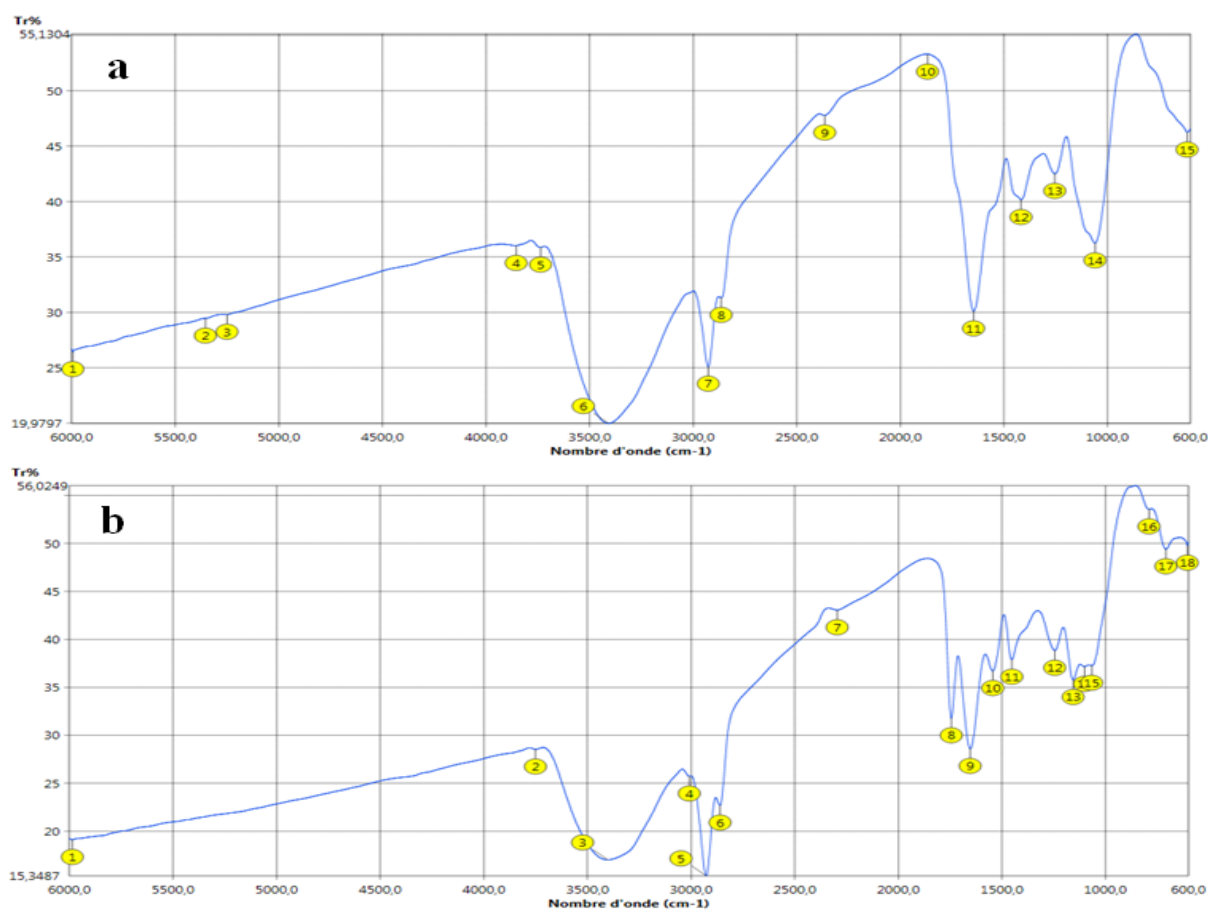


Figure 3. Fourier Transform Infrared Spectroscopy (FTIR) spectra of *Lepidium sativum* L.

(a) dry cress seeds powder, (b) seedling cress seeds powder

Table 3. Characteristic absorption peaks of FTIR pectroscopy of *Lepidium sativum* L. seeds and seedling, assigned functional groups

Wavenumber peak (cm ⁻¹)	Coumpound	Transmittance (%)
3751	Phenols (O-H)	28.534
3402	Alcohols (OH intramolecular)	17.015
3008	Alkene (elongation =C-H)	25.723
2927	Alkane	15.349
2860	Alkane	22.698
2295	Alkyne	43.053

1744	Anhydrides	31.794
1653	Amide	28.608
1544	Amide	36.716
1452	Alkane	37.902
1245	Ester	38.846
1156	Alcohol	35.795
1101	Alcohol	37.158
1067	Alcohol	37.271

Atomic Absorption Spectrometry (AAS)

Table 4. Mineral concentrations (mg/100g) in cress seeds and seedlings (8 days after germination)

Mineral compounds	Dry cress seeds		Seedlings cress seeds		P
	Means	±SD	Means	±SD	
Calcium (Ca)	398.6 ^b	6.21	130.3 ^a	3.84	<0.05
Magnesium (Mg)	530.50 ^b	7.39	593.50 ^a	2.17	<0.05
Potassium (K)	219.83 ^b	2.31	234.96 ^a	1.96	<0.05
Zinc (Zn)	9.48 ^a	0.07	1.20 ^b	0.10	<0.05
Iron (Fe)	8.22 ^a	0.06	7.18 ^b	0.01	<0.05

Data are presented as mean ±standard deviation. Different letters (a, b) indicate significant differences between means within the same row with unlike superscripts differ at P <0.05

The results of our investigation demonstrate notable fluctuations in the mineral composition of cress seeds during the germination process, as illustrated in Table 4. The calcium content decreased notably, from 398.6 mg/100 g to 130.3 mg/100 g, in accordance with the findings of Benincasa et al. (2019). This reduction is primarily attributed to the mobilization of calcium reserves to support the metabolic demands of the developing seedling (Negi et al., 2023). Furthermore, the leaching of calcium ions during imbibition, as proposed by Bisht *et al.* (2024), may also be a contributing factor to this decline.

Conversely, the potassium content increased significantly (P < 0.05) from 219.83 mg/100 g to 234.96 mg/100 g, reflecting its crucial role in regulating cellular osmolarity and activating enzymes (Weng et al., 2022). Additionally, magnesium levels exhibited a slight increase, from 530.50 mg/100g to 593.50 mg/100g, which is consistent with its role as an essential enzymatic cofactor in energy metabolism (Weng et al., 2022).

The zinc content exhibited a marked decline, decreasing from 9.48 mg/100 g to 1.20 mg/100 g. This suggests that the redistribution of this element to growing tissues may be a contributing factor (Tondey et al., 2022). This decrease may be attributed to an increased

demand for zinc in the synthesis of new proteins and enzymes, or to yet unidentified regulatory mechanisms.

The iron content remained relatively stable, ranging from 8.22 mg/100 g to 7.18 mg/100 g. This indicates that effective homeostatic mechanisms are in place to prevent toxic accumulation (Connorton et al., 2017; Roschztardt et al., 2020; Grant-Grant et al., 2022). Mineral fluctuations during germination are indicative of the evolving metabolic needs of the seedling. The concomitant decrease in calcium and zinc, coupled with the increase in potassium and magnesium, underscores the significance of these elements in cellular processes.

Laser Particle Size Analysis

Laser diffraction analysis, as demonstrated in Figure 4, revealed a relatively narrow particle size distribution for both *Lepidium sativum* L. seeds and seedlings. The seeds exhibited a size range of 11.56 to 1754.61 μm , with a median diameter of 453.85 μm . Following germination, the particle size distribution shifted to a range of 5.86 to 1754 μm , with a reduced median diameter of 370.85 μm , representing an 18.5% decrease. These results, which were corroborated by scanning electron microscopy (Figure 2), indicate a significant reduction in particle size following germination.

This finding is consistent with prior research indicating the impact of germination on the physicochemical properties of seeds. During the germination process, enzymatic activity, particularly the activation of hydrolases, facilitates the breakdown of complex macromolecules, including proteins, starch, and fibers. This process results in a reduction in particle size, as evidenced by observations made on a variety of seeds, including black beans (Wang et al., 2024).

The observed reduction in particle size has significant implications for the functional properties of germinated seeds. The reduction in particle size generally results in enhanced solubility, accelerated hydration rates, and an increased surface area, which facilitates more efficient extraction of bioactive compounds (Recharla et al., 2017). These characteristics render germinated seeds a valuable resource in a variety of food applications, including the development of nutritional products for infants, athletes, and individuals seeking specialized diets. Furthermore, our findings are in accordance with those of Zhu and Li (2019), who demonstrated the impact of particle size on the physicochemical properties of quinoa flour and the antioxidant activity.

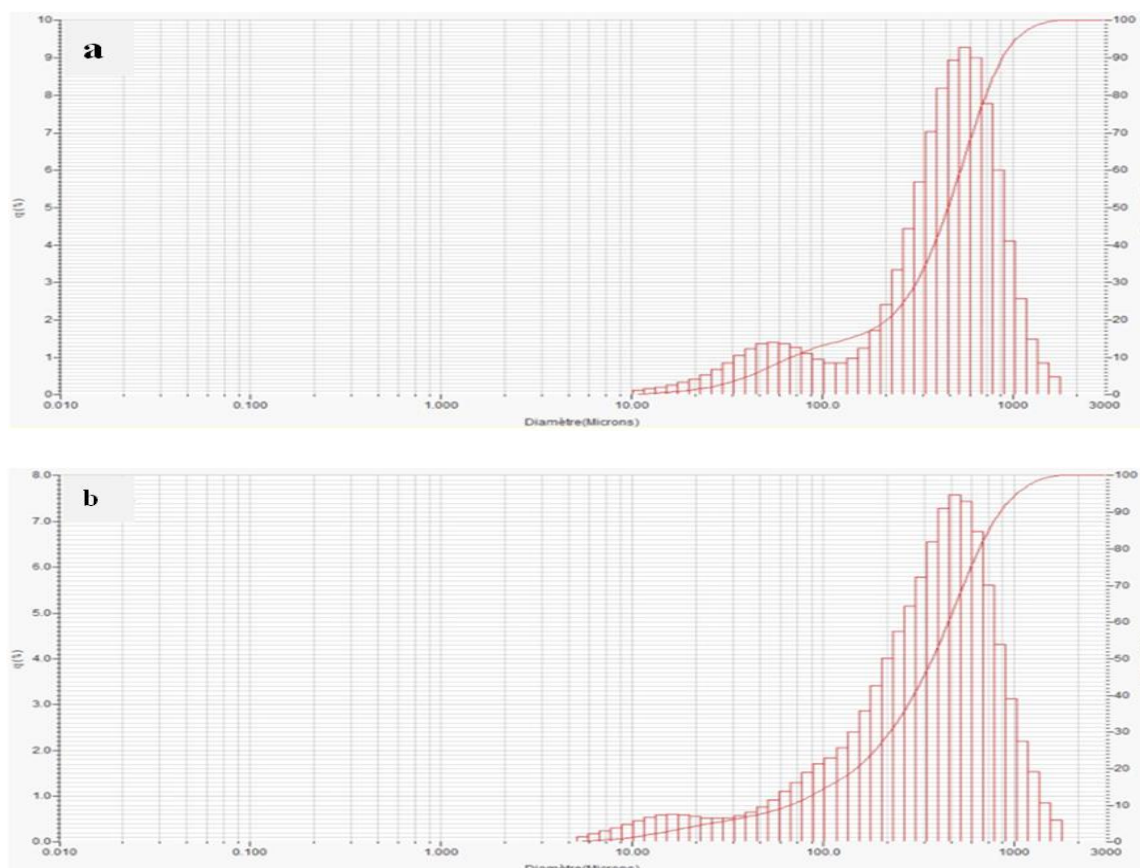


Figure 4. Particle size distribution of *Lepidium sativum* L. (cress) powders
(a) dry cress seeds powder, (b) seedling cress seeds powder

Lipid GC-MS Analysis

Table 5. Comparative lipid profile of *Lepidium sativum* seeds before and after germination by GC/MS analysis

Peak No.	Retention time(min) (Before)	Compound Name	Chemical formula	Compound class	Percentage (%) (Before)	Retention time(min) (After)	Percentage (%) (After)
1	16.675	Linoleic acid	C ₁₈ H ₃₂ O ₂	Omega-6 polyunsaturated fatty acid	64.594	17.318	85.184
2	22.209	Monoolein	C ₅₁ H ₉₈ O ₄	Monounsaturated fatty acid derivative	0.328	19.738	0.318
3	28.074	1-Monolinolenin	C ₅₇ H ₁₀₄ O ₆	Omega-3 polyunsaturated fatty acid	0.417	23.284	0.322
4	—	Erucic acid	C ₂₂ H ₄₂ O ₂	Omega-9 monounsaturated fatty acid	—	24.228	0.213
5	—	Glycidyleolate	C ₂₁ H ₃₈ O ₃	glycerol ester	—	27.391	0.244
7	33.257	γ-Tocopherol	C ₂₈ H ₄₈ O ₂	Vitamin E, unsaturated fatty acid	4.618	33.317	1.005

8	33.869	β -Sitosterol	$C_{29}H_{50}O$	Sterol	2.575	33.959	2.960
9	34.211	Stigmasterol	$C_{29}H_{48}O$	Sterol	4.221	34.281	0.778
10	—	α -Tocopherol	$C_{29}H_{50}O_2$	Vitamin E	—	34.642	0.507
12	—	Stigmasterol acetate	$C_{31}H_{50}O_2$	Sterol ester	—	36.520	0.823
13	37.294	γ -Sitosterol	$C_{29}H_{50}O$	Sterol	10.057	37.434	4.927

As evidenced by the data presented in Table 5 and Figures 5 and 6, the results indicate a considerable increase in linoleic acid (C18:2) concentration during the germination of garden cress (*Lepidium sativum*) seeds, reaching 85.1 8% after eight days, a notable rise from the initial 64.59 %. This increase is consistent with previous research on other species of the Brassicaceae family, including sacha inchi, Peruvian quinoa, and mustard seeds (Chandrasekaran and Liu, 2011; Pachari Vera et al., 2019; Belt et al., 2023). These findings underscore the pivotal role of this polyunsaturated fatty acid (PUFA) during the nascent stages of plant development. The observed increase in linoleic acid content is likely due to the activation of Δ -12 fatty acid desaturase (FAD2), a key enzyme in polyunsaturated fatty acid (PUFA) biosynthesis, as demonstrated by Lakhssassi et al. (2017). Linoleic acid exerts its influence on essential cellular processes, including signal transduction, membrane transport, and enzymatic activity, by modulating membrane fluidity (Zhang et al., 2024). Moreover, as a precursor of eicosanoids and docosanoids, it plays a role in the stress response and pathogen defense (Mercola et al., 2023). These properties, in conjunction with its role in growth and development, render linoleic acid a compound of considerable interest within the field of plant biology.

In addition to its significance for plant biology, linoleic acid offers substantial advantages for human health. Indeed, it contributes to the maintenance of good cardiovascular, skin, and metabolic health (Kapoor et al., 2021; Manosalva et al., 2024). The findings underscore the nutritional value of sprouted garden cress seeds, which are a rich source of linoleic acid. The elevated concentration of this indispensable fatty acid, discerned following eight days of germination, suggests the potential for developing novel functional foodstuffs.

Monoolein is a monoglyceride consisting of a glycerol molecule esterified with a single oleic acid. It is a monounsaturated fatty acid derivative that demonstrated relative stability during the germination process, with a slight decrease from 0.328% to 0.318 %. This stability highlights monoolein's distinctive role in both membrane maintenance and lipid metabolism (Nautiyal et al., 2023). In contrast to triglycerides, which are extensively metabolized for

energy, monoolein is consumed in a controlled manner, reflecting its strategic importance. It serves as both an energy intermediary and a stabilizing component of cellular membranes, fulfilling a balanced but essential role in the germination process (Nautiyal et al., 2023). This comparative analysis underscores the multifunctional significance of monoolein in lipid dynamics during seed germination (Weitbrecht et al., 2011).

The findings of our study indicated a slight reduction of 0.95 % in 1-monolinolein content, a monoacylglycerol derived from linoleic acid, within *Lepidium sativum* seeds during the germination process. This suggests that a notable mobilization of lipids occurs during this stage.

The underlying mechanisms involve the action of specific lipases, which catalyze the hydrolysis of triacylglycerols, releasing free fatty acids, including linoleic acid. These can subsequently undergo β -oxidation, thereby providing energy for seedling growth (Fan et al., 2017). Furthermore, our findings align with those of Song et al. (2019), who have demonstrated that hormonal signaling, particularly through gibberellins, stimulates lipid breakdown in *Fraxinus hupehensis*. It is noteworthy that recent research has underscored the role of epigenetic modifications in regulating seed germination (Zhao et al., 2024). It is plausible that these modifications exert an influence on lipid metabolism and, consequently, on the concentration of 1-monolinolein in *Lepidium sativum*. The results of this study indicate that the mobilization of 1-monolinolein, a crucial component of the seed lipid reserve, is a vital process in providing the energy necessary for successful germination.

The concentration of erucic acid (C22:1), a long-chain fatty acid, in cress seed oil increased during the germination process, reaching a concentration of 0.213 % on the eighth day. This increase indicates the occurrence of a specific metabolic adaptation associated with the germination process. Prior research has indicated the potential involvement of erucic acid in plant stress responses. For example, Ai et al. (2024) demonstrated in *Brassica napus* that erucic acid plays a pivotal role in the tolerance of water stress during germination. Although the present study did not impose specific stress conditions, the observed increase in erucic acid may be attributed to a reorganization of lipid metabolism induced by germination. It is reasonable to hypothesize that erucic acid serves as an energy source, influences membrane fluidity, or is involved in the synthesis of specific lipid compounds essential for embryonic development.

Similar findings have been reported for other species within the Brassicaceae family, including *Brassica rapa* (Pagnotta et al., 2022). These studies collectively indicate that the

accumulation of erucic acid during germination may represent a common adaptive mechanism across the Brassicaceae family, enabling seeds to cope with the energetic and environmental demands of early development.

Notable fluctuations were observed in the concentrations of the principal sterols throughout the germination process of *Lepidium sativum*. The most substantial decline was observed in campesterol, which decreased from 5.804 % to 0.778 %, representing an 82% reduction. There was a slight increase in β -sitosterol (8%), while γ -sitosterol exhibited a notable decline of 51 %.

This overall decrease in sterols is consistent with observations in other species of the Brassicaceae family, including *Brassica napus* and *Raphanus sativus* (Bellani et al., 2012; Belt et al., 2023). This evolutionary trajectory indicates that sterols are subjected to intensive utilization during the initial stages of development. Indeed, sterols play a pivotal role in the stabilization of cell membranes, which undergo rapid expansion during germination, as well as in the biosynthesis of brassinosteroids, plant hormones that are essential for growth and stress response (Rogowska and Szakiel, 2020).

The specific decrease in campesterol and γ -sitosterol may indicate a preferential use of these sterols in brassinosteroid biosynthesis or in other metabolic processes specific to germination. It is similarly conceivable that additional factors, such as the germination conditions or the variety of cress, may exert an influence on the sterol profiles observed. The study of *Lepidium sativum* seeds revealed a notable alteration in tocopherol composition during the germination process. It is noteworthy that there was a marked decrease in γ -tocopherol levels, from 4.618 % to 1.005 %, while α -tocopherol, which was initially absent, emerged as the predominant form at 0.507 %. This transition indicates a metabolic adaptation to meet the increased antioxidant demands of the developing seedling.

This pattern is consistent with findings from studies on other species within the Brassicaceae family, including *Brassica napus* and *Brassica juncea*. A reduction in γ -tocopherol and an accompanying increase in α -tocopherol have also been documented in other species during the germination process (Fritsche et al., 2017; Belt et al., 2023). This suggests the existence of a conserved mechanism within the Brassicaceae family for enhancing antioxidant protection during the early stages of seedling development.

The observed shift in tocopherol is likely due to the metabolic conversion of γ -tocopherol to α -tocopherol, a process that is activated during germination. α -Tocopherol, the

most biologically active form of vitamin E, provides superior protection against reactive oxygen species (ROS) generated during germination (García-Navarro et al., 2014).

The biosynthesis of tocopherols is susceptible to influence from environmental factors, including light and moisture. In a study conducted by Li et al. (2020), it was demonstrated that the biosynthesis of α -tocopherol is enhanced by light, which is a vital component of photosynthetic activity. Although our study did not impose specific stress conditions, the observed metabolic shifts are likely to reflect intrinsic responses to germination processes.

Our findings are consistent with those of Zhang et al. (2007) in rapeseed, but contrary to the results of Shi et al. (2010) in soybean, who observed a decline in total tocopherols after an initial increase. This suggests that tocopherol dynamics may exhibit species-specific variations contingent on their physiological requirements and the specific stages of germination.

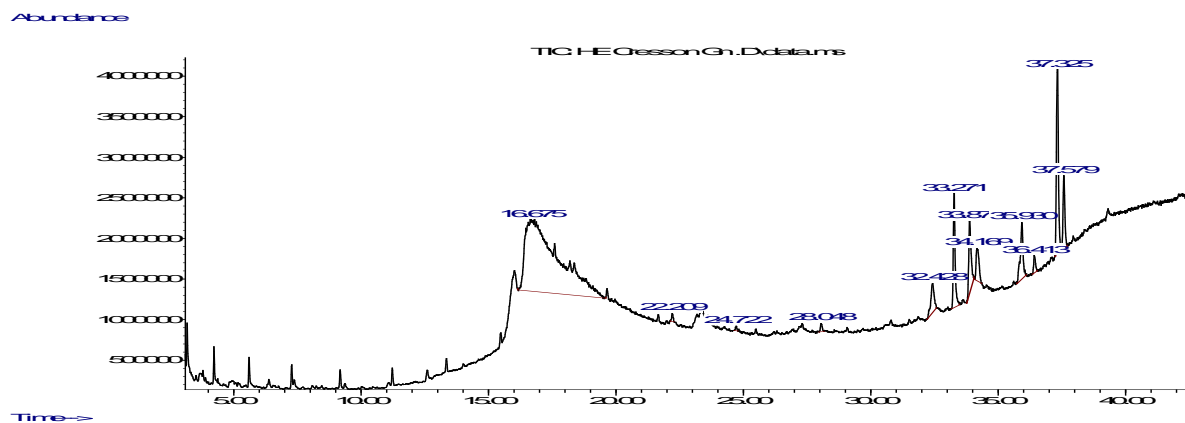


Figure 5. Chromatogram of the chemical profile of dry garden cress seed oils obtained by GC/MS

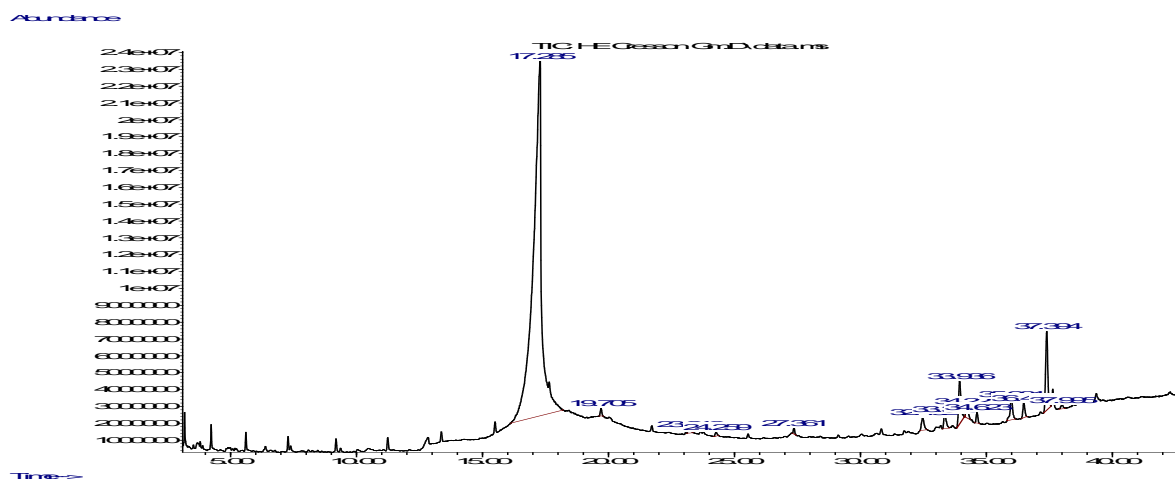


Figure 6. Chromatogram of the chemical profile of germinated garden cress seed oils obtained by GC/MS

Conclusion

The present study offers a comprehensive investigation into the physicochemical and biochemical transformations that occur in *Lepidium sativum* seeds following an eight-day germination period. It is noteworthy that the moisture content increased, the mineral composition changed, and the surface morphology exhibited degradation of cellular structures with increased porosity. These changes, in conjunction with alterations in functional groups identified through FTIR spectroscopy, indicate an increase in metabolic activity. Additionally, germination resulted in a considerable rise in linoleic acid content, a beneficial fatty acid linked to health benefits. Consequently, germinated *Lepidium sativum* seeds exhibit enhanced nutritional and functional characteristics, positioning them as a promising ingredient for innovative food and pharmaceutical applications. Further research is necessary to elucidate the specific mechanisms behind these transformations and to optimize germination conditions to maximize their potential.

References

- Alsadee, A. and Agbashee, S. (2021). Hepato-nephroprotective role of *Lepidium sativum* against oxidative stress induced by dexamethasone in rats. *Indian Journal of Forensic Medicine and Toxicology*, 15(1), 2643-2653. <https://doi.org/10.37506/ijfmt.v15i1.13797>
- Al-Sayed, H.M., Zidan, N.S. and Abdelaleem, M.A. (2019). Utilization of Garden Cress Seeds (*Lepidium sativum* L.) as a natural source of protein and dietary fiber in noodles. *International Journal of Pharmaceutical Research and Allied Sciences*, 8(3), 17-28.
- AOAC International. (2016). *Official Methods of Analysis of AOAC International* (20th ed.). AOAC International, Gaithersburg, MD, USA.
- Atlaw, T.K., Kumar, J.Y. and Satheesh, N. (2018). Effect of germination on nutritional composition and functional properties of Fenugreek (*Trigonella foenum-graecum* Linn) seed flour. *International Journal of Nutrition and Food Sciences*, 7(3), 110-115.
- Baregama, C. and Goyal, A. (2019). Phytoconstituents, pharmacological activity, and medicinal use of *Lepidium sativum* Linn.: A review. *Asian Journal of Pharmaceutical and Clinical Research*, 12(4), 45-50. <https://doi.org/10.22159/ajpcr.2019.v12i4.31292>
- Baskin, J.M. and Baskin, C.C. (1998). *Seeds: Ecology, biogeography, and evolution of dormancy and germination*. Academic Press.
- Bathish, Y., El Kilani, N., Dawaba, A. and Farid, Z. (2021). Effect of *Lepidium sativum* gel as an adjunct to non-surgical treatment in management of periodontitis patients Stage (II, III) and Grade (A, B). *Al-Azhar Journal of Dentistry*, 8(2), Article 14. <https://doi.org/10.21608/adjg.2021.48100.1315>
- Bellani, L.M., Salvini, L., Dell'Aquila, A., et al. (2012). Reactive oxygen species release, vitamin E, fatty acid and phytosterol contents of artificially aged radish (*Raphanus sativus* L.) seeds during germination. *Acta Physiologiae Plantarum*, 34, 1789-1799. <https://doi.org/10.1007/s11738-012-0976-0>
- Belt, D., Grygier, A., Siger, A., Kmiecik, D., Spasibionek, S. and Rudzinska, M. (2023). Changes in oil quality and peroxidase activity during germination of rape seeds and mustard seeds. *Applied Sciences*, 13(4), 2196. <https://doi.org/10.3390/app13042196>
- Benincasa, P., Falcinelli, B., Lutts, S., Stagnari, F. and Galieni, A. (2019). Sprouted grains: A comprehensive review. *Nutrients*, 11(2), 421. <https://doi.org/10.3390/nu11020421>
- Bewley, J.D. and Black, M. (1994). *Seeds: Physiology of development, germination and dormancy*. Plenum Press.
- Bhatia, K. and Bhasin, A. (2023). Exploring the versatile potential of garden cress seeds: Therapeutic applications and industrial utilization: A comprehensive review. *Pharma Innovation*, 12(9), 101-108. <https://doi.org/10.22271/tpi.2023.v12.i9b.22647>
- Bisht, D., Mishra, S., Bihani, S.C., et al. (2024). Salt stress tolerance and calcium signalling components: Where we stand and how far we can go? *Journal of Plant Growth Regulation*. <https://doi.org/10.1007/s00344-024-11235-9>
- Grant-Grant, S., Schaffhauser, M., Baeza-Gonzalez, P., Gao, F., Conéjéro, G., Vidal, E.A., Gaymard, F., Dubos, C., Curie, C. and Roschztardt, H. (2022). B3 transcription factors determine

iron distribution and FERRITIN gene expression in embryo but do not control total seed iron content. *Frontiers in Plant Science*, 13, 870078. <https://doi.org/10.3389/fpls.2022.870078>

Hashem, A., Aniagor, C.O., Farag, S., et al. (2022). *Lepidium sativum* seed powder: A novel biosorbent for acid orange 142 dye uptake. *Environmental Processes*, 9, 56. <https://doi.org/10.1007/s40710-022-00607-6>

ISTA (International Seed Testing Association). (2000). *International rules for seed testing*. International Seed Testing Association.

Chandrasekaran, U. and Liu, A. (2015). Stage-specific metabolization of triacylglycerols during seed germination of Sacha Inchi (*Plukenetia volubilis* L.). *Journal of the Science of Food and Agriculture*, 95(9), 1764-1766. <https://doi.org/10.1002/jsfa.6889>

Chinma, C.E., Abu, J.O., Asikwe, B.N., Sunday, T. and Adebo, O.A. (2021). Effect of germination on the physicochemical, nutritional, functional, thermal properties, and *in vitro* digestibility of Bambara groundnut flours. *LWT - Food Science and Technology*, 140, 110749. <https://doi.org/10.1016/j.lwt.2020.110749>

Chumroenphat, H., Somboonwatthanakul, I., Saensouk, S. and Siriamornpun, S. (2021). Changes in curcuminoids and chemical components of turmeric (*Curcuma longa* L.) under freeze-drying and low-temperature drying methods. *Food Chemistry*, 339, 128121. <https://doi.org/10.1016/j.foodchem.2020.128121>

Connorton, J.M., Balk, J. and Rodríguez-Celma, J. (2017). Iron homeostasis in plants - A brief overview. *Metallomics*, 9(7), 813-823. <https://doi.org/10.1039/c7mt00136c>

Demir, I., Kenanoglu, B.B. and Özden, E. (2019). Seed vigour tests to estimate seedling emergence in cress (*Lepidium sativum* L.) seed lots. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 47(3), 881-886. <https://doi.org/10.15835/nbha47311453>

Djordjević, M., Maravić, N., Teofilović, V., Šoronja-Simović, D. and Šereš, Z. (2023). Processing of alfalfa seeds by convective hot air drying, vacuum drying, and germination: Proximate composition, techno-functional, thermal and structural properties evaluation. *Food Chemistry*, 402, 134300. <https://doi.org/10.1016/j.foodchem.2022.134300>

Doke, S. and Guha, M. (2014). Garden cress (*Lepidium sativum* L.) seed—An important medicinal source. *Cellulose*, 9(0.03). <https://doi.org/10.1007/s10570-014-0304-6>

Fritsche, S., Wang, X. and Jung, C. (2017). Recent advances in our understanding of tocopherol biosynthesis in plants: An overview of key genes, functions, and breeding of vitamin E improved crops. *Antioxidants*, 6(4), 99. <https://doi.org/10.3390/antiox6040099>

García-Navarro, E., Pérez-Vich, B. and Velasco, L. (2014). Changes in plastochromanol-8 and tocopherols during germination in Ethiopian mustard lines with contrasting tocopherol levels. *Seed Science Research*, 24, 101-112. <https://doi.org/10.1017/S0960258514000066>

Gnanwa, M. J., Fagbohoun, J. B., Ya, K. C., Blei, S. H., & Kouame, L. P. (2021). Assessment of minerals, vitamins and functional properties of flours from germinated yellow maize (*Zea mays* L.) seeds from Daloa (Côte D'Ivoire). *International Journal of Food Science and Nutrition Engineering*, 11(2), 35-42. <https://doi.org/10.5923/j.food.20211102.01>

ISTA Moisture Committee. (2007). *Moisture Determination* (H. Nijënstein, J. Nydam, & R. Don, Eds.; 1st ed.). International Seed Testing Association.

Kanabur, V., & Sharavathi, V. (2022). Nutritional significance and usage of garden cress seeds (*Lepidium sativum* L.)—A review. *American Journal of Food Science and Technology*, 1(1), 50–55. <https://doi.org/10.54536/ajfst.v1i1.500>

Kapoor, B., Kapoor, D., Gautam, S., et al. (2021). Dietary polyunsaturated fatty acids (PUFAs): Uses and potential health benefits. *Current Nutrition Reports*, 10, 232–242. <https://doi.org/10.1007/s13668-021-00363-3>

Kaur, H., & Gill, B. S. (2021). Changes in physicochemical, nutritional characteristics and ATR-FTIR molecular interactions of cereal grains during germination. *Journal of Food Science and Technology*, 58(6), 2313–2324. <https://doi.org/10.1007/s13197-020-04742-6>

Kotowski, W. (1926). Untersuchungen über Keimungskräfte. *Berichte der Deutschen Botanischen Gesellschaft*, 44, 401-410.

Kreitschitz, A., & Gorb, S. N. (2018). The micro- and nanoscale spatial architecture of the seed mucilage—Comparative study of selected plant species. *PLOS ONE*, 13(7). <https://doi.org/10.1371/journal.pone.0201414>

Lakhssassi, N., Zhou, Z., Liu, S., Colantonio, V., AbuGhazaleh, A., & Meksem, K. (2017). Characterization of the FAD2 gene family in soybean reveals the limitations of gel-based TILLING in genes with high copy number. *Frontiers in Plant Science*, 8, 324. <https://doi.org/10.3389/fpls.2017.00324>

Li, X., Dong, S., Bai, W., Jia, J., Gu, R., Zhao, C., & Wang, Y. (2020). Metabolic and transcriptional regulation of phenolic conversion and tocopherol biosynthesis during germination of sesame (*Sesamum indicum* L.) seeds. *Food & Function*, 11(11), 9848–9857. <https://doi.org/10.1039/D0FO01706J>

Maguire, J. D. (1962). Rapid germination tests in lettuce. *Proceedings of the American Society for Horticultural Science*, 81, 333-338.

Malhotra, U., Sontakke, M., Shams, R., & Pandey, V. K. (2023). Effects of pre-treatments on nutritional and mineral composition of garden cress seeds (*Lepidium sativum*). *Food Chemistry Advances*, 3, 100398. <https://doi.org/10.1016/j.focha.2023.100398>

Manosalva, C., Bahamonde, C., Soto, F., Leal, V., Ojeda, C., Cortés, C., Alarcón, P., & Burgos, R. A. (2024). Linoleic acid induces metabolic reprogramming and inhibits oxidative and inflammatory effects in keratinocytes exposed to UVB radiation. *International Journal of Molecular Sciences*, 25(19), 10385. <https://doi.org/10.3390/ijms251910385>

Mao, H., Yuan, S., Li, Q., Zhao, X., Zhang, X., Liu, H., Yu, M., & Wang, M. (2024). Influence of germination on the bioactivity, structural, functional, and volatile characteristics of different chickpea flours. *Food Chemistry: X*, 21, 101195. <https://doi.org/10.1016/j.fochx.2024.101195>

Mercola, J., & D'Adamo, C. R. (2023). Linoleic acid: A narrative review of the effects of increased intake in the standard American diet and associations with chronic disease. *Nutrients*, 15(14), 3129. <https://doi.org/10.3390/nu15143129>

Nautiyal, P. C., Sivasubramaniam, K., & Dadlani, M. (2023). Seed dormancy and regulation of germination. In M. Dadlani & D. K. Yadava (Eds.), *Seed Science and Technology* (pp. 39–66). Springer. https://doi.org/10.1007/978-981-19-5888-5_3

Negi, N. P., Prakash, G., Narwal, P., et al. (2023). The calcium connection: Exploring the intricacies of calcium signaling in plant-microbe interactions. *Frontiers in Plant Science*, 14, 1248648. <https://doi.org/10.3389/fpls.2023.1138252>

Pagnotta, E., Ugolini, L., Matteo, R., & Righetti, L. (2022). Bioactive compounds from *Eruca sativa* seeds. *Encyclopedia*, 2(4), 1866–1879. <https://doi.org/10.3390/encyclopedia2040129>

Papayrata, C., Saensouk, S., & Chumroenphat, T. (2024). Influence of germination time on free amino acids, phenolic compounds, and γ -aminobutyric acid in pigeon pea (*Cajanus cajan* (L.) Huth) seeds. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 52(3), 13674. <https://doi.org/10.15835/nbha52313674>

Patat, A. S., Sen, F., Erdogdu, B. S., et al. (2022). Construction and characterization of a de novo draft genome of garden cress (*Lepidium sativum* L.). *Functional & Integrative Genomics*, 22, 879–889. <https://doi.org/10.1007/s10142-022-00866-4>

Rahate, K. A., Madhumita, M., & Prabhakar, P. K. (2021). Nutritional improvement and reduction of anti-nutritional factors by germination in legumes: A review. *Journal of Food Science and Technology*, 58(10), 3977–3991. <https://doi.org/10.1007/s13197-021-05030-5>

Raj, J. D., Pares, D., & Avdhut, P. (2020). Studies and extraction of garden cress seed oil by different solvent. *Journal of Pharmacognosy and Phytochemistry*, 9(2), 1633-1637.

Ramadan, M. F., & Oraby, H. F. (2020). *Lepidium sativum* seeds: Therapeutic significance and health-promoting potential. In *Nuts and Seeds in Health and Disease Prevention* (pp. 273-289). Academic Press. <https://doi.org/10.1016/B978-0-12-818553-7.00020-6>

Ramos-Pacheco, B. S., Choque-Quispe, D., Ligarda-Samanez, C. A., et al. (2024). Effect of germination on the physicochemical properties, functional groups, content of bioactive compounds, and antioxidant capacity of different varieties of quinoa (*Chenopodium quinoa* Willd.). *Foods*, 13, 417. <https://doi.org/10.3390/foods13020417>

- Recharla, N., Riaz, M., Ko, S., & Park, S. (2017). Novel technologies to enhance solubility of food-derived bioactive compounds: A review. *Journal of Functional Foods*, 39, 63–73. <https://doi.org/10.1016/j.jff.2017.10.001>
- Rezig, L., Chemkhi, H., Gharsallah, K., et al. (2022). Profile characterization and biological activities of cold pressed garden cress (*Lepidium sativum*) seed oil. *Arabian Journal of Chemistry*. <https://doi.org/10.1016/j.arabjc.2022.103958>
- Rogowska, A., & Szakiel, A. (2020). The role of sterols in plant response to abiotic stress. *Phytochemistry Reviews*, 19, 1525–1538. <https://doi.org/10.1007/s11101-020-09708-2>
- Roschztardt, H., Gaymard, F., & Dubos, C. (2020). Transcriptional regulation of iron distribution in seeds: A perspective. *Frontiers in Plant Science*, 11, 725. <https://doi.org/10.3389/fpls.2020.00725>
- Shah, M. B., Dudhat, V. A., & Gadhvi, K. V. (2021). *Lepidium sativum*: A potential functional food. *Journal of Ayurveda and Herbal Medicine*, 7(2), 140-149. <https://doi.org/10.31254/jahm.2021.7213>
- Sharma, A. (2020). A comprehensive review on pharmacological properties of garden cress (*Lepidium sativum*) seeds. *Current Research in Pharmaceutical Sciences*, 10(2), 13-18. <https://doi.org/10.24092/CRPS.2020.100201>
- Shi, H., Nam, P. K., & Ma, Y. (2010). Comprehensive profiling of isoflavones, phytosterols, tocopherols, minerals, crude protein, lipid, and sugar during soybean (*Glycine max*) germination. *Journal of Agricultural and Food Chemistry*, 58(8), 4970–4976. <https://doi.org/10.1021/jf1003709>
- Singh, C. S., Paswan, V. K., & Naik, B. (2015). Exploring potential of fortification by garden cress (*Lepidium sativum* L.) seeds for development of functional foods—A review. *Indian Journal of Natural Products and Resources*, 6(3), 167–175. <https://doi.org/10.56042/ijnpr.v6i3.6267>
- Sofi, S. A., Muzaffar, K., Farooq, A., et al. (2023). Spectroscopic techniques for elucidation of structural changes in temperate cowpea cultivars under germination: A useful tool for quality determination and industrial application. *Applied Food Research*, 3(1), 100246. <https://doi.org/10.1016/j.afres.2022.100246>
- Song, Q., Cheng, S., Chen, Z., et al. (2019). Comparative transcriptome analysis revealing the potential mechanism of seed germination stimulated by exogenous gibberellin in *Fraxinus hupehensis*. *BMC Plant Biology*, 19(1), 199. <https://doi.org/10.1186/s12870-019-1801-3>
- Syeda Kaniz, T., Bader Ul Ain, H., & Tufail, T., et al. (2022). Therapeutic potential and nutraceutical aspects of *Lepidium sativum*. *Pakistan BioMedical Journal*, 5(7), 03–06. <https://doi.org/10.54393/pbmj.v5i7.649>
- Tok, H., & Ertaş, N. (2020). Effects of different germinated seeds flour on mineral, phytic acid, and total phenolic content of cookies. *Journal of Agricultural Sciences*, 26(4), 424-433. <https://doi.org/10.15832/ankutbd.535601>
- Tondey, M., Kalia, A., Singh, A., et al. (2022). A comparative evaluation of the effects of seed invigoration treatments with precursor zinc salt and nano-sized zinc oxide (ZnO) particles on vegetative growth, grain yield, and quality characteristics of *Zea mays*. *Journal of Analytical Science and Technology*, 13(1), 40. <https://doi.org/10.1186/s40543-022-00299-4>
- Tufail, T., Khan, T., Bader Ul Ain, H., et al. (2024). Garden cress seeds: A review on nutritional composition, therapeutic potential, and industrial utilization. *Food Science & Nutrition*. <https://doi.org/10.1002/fsn3.3078>
- Waheeb, M. Q., & Makki, M. A. (2023). Using of *Lepidium sativum* L. extract, as antimicrobial and anti-mosquito. <https://doi.org/10.21203/rs.3.rs-2576870/v1>
- Wang, X.-H., Tai, Z.-J., Song, X.-J., et al. (2024). Effects of germination on the structure, functional properties, and in vitro digestibility of a black bean (*Glycine max* (L.) Merr.) protein isolate. *Foods*, 13, 488. <https://doi.org/10.3390/foods13030488>
- Weitbrecht, K., Müller, K., & Leubner-Metzger, G. (2011). First off the mark: Early seed germination. *Journal of Experimental Botany*, 62(10), 3289–3309. <https://doi.org/10.1093/jxb/err101>
- Weng, X., Li, H., & Ren, C., et al. (2022). Calcium regulates growth and nutrient absorption in poplar seedlings. *Frontiers in Plant Science*, 13, 887098. <https://doi.org/10.3389/fpls.2022.887098>

Zhang, H., Vasanthan, T., & Wettasinghe, M. (2007). Enrichment of tocopherols and phytosterols in canola oil during seed germination. *Journal of Agricultural and Food Chemistry*, 55(2), 355–359. <https://doi.org/10.1021/jf062697+>

Zhao, J., He, Y., Zhang, H., & Wang, Z. (2024). Advances in the molecular regulation of seed germination in plants. *Seed Biology*, 3(1). <https://doi.org/10.1007/s43170-024-00025-9>

Zhu, F., & Li, H. (2019). Effect of high hydrostatic pressure on physicochemical properties of quinoa flour. *LWT*, 114, 108367. <https://doi.org/10.1016/j.lwt.2019.108367>

Zia-Ul-Haq, M., Cavar, S., Qayum, M., et al. (2011). Compositional studies: Antioxidant and antidiabetic activities of *Capparis decidua* (Forsk.) Edgew. *International Journal of Molecular Sciences*, 12(12), 8846–8861. <https://doi.org/10.3390/ijms1212884>