



## Determination of Essential and Heavy Metals and Phytochemical Screening of *Lepidium sativum* Seeds from Libya

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### تحديد المعادن الأساسية و الثقيلة والمسح الفيتوكيميائي لبذور نبات حب الرشاد

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#### Abstract

The study investigated *Lepidium sativum* seeds, *Lepidium sativum*, which were obtained from herbal shops in Libya, to analyze their phytochemical makeup and essential metal and heavy metal content. Phytochemical testing of the aqueous, methanolic, and acetone extracts identified the presence of alkaloids, saponins, flavonoids, phenols, glycosides, carbohydrates, proteins, and amino acids while tannins and anthraquinones were absent. The essential metals showed high levels of potassium, magnesium, calcium, sodium, phosphorus, and iron. The sample contained different heavy metals which were present in extremely small amounts with Pb measured at 0 µg/100g and Ni at 28.5 ± 1.32 µg/100g and Cu at 35.98 ± 1.05 µg/100g and Hg at 0.277 ± 0.074 µg/100g and Mn at 0.004 ± 0.003 µg /100g. The scientists prepared the samples by first dry ashing 2 grams of powdered seeds at 550 degrees Celsius for 3 hours and then they digested the ash with 12.5 milliliters of HNO<sub>3</sub> before they diluted it to 100 milliliters. The results showed that all detected metals were below the permissible safety limits. The results demonstrate that *Lepidium sativum* seeds which are sold in stores contain important essential minerals and bioactive substances while showing minimal heavy metal pollution which makes them safe for use in dietary and traditional healing purposes.

**Keywords:** *Lepidium sativum*, phytochemical screening, essential metals, heavy metals, commercial samples.

#### المخلص

تمت دراسة بذور حب الرشاد، *Lepidium sativum*، المشتراة من محل العطارة في ليبيا، وذلك لتحديد محتواها الفيتوكيميائي ومستويات العناصر الأساسية والثقيلة فيها. أظهر المسح الفيتوكيميائي للمستخلصات المائية والميثانولية والأسيتونية وجود الفلويديات، الصابونينات، الفلافونويدات، الفينولات، الجليكوسيدات، الكربوهيدرات، والبروتينات والأحماض الأمينية، بينما لم تظهر التانينات والأنثراكوينونات. أوضحت النتائج وجود مستويات مرتفعة من العناصر الأساسية مثل البوتاسيوم، المغنيسيوم، الكالسيوم، الصوديوم، الفوسفور، والحديد. أما العناصر الثقيلة فقد ظهرت بمستويات منخفضة جداً، حيث بلغ الرصاص 0 ميكروغرام/100غ، والنيكل 28.5 ± 1.32 ميكروغرام/100غ، والنحاس 35.98 ± 1.05 ميكروغرام/100غ، والزنك 0.277 ± 0.074 ميكروغرام/100غ، والمنغنيز 0.004 ± 0.003 ميكروغرام/100غ. تم تحضير العينات باستخدام الحرق الجاف لـ 2 غرام من مسحوق البذور عند 550 درجة مئوية لمدة 3 ساعات، ثم إذابة الرماد في 12.5 مل من حمض النيتريك وإكمال الحجم إلى 100 مل. بينت النتائج أن جميع العناصر المكتشفة كانت ضمن الحدود الآمنة المسموح بها. وتشير النتائج إلى أن بذور حب الرشاد المتاحة تجارياً تحتوي على عناصر غذائية ومركبات نشطة حيويًا، مع انخفاض واضح في تلوث العناصر الثقيلة، مما يدعم استخدامها الآمن في التغذية والطب التقليدي.

**الكلمات المفتاحية:** حب الرشاد، المسح الفيتوكيميائي، العناصر الأساسية، العناصر الثقيلة، العينات التجارية.

## Introduction

*Lepidium sativum*, which people refer to as *Lepidium sativum* and حب الرشاد, exists as an annual herbaceous plant that belongs to the Brassicaceae family. The plant has gained wide recognition because it provides essential nutrients and bioactive compounds which make it both a food source and a medicinal remedy. People use the seeds in traditional medicine to treat breathing problems and stomach issues while also using them for overall health maintenance. The seeds serve as an essential part of human nutrition because they provide high amounts of proteins and minerals and active biological substances.<sup>[15] [20]</sup>

*Lepidium sativum* seeds contain essential nutrients which include proteins and dietary fiber and fatty acids and vitamins and minerals including calcium and potassium and magnesium and phosphorus. The elements in this composition support essential body functions which include bone growth and enzyme activity and maintenance of electrolyte balance. The seeds also contain iron which supports hemoglobin production and protects against anemia.<sup>[21] [1]</sup>

The seeds are also an excellent source of iron, which is essential for hemoglobin synthesis and can prevent anemia. These nutritional attributes make *Lepidium sativum* a valuable functional food that has the potential to alleviate nutritional deficiencies, especially in people with low dietary diversity<sup>[2] [20]</sup> Moreover, *Lepidium sativum* seeds reportedly contain bioactive compounds with antioxidant and anti-inflammatory properties, making them a valuable ingredient in food and medicine<sup>[15] [1]</sup>

The seeds of *Lepidium sativum* contain a wide range of phytochemicals such as phenolics, flavonoids, alkaloids and glucosinolates. These compounds exhibit significant antioxidant activity, which helps to scavenge free radicals and alleviate oxidative stress-related chronic conditions, including heart diseases and cancer. The presence of these compounds and their biological activities (antimicrobial and anti-inflammatory) has been verified by phytochemical screening<sup>[3] [13]</sup> These compounds have also been identified through the use of advanced analytical methods such as UPLC-ESI-MS, emphasising their pharmacological significance<sup>[6]</sup>

Environmental factors and processing, transport and storage conditions may contribute to the contamination of medicinal plants, such as *Lepidium sativum*, with heavy metals. The sources of contamination can be soil, water, industrial pollution, or post-harvest processing. Heavy metals can be broadly categorised into essential elements needed in trace quantities (iron, copper, and manganese) and non-essential toxic elements (lead and mercury) which can be harmful to human health even at low levels<sup>[12] [10]</sup> The growth conditions and manufacturing processes play a role in the accumulation of elements in plant tissues<sup>[12] [10]</sup> Exposure to contaminated plant materials may result in bioaccumulation in the body and cause toxicity, including neurotoxicity and kidney damage.

There is growing concern about heavy metal contamination in medicinal plants globally, resulting in the development of standards and regulations to ensure safety. Variations in permissible limits in different countries are largely due to differences in risk assessment methodologies and consumer behaviour<sup>[9]</sup> Various studies have been conducted to determine the presence of toxic metals in medicinal plants, highlighting the need for constant monitoring and quality assessment<sup>[19] [14]</sup> *Lepidium sativum* studies have also shown that it can accumulate some metals such as lead and nickel, which could pose a risk to human health<sup>[8]</sup>

Analytical methods play a crucial role in determining the elemental content of plant materials. Analytical techniques such as digestion and extraction are crucial for accurate determination of trace elements. Atomic absorption spectroscopy, inductively coupled plasma mass spectrometry, and X-ray fluorescence analysis are the most common techniques for measuring essential and toxic metals. Technologies have been improved to increase the speed and sensitivity, allowing a comprehensive analysis of element content, and supporting risk assessment studies<sup>[5]</sup>

With the increasing use of *Lepidium sativum* seeds as a supplement and therapeutic product, it is crucial to assess both the good phytochemical properties and the safety aspects, including contamination by heavy metals. In this regard, the current study is focused on the examination of *Lepidium sativum* seeds sourced from the market. The goal is to quantify the essential elements iron, calcium, potassium, magnesium, phosphorus and sodium, and the toxic metals lead, nickel, manganese, copper and mercury. This approach offers a holistic view of the nutritional and toxicological properties of edible *Lepidium sativum* seeds<sup>[18] [11]</sup>

## Material and methods

### 1.1 Plant Material

The researchers acquired *Lepidium sativum* seeds for their research from herbal store. The samples represent commercially available products rather than plants which scientists extracted from particular agricultural fields. The researchers obtained seeds from various vendors by using clean dry containers which they transported to the laboratory to maintain their original state.

The seeds underwent manual cleaning to eliminate all non-seed substances which included dust and stones and plant debris so that researchers could assess only unadulterated seed samples. The cleaned seeds underwent air drying at room temperature while scientists maintained specific conditions until their moisture content decreased

to the desired level without affecting any thermolabile compounds. The chemical stability of substances depends on moisture regulation which also prevents the growth of microorganisms.

The seeds underwent grinding after drying through an electric grinder which produced fine powder that distributed evenly throughout to improve extraction efficiency and boost analytical reproducibility. The research team kept powdered samples inside airtight glass containers which they placed in a location that remained dry and dark until the time came for their analysis.

Sample preparation serves as an essential component of plant analysis because sample heterogeneity or contamination issues make it difficult to achieve accurate test results. Researchers used standardized methods to achieve both accurate sample representation and dependable study outcomes [5] The selection of seeds as the study material is justified by their widespread use in nutritional and medicinal applications, as well as their high content of bioactive compounds and essential minerals [20]

### 1.1 Phytochemical Screening

Researchers conducted qualitative phytochemical screening through testing aqueous, methanolic, and acetone extracts to determine primary secondary metabolites present in the samples. The use of different solvents enabled the extraction of a wide range of compounds. The standard tests identified multiple phytochemicals through their characteristic color changes or precipitate formation which included alkaloids, carbohydrates, saponins, glycosides, phenolic compounds, flavonoids, proteins, and amino acids.

The results confirmed the presence of key bioactive compounds which included alkaloids and saponins and flavonoids, with variations depending on the solvent type. The aqueous extract showed higher saponin content, while the methanolic extract was more effective in extracting flavonoids. The findings demonstrate that *Lepidium sativum* seeds contain phytochemical constituents which exhibit strong biological activities according to research conducted by Chatoui and his colleagues in 2016 together with Mohamed and his team in 2023.

Further research studies confirmed the existence of multiple bioactive compounds which demonstrate antioxidant and antimicrobial effects, which strengthen the medicinal properties of *Lepidium sativum* seeds according to research findings from Elsayed and his team in 2025.

*Table 1* Phytochemical Screening of *Lepidium sativum* Seed Extracts

Test	Reagent/Test	Aqueous	Methanol	Acetone
Alkaloids	Mayer's	+++	++	-k
	Wagner's	++	+	-
	Dragendorff's	+++	+++	-
Carbohydrates	Hager's	++	++	-
	Molisch's	+	+	-
	Benedict's	-	+	-
Saponins	Fehling's	+	+	+
	Frothing	+++	-	-
	Keller-Kiliani	+	+	-
Glycosides	Keller-Kiliani	+	+	-
Phenols	Ferric chloride	+	+	-
Tannins	-	-	-	-
Flavonoids	Alkaline test	++	+++	+
	Lead acetate	+	+	-
Anthraquinones	Bortrager's	-	-	-
Proteins/Amino acids	Millon's	+	++	-
	Biuret	-	-	-
	Xanthoproteic	++	++	+
	Ninhydrin	+	-	+

The table presents qualitative results which use the following system of ratings to describe outcomes: + shows weak positive results, ++ indicates moderate results, +++ denotes strong positive outcomes and - displays negative

results. The seeds contain high levels of alkaloids and saponins and flavonoids which provide them with medicinal properties that exhibit both antioxidant and antimicrobial effects.



**Figure 1** *Lepidium sativum* Plant and Seeds

It is a *Lepidium sativum* mainly botanical representation with a detailed explanation of other features. The visual display shows plant identification features through its depiction of upright slender stems and deeply lobed basal leaves and primary taproot system. The central and magnified sections focus on the inflorescence and the development of silicles (seed pods), alongside a close-up of the reddish-brown, elliptical seeds. The image displays botanical structures through a clean background design which was created for academic publication in studies about germination and allelopathy and pharmacognosy research.

### 1.2 Preparation of Sample to be analyzed to determine Metal.

The preparation of the sample to be under elemental analysis was done through the dry ashing technique which is commonly known to be accurate when used to determine the mineral content in plant matter. The finely powdered seed sample (exactly 2 g) was weighed on an analytical balance and put into porcelain crucibles. The samples were then dried in a muffle furnace to 550°C in 3 hours. This is to make sure that all the organic material is completely oxidized and results in the mineral residues, which are inorganic.

The samples were also ashed and then allowed to cool in a desiccator to avoid uptake of moisture. This ash was then dissolved in 12.5 mL of concentrated nitric acid (HNO<sub>3</sub>), which helps in dissolving mineral elements. The solution in the 100ml volumetric flask is thus diluted to volume by adding distilled water. Where required, filtration was done to eliminate any insoluble particles.

This is a way of preparation that reduces the interference of the matrix and provides correct quantification of the trace elements. It aligns with the standard procedures in mineral analysis of plants, where organic elements need to be fully digested to accurately determine the elements [5] The process was based on the earlier reported procedures on *Lepidium sativum* and other comparable plant materials with some modifications on the sample weight and the volumes of the reagents to suit the seed analysis [8]



**Figure 2** Dry Ashing Method for Sample Preparation

The scientific image shows dry ashing which serves as the essential method for preparing samples to extract their inorganic mineral components while eliminating their organic materials. The process begins with sample

preparation when plant material undergoes a grinding process which produces fine particles. The process starts with sample preparation which requires plant material to be ground into fine particles. The process continues with sample preheating which uses a ceramic crucible to eliminate moisture and start carbonization. The process continues with high-temperature burning which occurs in a muffle furnace that operates at 550°C to achieve complete oxidation of the carbonized material. The process ends with the collection of white or gray ash which researchers will use for their elemental analysis. The academic documentation process uses this image as its ideal visual protocol because it shows how raw organic material changes into pure mineral residue.

### 1.3 Metal Quantification and Quality Control

The quantification of essential and toxic metals in the elemental analysis was done using flame atomic absorption spectrometry (AAS) which is a sensitive and a reliable method of quantifying essential and toxic metals. The analyzed elements were essential minerals (iron, calcium, potassium, magnesium, phosphorus, and sodium), and heavy metals (lead, nickel, manganese, copper, and mercury).

The standard solutions with known concentrations of each element were used to set up calibration curves. These calibration curves were used to compare the absorbance readings of the samples to the respective concentrations. To achieve reproducibility and accuracy, all measurements were done in triplicates. The precision was estimated using statistical parameters like the standard deviation (SD) and relative standard deviation (RSD).

The quality control was observed with strict rules during the analytical procedure. These involved the use of reagent blanks, high-purity chemicals, and correct calibration of the instruments in order to reduce the errors in analysis. The find was reported in mg/100 g or µg/100 g according to the levels of different elements which matches international standards of food and medicinal plants testing <sup>[14]</sup> <sup>[10]</sup>

**Table 2** Concentrations of Essential Metals in *Lepidium sativum* Seeds (mg/100g)

Element	Mean ±SD	RSD (%)
Fe	8.5 ± 0.26	3.03
Ca	20.8 ± 0.76	3.67
K	1039.2 ± 37.06	3.57
Mg	50.5 ± 5.32	10.53
P	8.5 ± 0.5	5.88
Na	142.3 ± 8.95	6.29

The seeds contain high potassium and magnesium levels which show their nutritional value as a mineral supplement. The values are presented according to their dry weight measurement.

**Table 3** Concentrations of Heavy/Trace Metals in *Lepidium sativum* Seeds

Element	Unit	Mean ± SD	Equivalent (mg/kg)
Pb	µg/100g	0	0
Ni	µg/100g	28.5 ± 1.32	0.285
Mn	µg /100g	0.004 ± 0.003	0.00004
Cu	µg/100g	35.98 ± 1.05	0.3598
Hg	µg/100g	0.277 ± 0.074	0.00277

The concentrations of heavy metals in the samples exist at two levels either as extremely low values or as complete undetectability. The testing results show all substance concentrations to be under the WHO safe limits which apply to medicinal plants because lead exists at levels below 10 milligrams per kilogram and cadmium exists at levels below 0.3 milligrams per kilogram.

### 1.4 Statistical Analysis

Descriptive statistical analysis was used to analyze the data obtained. The presentation of results is in the form of the mean and standard deviation which gives a clue about the central tendency and variability. Relative standard deviation was also obtained to determine the consistency of measurements of replicates.

Moreover, the concentrations of heavy metals measured were compared with the allowable levels set by international health bodies to determine the level of possible health hazards caused by their consumption. These comparisons are necessary to establish the quality and safety of medicinal plants, especially when it comes to prolonged contact with toxic substances <sup>[9]</sup>

The study achieves greater trustworthiness through its statistical evaluation which demonstrates an impartial approach to data interpretation while allowing researchers to assess their findings against previously published

research. The system helps evaluate risks because it determines whether found metal levels match established safety limits [12] [19]

## 2. Results and Discussion

### 2.1 Overall Results

The analytical evaluation of *Lepidium sativum* seeds obtained from commercial sources provides a comprehensive dataset which shows their elemental composition and their phytochemical content and their statistical validation results. The results show that the studied seeds have a nutritionally valuable profile which contains high concentrations of essential macroelements and shows no presence of toxic heavy metals. The analytical procedures achieve high precision and reproducibility through triplicate measurements and standard deviation (SD) and relative standard deviation (RSD) statistical indicators. The dataset enables the identification of nutritionally beneficial elements and potentially dangerous contaminants which allows for an accurate evaluation of both product quality and safety.

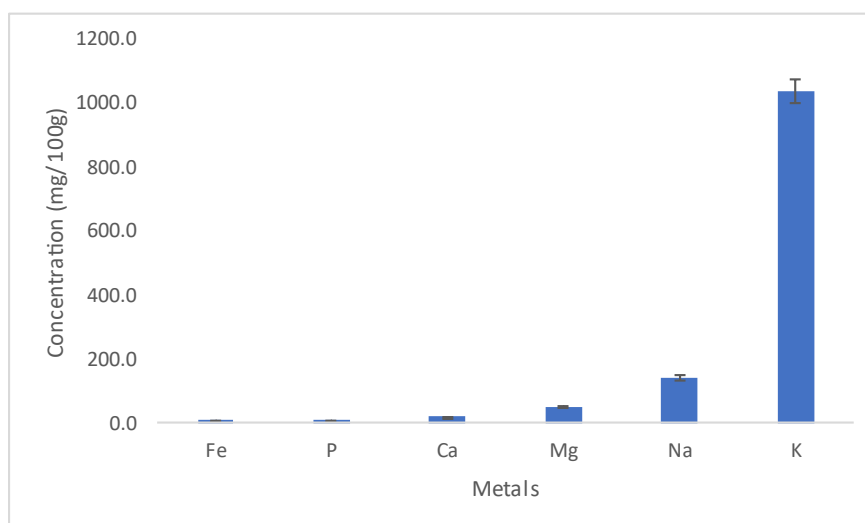
**Table 4** Elemental Composition of *Lepidium sativum* Seeds (Commercial Samples)

Element	Unit	Reading 1	Reading 2	Reading 3	Average	SD	RSD (%)
Fe	mg/100g	8.4	8.8	8.3	8.5	0.26	3.03
Ca	mg/100g	20.0	21.0	21.5	20.8	0.76	3.67
K	mg/100g	1041.5	1001.0	1075.0	1039.2	37.06	3.57
Mg	mg/100g	50.0	56.0	45.4	50.5	5.32	10.53
P	mg/100g	8.5	8.0	9.0	8.5	0.50	5.88
Na	mg/100g	144.5	150.0	132.5	142.3	8.95	6.29
Pb	µg/100g	0.00	0.00	0.00	0.00	0.00	—
Ni	µg/100g	29.50	27.00	29.00	28.50	1.32	4.64
Mn	µg/100g	0.01	0.00	0.01	0.004	0.003	74.23
Cu	µg/100g	36.05	37.00	34.90	35.98	1.05	2.92
Hg	µg/100g	0.34	0.30	0.20	0.28	0.07	26.83

The results show that potassium functions as the primary element because its average concentration reaches 1039.2 mg per 100 grams which surpasses all other elements. Sodium and magnesium follow at substantially lower levels while calcium and phosphorus and iron exist at moderate levels. The analysis shows that heavy metals exist either in nonexistent amounts or in extremely low concentrations which includes lead as undetectable and mercury as present in extremely low amounts.

### 2.2 Graphical Representation of Mineral Content

The graphical representation shows the numerical data which confirms essential element distribution through their movement in the examined seeds. The pattern shows that potassium exists in higher amounts than sodium and magnesium while calcium and phosphorus and iron exist at lower levels. The distribution shows how these elements function in plant metabolism while demonstrating the nutritional value of seeds.



**Figure 3** Concentration of Essential Elements in *Lepidium sativum* Seeds (mg/100g)

The figure shows a steep concentration gradient, with potassium exceeding 1000 mg/100g, showing that potassium functions as the primary mineral component. The error bars in the chart show how measurement results

ranged among different test runs and they proved most elements showed low spread which confirmed the testing results were accurate.

### 2.3 Phytochemical Results and Interpretation

The research discovered through phytochemical tests seven different types of bioactive substances which included both alkaloids and flavonoids and saponins and phenolic compounds. The active components of *Lepidium sativum* provide essential medicinal benefits which include these compounds that display pharmacological properties. Alkaloids provide microbes with protection while they also relieve pain with their analgesic properties whereas flavonoids and phenolic compounds help people defend against antioxidants through their ability to counteract harmful reactive oxygen species.

*Lepidium sativum* exhibits identical phytochemical profiles which previous research established while the active compounds in this plant work together to create biological effects according to Painuli et al. 2022 and Mohamed et al. 2023. The study results received validation through UPLC-ESI-MS advanced analytical methods which established complex phytochemical profiles and confirmed study results<sup>[6]</sup>

### 2.4 Nutritional Evaluation of Essential Elements

The nutritional value of this study results from its high potassium concentration. Potassium plays a crucial role in maintaining the body's internal fluid balance and controlling blood pressure while enabling both nerve and muscle operations. The potassium-to-sodium ratio present in the seeds supports heart health because potassium-rich diets help people lower their chances of developing high blood pressure.

Magnesium exists at a level of 50.5 mg per 100 grams which enables its involvement with enzymatic processes and energy production and neuromuscular activities. Calcium promotes bone growth while serving as a signaling molecule for cells. Phosphorus functions in ATP synthesis and nucleic acid metabolic processes. The body maintains iron levels at moderate amounts because this element plays an essential role in producing hemoglobin and transporting oxygen. The analytical results show high reliability because most elements exhibit low RSD values which demonstrate exceptional testing accuracy. Previous studies have demonstrated that *Lepidium sativum* seeds possess high nutritional value, supporting their use as dietary supplements. The present study shows results that match previous research findings which prove the nutritional value of the examined substances<sup>[20]</sup> <sup>[11]</sup>

### 2.5 Heavy Metal Assessment

The research demonstrated that all samples tested negative for lead which showing that there was no discernible contamination in the examined samples that the examined samples were free of substantial contamination. The analysis found nickel and copper at low levels while mercury was detected at extremely low concentrations. The sample contained manganese at extremely low levels which approached the instrument's detection limit.

Lead absence proves especially important because lead possesses extreme toxicity while it can build up in human systems. Scientists determined the nickel and copper levels which they tested during their study to be safe because those elements serve vital functions in living organisms at minimal concentrations. The study found mercury levels to be extremely low which resulted in an extremely low risk of exposure to the substance.

The measurement of manganese and mercury showed high RSD values because their very low concentrations made their actual amounts undetectable. Research studies have found similar patterns when they examined trace metal content in plant materials <sup>[12]</sup> <sup>[16]</sup>

### 2.6 Safety Evaluation and Regulatory Comparison

The study measured heavy metal concentrations which were then compared to international safety standards established for medicinal plants. The results show that all detected elements remain within allowable limits which proves the seeds are safe for human consumption. The absence of lead and the extremely low levels of mercury provide additional support for this conclusion. The herbal product regulations for heavy metals require monitoring to detect contamination which protects people from health dangers. The study results show that sample analysis in the research study demonstrates compliance with safety standards which the regulations require. <sup>[9]</sup> <sup>[10]</sup>

### 2.7 Method Validation and Reliability

The dry ashing method used for sample preparation proved to be effective in removing organic matter and isolating mineral components for analysis. The controlled temperature establishment succeeded in achieving total oxidation while maintaining most volatile elements. The subsequent acid digestion step enabled the dissolution of inorganic residues which allowed accurate quantification through atomic absorption spectrometry.

The analytical method demonstrates reliable performance because the results show consistent output which low SD and RSD values. The use of triplicate measurements and calibration with standard solutions further enhances

the accuracy of the data. These findings support previous studies which confirmed the effectiveness of dry ashing and AAS for plant analysis. <sup>[5]</sup>

## 2.8 Environmental Implications

The study results show that heavy metal levels remained below thresholds which would create contamination problems for the tested samples. The research results show that products which commercial sources provide to consumers maintain both safety and quality standards because seeds were obtained from these sources. The monitoring of heavy metal levels in medicinal plants stays crucial because contamination affects both their safety and their medicinal effectiveness.

The results support previous studies showing that lower levels of heavy metals are typically associated with reduced contamination exposure. The safe handling of herbal products depends on quality control procedures which should be followed during product sourcing and storage activities <sup>[19] [14]</sup>

## 2.9 Integrated Nutritional and Medicinal Value

The mineral makeup and plant chemical components of *Lepidium sativum* seeds create their nutritional and medicinal properties. The body receives antioxidant defense through bioactive compounds that include flavonoids and phenolic compounds while essential minerals enable physical processes to function properly. The combination of these properties enables researchers to classify *Lepidium sativum* seeds as functional food products.

Recent research demonstrates that these seeds function as dietary supplements which enhance health and decrease chronic disease risks <sup>[18] [11]</sup> The present study demonstrates both safety and effectiveness which support this classification.

## 3. Conclusion

### 3.1 General Summary of Findings

The scientists examine all chemical properties and elemental content of *Lepidium sativum* seeds which were obtained from commercial sources. The seeds function as a plant resource which delivers high nutritional value through its essential mineral content and multiple bioactive compounds. The results show that the studied samples contain only small amounts of toxic heavy metals which makes them safe for human consumption. Researchers can use phytochemical screening together with quantitative elemental analysis to determine both health benefits and potential dangers of eating seeds.

The analytical data showed that potassium exists in higher quantities than all other elements which include sodium and magnesium but calcium and phosphorus and iron exist in intermediate amounts. The mineral composition of *Lepidium sativum* supports its function as a dietary supplement which helps maintain electrolyte balance and supports metabolic activities and general body functions. Previous studies have shown that *Lepidium sativum* seeds contain high nutritional value which makes them suitable for use in functional foods according to the current research findings <sup>[20] [11]</sup>

### 3.2 Phytochemical Significance

The phytochemical screening results confirmed the presence of multiple bioactive compounds which included alkaloids, flavonoids, saponins, phenols. The seeds contain these compounds because they have antioxidant and antimicrobial and anti-inflammatory effects which create their medicinal properties. The phytochemicals present in *Lepidium sativum* explain its traditional use for respiratory and digestive disorders and its ability to improve overall health.

Flavonoids and phenolic compounds function as the main components in oxidative stress reduction because they neutralize free radicals which results in protection against cellular damage and chronic diseases. Alkaloids produce pharmaceutical effects which include antimicrobial and analgesic effects while saponins provide cholesterol reduction together with immune system control. The compounds in this study interact with each other to create combined effects which increase the total biological power of the seeds <sup>[15] [7]</sup>

The advanced analytical studies established that *Lepidium sativum* contains complex phytochemical compounds which include multiple phenolic and flavonoid derivatives that produce its high antioxidant potential <sup>[5]</sup> The phytochemical content of these seeds makes them medicinal plants with important therapeutic properties.

### 3.3 Nutritional and Functional Importance

This study discovered high content of essential minerals in the seeds of *Lepidium sativum*, thereby revealing their nutritional value. Potassium served as the main element which protects against human diseases through its functions in blood pressure control and muscle movement and body fluid management. The seeds contain a potassium-to-sodium ratio which promotes better heart health because it decreases the chances of developing hypertension and associated disorders. The body needs magnesium for enzymatic functions and energy production and nerve system activities while calcium provides protection to bones and assists in cell signaling. Phosphorus

functions in energy distribution and nucleic acid synthesis whereas iron serves as the vital component required for oxygen transport and hemoglobin synthesis.

The seeds achieve nutritional excellence because their essential elements exist in suitable amounts which enable their use as dietary supplements.

The research findings support earlier studies which showed that *Lepidium sativum* seeds provide essential nutrients which help people who cannot access regular meals to treat their nutritional deficiencies [2] The essential minerals together with bioactive compounds create multiple functional benefits for seeds which make them appropriate for food production and pharmaceutical development.

### **3.4 Heavy Metal Safety Evaluation**

The study confirms that tested samples show minimal heavy metal pollution as its primary result. The samples showed no lead presence which proves that environmental contamination from lead sources does not exist. The samples showed nickel and copper at levels which stay within acceptable limits yet mercury appeared at minimal detectable amounts. The analytical instrument detected manganese at its most minimal level which approached its lowest detection capability.

Lead absence holds special importance because it ranks among the most hazardous substances which people accumulate through time. The detected levels of other heavy metals are within safe limits established by international health organizations which indicate that these seeds do not present major health dangers. The research results match worldwide research which shows that monitoring heavy metal contamination in medicinal plants must occur to protect their safety [9] [10]

The study results show low heavy metal levels because the tested area maintains clean environmental conditions. Plants in the sampling area accumulate metals through environmental factors which include soil composition and water quality and agricultural practices.

### **3.5 Methodological Reliability**

The study employed the analytical techniques such as dry ashing and atomic absorption spectrometry as a way of generating precise findings. The dry ashing technique facilitated maximum oxidation of organic matter that led to accurate recovery of mineral elements. All the essential and minor elements in the sample were accurately measured using flame atomic absorption spectrometry. The values of the standard deviation are low, and it indicates that results have consistent performance that indicates that the analytical procedure can be repeated. Triplicate measurements and the standard solution also increase the accuracy and reliability of the data. The results validate earlier studies that demonstrated that these procedures are effective in analyzing plant materials [5]

### **3.6 Environmental and Public Health Implications**

The implications of the study findings on the environmental monitoring work and the protection of the health of people is tremendous. The site exhibits minimal heavy metal contamination that attests to the fact that it has not been contaminated by industry activities and hence providing good commercial product quality and handling conditions. The study indicates that site selection should be done properly since it not only influences the quality of plant-based products but also their safety. *Lepidium sativum* seeds are good sources of essential nutrients as well as bioactive compounds that prevent diseases and enhance the health of the population. The seeds grow safer to be consumed over a long period of time since there are no harmful contaminants. The study proves that individuals are becoming more inclined towards natural vegetable products rather than synthetic drugs and nutritional supplements. [12] [18]

### **3.7 Recommendations for Future Research**

Further studies are required to improve the knowledge of *Lepidium sativum* seeds since scientists will perform experiments using the seed samples of different commercial sources to analyze the correlation between the environmental factors and the chemical and metal composition of the seeds. The scientists should adopt the latest scientific techniques that apply both the chromatography and mass spectrometry technology in order to attain accurate identification and quantification of bioactive molecules. The research study will require long term clinical research that will explore the health consequences of regular consumptions of the products by the participants. The continuous research to monitor the level of heavy metals should also enable researchers to address the worldwide safety standards and control the potential pollutants to the environment [12] [9]

### **3.8 Final Conclusion**

This study indicates that these seeds of commercially available *Lepidium sativum* seeds have essential minerals in combination with bioactive phytochemicals that are in the seeds at low levels and they exhibit this finding. The seeds contain both nutritional and medicinal benefits that allow their utilization in the traditional and modern usage. The research indicates that their contents including their low health risks render them to be viable as

functional food products. The study needs continuous observation and further research to create safety over the long-term usage with exploring the new possible applications <sup>[15]</sup> <sup>[18]</sup>

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### Compliance with ethical standards

#### *Disclosure of conflict of interest*

The authors declare that they have no conflict of interest.

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