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Research Article

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Pharmacological Activities of the Nutraceutical Plant *Lepidium meyenii*: A Critical Review

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Abstract

Lepidium meyenii is a medicinal edible plant that have nutritional and therapeutic benefits due to synthesis of bioactive compounds. The main phytochemicals found in *Lepidium meyenii* can be categorized into six classes: glucosinolates and isothiocyanates, thiohydantoins, macaene and macamides, alkaloids, polysaccharides, and fatty acids. These compounds show a wide range of biological activities, which include antioxidant, anti-inflammatory, antimicrobial, cytotoxic, and immunomodulatory activities. Hereby, the objective of this review is to provide a wide comprehension of the nutraceutical properties of *Lepidium meyenii*. For that, we review and critically discussed original manuscripts describing the chemical and nutritional composition, as well as biological activities of *Lepidium meyenii* extracts. We showed that the nutraceutical properties of the belowground part of *Lepidium meyenii* shows great variations that are dependent of differences of phenotype, place of cultivation, type of soil, environmental conditions, and time of harvest. Additionally, we have demonstrated that diet supplementation with *Lepidium meyenii* may exert several health prophylactics benefits.

Keywords

Macamides, Peruvian maca, Traditional medicine

Introduction

Traditional medicine is intrinsically based on health knowledge and beliefs about herbs, spiritual therapies, manual techniques and exercises in order to maintain well-being and to treat or to prevent diseases [1, 2]. Plants are historically used by communities that have scarce access to modern medicine treatments. These communities are usually economically vulnerable populations in isolated areas, such as in villages, provinces, islands and tribes far from large cities or urban centers [3, 4]. Therefore, the use of plants and traditional medicine for these populations is fundamental for the maintenance of the life of these individuals and to ensure basic healthcare [5].

Medicinal edible plants and plant-derived foods have nutritional and therapeutic benefits due to synthesis of bioactive compounds, which are responsible for the pharmacological activities and nutritional value [6-9]. These bioactive compounds encompass alkaloids, phenolic compounds (phenolic acids, flavonoids, lignans, stilbenes, and tannins), steroids, glucosides, tannins, terpenoids, and phytoalexins [10-13]. These compounds show a wide range of biological activities, which include antioxidant [14], anti-inflammatory and antimicrobial [10], cytotoxic [15, 16], and immunomodulatory activities [17].

The production of bioactive compounds by the food industry has grown significantly due to the pharmacological potential of plants and the increasing resistance to chemical agents by pathogenic bacteria, parasites, viruses, and fungi [18]. Drugs produced from synthetic products might have undesirable side effects and, for this reason, a considerable part of the drugs used to treat diseases are currently originated from natural products [19, 20]. Moreover, several herbal-based products have already been patented, such as *Ginkgo biloba* leaves, which have antioxidant effect, and Liuwei Dihuang, a medicinal formula composed of 6 Chinese plants that assists the process of memory and learning [21, 22]. In this context, the research of food-based natural products has grown, and new pharmacological activities of several plants have been studied, thus increasing the possibility of drug production [23].

Lepidium meyenii is traditionally found in the Andean region of Peru and it has been traded as capsules or powder worldwide, due to its medicinal and nutritional potential [24]. This includes its capacity to improve spermatogenesis [25-27], female and male fertility [28-20], sexual performance [31-33], learning and memory [34-36], to reduce risk of osteoporosis [37, 38], and to provide protection against ultraviolet radiation [39-42], as well as anti-fatigue [43-46], cell protective [47-49], antioxidant [50-54], and immunomodulatory activities [55-57]. Most certainly, these pharmacological activities are related to the chemical components of *Lepidium meyenii* [7, 58-60]. Therefore, this plant can be considered as nutraceutical, which encompass plants and food-based products capable of providing treatment or prevention of diseases. In view of the rapid advance of the studies with the plant, the objective of this work is to present a broad view on the chemical composition of the *Lepidium meyenii*, in order to list the new discoveries regarding the chemical constituents, as well as the pharmacological activities already tested.

Botanical Description, Cultivation and Morphology

The genus Lepidium belongs to the Brassicaceae family and encompasses 250 species. *Lepidium meyenii* is a nutraceutical species popularly known as *Lepidium meyenii* [61]. In traditional medicine, this species is named after its place of origin, the Peruvian Andes. This region presents specific climatic and environmental conditions, such as high altitudes, low pressure, low temperature, low humidity, intense winds, frequent rain and sunlight, high ultraviolet, and cosmic radiation [24]. The aboveground part of the plant is composed of a crown with 12 to 20 leaves. The underground part comprises the edible part of the plant, which is usually referred as the hypocotyl, tuber or root [24, 62]. There are different phenotypes of *Lepidium meyenii*, which are classified by the color of the underground part. Nevertheless, the most common types used are the red, yellow and black cultivars [24, 63]. Its cultivation has low requirements, which prevents the use of synthetic pesticides. Additionally, its cultivation starts at November, whereas its harvesting occurs in June when the belowground part are naturally dried [64].

Historical Traditional Uses

Historically, the belowground part is mainly used in liquid preparations such as juices, but before consumption they are boiled to make it softer [65, 66]. According to popular belief, it has aphrodisiac properties and its use is related to improvement of sexual performance and female fertility, rheumatism, to treat rheumatism and respiratory diseases, and as laxative. Curiously, it is widely used to assist reproduction of pigs, chickens and horses [67]. During the Inca empire, there was a legend that warriors were fed *Lepidium meyenii* to increase their energy and vitality, and at the end of wars soldiers were forbidden to consume the plant to protect women from their sexual impulses. In addition, it was also used as active ingredient in hallucinogenic beverages as part of religious ceremonies [67]. *Lepidium meyenii* was at the brink of extinction, but largescale cultivation of the plant for production of plant-based products that promised to improve sexual performance changed this scenario, strengthening the plant's trade even to other countries. Nowadays, *Lepidium meyenii* cultivation represents an important source of income for local family.

Nutritional Composition of *Lepidium meyenii*

The nutritional composition of the belowground part of *Lepidium meyenii* shows great variations that are dependent of differences of phenotype, place of cultivation, type of soil, environmental conditions, and time of harvest. Chen et al. assessed the nutritional composition of seven cultivars of *Lepidium meyenii*, one from Peru and six from China [8]. Interestingly, the Peruvian cultivar showed systematically lower levels of proteins, total dietary fibers, as well as soluble and insoluble dietary fiber as compared to the Chinese cultivars. Crude lipids, however, were found at almost same levels in all cultivars. Despite the fact that the Peruvian cultivar showed lower levels of proteins as compared to the Chinese cultivars, the content of essential amino acids were higher in the Peruvian cultivar than in the Chinese cultivars, whereas the content of nonessential amino acids did not show a clear pattern [8]. Additionally, the different cultivars showed similar levels of minerals and total Alkaloids, whereas the Peruvian cultivar showed lower levels of Benzyl Glucosinolate and N-Benzyl hexadecanamide than in the Chinese cultivars. Li et al., assessed the nutritional composition of one *Lepidium meyenii* cultivar from Xinjiang-China [60]. Compared to the work of Chen et al., the Xinjiang cultivar showed average water, glucosinolate and *Lepidium meyenii*mide contents and higher protein levels than the Peruvian cultivar, but lower protein levels as compared to the other six cultivars [8]. It also showed higher lipid levels, but lower alkaloid content than all 7 cultivars tested by Chen et al. [8]. These results highlight that the nutraceutical properties of *Lepidium meyenii* is not only cultivar-dependent, but also it depends on the color of the belowground part and place of cultivation.

The average nutritional value of *Lepidium meyenii* is presented in table 1. Water content varies from 7.01 to

10.4%, protein content varies from 9.56 to 13.42%, and lipids content varies from 0.88 to 1.42%. The average contents of hydrolyzable carbohydrates, total dietary fibers, soluble dietary fibers, and insoluble dietary fibers are 59.0%, 18.25%, 3.37%, and 14.88%, respectively. Micro and macronutrients are also displayed (Table 1).

Table 1: Nutritional composition of *Lepidium meyenii* dry hypocotyl.

Nutrient	(%)	(mg/kg)
Water	7.01[a] - 10.4[b]	
Proteins	9.56[c]- 13.42 [a]	
Lipids	0.88[c] - 1.42[a]	
Hydrolyzable carbohydrates	59.0[b]	
Total dietary fiber[a]	18.25[c]	
Soluble dietary fiber[a]	3.37 ± 0.18 [c]	
Insoluble dietary fiber[a]	14.88 ± 0.15	
Minerals		
Copper (Cu)		4.3[c] - 5.9[a]
Manganese (Mn)		11.2[a, c]
Zinc (Zn)		26.5[c] - 30.7[a]
Iron (Fe)		70.4[c] - 82.4[a]
Sodium (Na)		150.2
Magnesium (Mg)		737.7[c] - 847.5[a]
Calcium (Ca)		4128.8[c] - 13700.0[a]
Potassium (K)		8063.3[c] - 11700.0[a]

a: Dried yellow *Lepidium meyenii* root collected from Xinjiang Province, adapted from Li et al. [60]
b: Dried hypocotyl cultivated in Peru and phenotype not characterized, adapted from Dini et al. [68]
c: Dried yellow *Lepidium meyenii* hypocotyl cultivated in Peru, adapted from Chen et al. [8]

a: Dried yellow *Lepidium meyenii* root collected from Xinjiang Province, adapted from Li et al. [60].

b: Dried hypocotyl cultivated in Peru and phenotype not characterized, adapted from Dini et al. [68].

c: Dried yellow *Lepidium meyenii* hypocotyl cultivated in Peru, adapted from Chen et al. [8].

Phytochemicals

The main phytochemicals found in *Lepidium meyenii* can be categorized into six classes: glucosinolates and isothiocyanates [54, 59, 63, 68-72], macaene and macamides [47, 58, 73-81] , alkaloids [52, 82-84], thiohydantoins [85-87], polysaccharides [43, 44, 51, 55, 77, 88-93], and fatty acids [46, 77, 78, 94, 95]. Here, we discuss the in-depth contribution of polysaccharides to the nutraceutical properties of *Lepidium meyenii*.

Polysaccharides are carbohydrates composed by several units of monosaccharides linkd by glycosidic bonds. In plants, they are important as energy reserves, for structural functions, and as precursors of various compounds synthesized by plants. Additionally, they present biological properties crucial for human health, such as immunological [56], antioxidant [96], and neuroprotective [97, 98]. Several polysaccharides have already been isolated from *Lepidium meyenii* hypocotyl and are generally heteropolysaccharides composed primarily of glucose, arabinose, galactose, rhamnose and mannose [43-45, 56, 91, 99, 100-102]. *Lepidium meyenii* polysaccharides have shown to possess antioxidant [51, 99], anti-fatigue [43-45], cell protective [49, 99], and immunomodulatory properties [93, 101, 102]. Therefore, these polysaccharides contribute to the nutraceutical properties of *Lepidium meyenii*.

Table 2: Polysaccharides isolated from *Lepidium meyenii*

Polysaccharide	Monosaccharide composition	Reference
LMP	arabinose, galactose, glucose, and rhamnose	[100]
LMP-1	arabinose and glucose	[101]
LMLP	arabinose, galactose, glucose, mannose, and rhamnose	[63]
MC-1	arabinose, galactose, glucose, and mannose	[102]
MC-2	arabinose, galactose, glucose, and mannose	
MLP-1	arabinose, galactose, glucose, mannose, rhamnose, ribose, and xylose	[51]
MLP-2	Glucose	
MP	arabinose, galactose, glucose, and mannose	[44]
MP1	arabinose and galactose	[9]
MP-1	arabinose, galactose, galacturonic acid, glucose, rhamnose, and xylose	[49]
MP21	arabinose, galactose and rhamnose	[93]
M-PL	arabinose, galactose, glucose, and mannose	[45, 103]
MPS-1	arabinose, galactose, glucose, and xylose	[43]
MPS-2	arabinose, galactose and glucose	

Biological and Pharmacological Activities

Antioxidant activity

The antioxidant activity of the aqueous extract of *Lepidium meyenii* hypocotyl was assessed by using different scavenging assays protocols. It has been demonstrated that *Lepidium meyenii* extracts acts in the detoxification of free radicals, in the reduction of cell death induced by peroxynitrite and in the protection of cells against hydrogen peroxide by maintaining the production of ATP at optimum levels, since under oxidative stress conditions the cellular production of ATP is reduced. Thus, aqueous extract of *Lepidium meyenii* have a protective effect on oxidative cellular damage. This is closely related to the presence of flavonols and isothiocyanates, since these compounds present a potential antioxidant [104-106]. Scavenging activity by 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay demonstrated that *Lepidium meyenii* leaf methanolic extract has greater antioxidant activity (2262.37 μmol of trolox EQ/100 g) than aqueous (1305.36

μmol of trolox EQ/100 g) and dichloromethane (246.42 μmol of trolox EQ/100 g) [53]. Scavenging activity by 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay supported the results of Rodríguez-Huamán et al. [53] that *Lepidium meyenii* methanolic extract showed the best antioxidant activity results. Additionally, the yellow and black cultivars showed the most promising results [107]. The hydroalcoholic extract of black *Lepidium meyenii* hypocotyls presented a variation in the percentage of the antioxidant activity from 3.59% (at concentration of 0.03 mg.mL^{-1}) to 42.19% (at concentration of 0.40 mg.mL^{-1}) [108].

Polysaccharides isolated from *Lepidium meyenii* leaves have strong antioxidant activity. MPL-1 showed percent inhibition of 82.71%, whereas MPL-2 showed percent inhibition of 79.07%. These values are close to that found in vitamin C (99,68%), used as a positive control [51]. Another polysaccharide, MP1, extracted from *Lepidium meyenii* hypocotyl also had the antioxidant activity analyzed by DPPH radical scavenging assay. By using concentrations of MP1 that ranged from 100 to 1000 μg.mL-1, the authors demonstrated that MP1 was able to consume DPPH radicals in the range of 9.12-31.23%, suggesting that MP1 exerted moderate DPPH radical scavenging activity [99].

Yábar et al., evaluated the antioxidant activity and the phenolic compound profile of yellow, red and black *Lepidium meyenii* cultivars [54]. Chromatographic analysis showed the presence of 11 phenolic compounds: six flavanol derivatives, four benzoic acid derivatives and one o-coumaric acid derivative. The authors claimed that improving cultivation techniques and post-harvest management could enhance antioxidant activity and to preserve the content of phenolic compounds in *Lepidium meyenii* extracts.

Cytoprotective activity

Cells are constantly exposed to factors that can cause cellular damage. Some of these factors are reactive oxygen species (ROS) that are subproducts of aerobic metabolism. There are several types of ROS, such as superoxide anion (O_2-), hydrogen peroxide (H_2O_2), hydroxyl radicals (OH.), and singlet oxygen ($^1O_2$). Low levels of ROS production are important to maintain normal physiological functions in the organisms. But in some conditions, the production of ROS exceeds the antioxidant capacity and the oxidative stress is caused, which can generate cells and tissues damage [109, 110].

Treatments of RAW264.7 macrophage cells with polysaccharide MP1 isolated from *Lepidium meyenii* roots have demonstrated cytoprotective effect of this compound. Initially, cells were treated with varying concentrations of MP1 (0-1000 μg.mL^{-1}) and cultivated for 24 h, then the H_2O_2 was added and cultivated for 1h. Markers of oxidative stress, such as malondialdehyde (MDA), lipid peroxidation marker and lactate dehydrogenase (LDL) were analyzed. It was demonstrated that the increase in both MDA and LDL was lower in the MP1 treated group compared to the group treated only with H_2O_2. These highlights that the group treated only with H_2O_2 showed higher production of ROS than the group treated with 1000 μg.mL^{-1} of MP1. Therefore, MP1 showed protective effect on H_2O_2-induced injure RAW264.7 cells [99].

Yu et al., showed that not only polysaccharides, but also macamides may exert protective effects [47]. For that, they assessed the protective effects of macamides on corticosterone-induced (CORT) neurotoxicity in rat pheochromocytoma (PC12) cells. They showed that macamides were able to reduce CORT-induced neurotoxicity, by increasing cell viability, reducing LDH release and preventing intracellular ROS generation. These results demonstrate the great potential of macamides to treat neuronal damages.

Immunomodulatory activity

The immune system is the set of cells, tissues, substances and mechanisms involved in protecting the organism against the action of exogeneous pathogens such as viruses, bacteria, toxic substances and allergens. Plant extracts and isolated compounds have demonstrated immunomodulatory effect on macrophages, the main cells of the defense system [111]. The defense action of macrophages against inflammation and infection is based on the phagocytosis of the pathogen or allergen and the synthesis of pro-inflammatory cytokines, such as interleukins, tumor necrosis factor (TNF-α) and chemokines, as well as, the production of reactive oxygen species (ROS) and reactive nitrogen intermediates such as nitric oxide (NO) [112].

The polysaccharide MP21 was extracted and purified from dry *Lepidium meyenii* roots. Different concentration of MP21 (62.5-1000 μg.mL^{-1}) were incubated with RAW264.7cells for 48 h. MP21 enhanced the phagocytic capacity and induce higher synthesis of NO, ROS, TNF-α, and IL-1β secretion in RAW264.7 cells. Therefore, MP21 has been shown to stimulate the innate immune system by modulating the action of macrophages [56]. The polysaccharide (LMLP) extracted from dried *Lepidium meyenii* leaves also stimulated the proliferation and the phagocytosis of RAW264.7 cells [113]. The polysaccharide (LMP-1) extracted from dried roots stimulated the expression of inflammatory factors (TNF-α, IL-1β and IL-6) in macrophages in a dose dependent manner [101]. Taken together, these results highlights great contribution of polysaccharides to *Lepidium meyenii* nutraceutical properties.

In an interesting study, Ren H evaluated the effect of supplementation with *Lepidium meyenii* in box athletes [114]. They have assessed the profile of red and white blood cells, as well as immunoglobulin (Ig) in the blood of the athletes in responses to the supplementation. Curiously, there was no differences in the levels of red blood cells, but white blood cells and IgA, IgM and IgG increased as compared to the control group. The authors then suggested that supplementation with *Lepidium meyenii* improve the immune function by raising the level of white blood cells and Ig in box athletes.

Anti-fatigue effect

Fatigue causes general tiredness and can be classified as physical or mental. Mental fatigue is usually caused by excessive mental work or sleep deprivation, whereas physical fatigue is usually caused by excessive exercises and inadequate recovery

[115, 116]. *Lepidium meyenii* extracts and isolated compounds show a beneficial effect for the reduction of fatigue. Choi et al., [117] demonstrated that after 3 weeks of supplementation with 30 and 100 mg.kg^{-1} of liposoluble extract from yellow *Lepidium meyenii* (obtained using supercritical carbon dioxide as solvent), the swimming time to exhaustion of mice increased by up to 41% as compared to the control group. It was also observed a reduction in oxidative stress caused by intense exercise, as measured by reduced levels of muscle lipid peroxidation, increased amount of total glutathione and increased activity of hepatic catalase (Choi et al., 2012) [117]. The aqueous extract of *Lepidium meyenii* was used in different concentrations (4, 10, 20 and 40 mg.g^{-1}) to evaluate the performance of rats during swimming. The duration of activity increased progressively over the 21 days of supplementation compared to the control group. The swimming time (minutes) of the supplemented group with 40 mg.g^{-1} of the extract was 19.33 on the 14th day and 21.37 on the 21st day of treatment. The control group obtained a time of 11.34 on the 14th day and 10.88 on the 21st day [118].

Supplementation with polysaccharides MPS-1, MPS-2 [43], and MP [44] (100 mg.g^{-1}) isolated from yellow *Lepidium meyenii* hypocotyls contributed to the anti-fatigue effect by improving antioxidant activity, helping to reduce metabolic products, which are related to fatigue, such as lactic acid and urea nitrogen. Therefore, supplementation improved the activity of glutathione peroxidase (GSH-PX) and lactate dehydrogenase (LDH), strengthening the antioxidant capacity, and potentiated the action of creatine kinase (CK), which contributes to the faster formation of ATP, generating more energy. Supplementation also increased the duration and speed of swimming in proportion to the increase in polysaccharide concentrations in the samples [43, 44].

Supplementation with polysaccharide M-PL extracted from fresh *Lepidium meyenii* hypocotyls also showed anti-fatigue effect. Forty mice were randomly divided into four groups: a) high dose (0.05 mg.g^{-1}), b) medium dose (0.03 mg.g^{-1}), c) low dose (0.01 mg.g^{-1}), and blank control group (normal saline). It was observed that the swimming time to exhaustion of the supplemented mice was 44.2 min, considerably higher than the control group (14.44 min). Muscle glycogen was greater in the high dose group (19.08 mg.g^{-1}) compared to the control group (6.74 mg.g^{-1}). This shows that supplementation with *Lepidium meyenii* polysaccharides reduced the expenses of energy reserves during exercise. This is important since the faster these reserves are spent the faster the feeling of fatigue will be present [45].

Supplementation with petroleum ether extract from *Lepidium meyenii* roots (40 mg.g^{-1}) in mice for 21 days improved swimming time to exhaustion and reduced lactate, serum ammonia levels and LDH activity, whereas increased superoxide dismutase (SOD) and GSH-PX in the brain, liver and muscle. Moreover, the control group had an increase in hepatic glycogen and non-esterified fatty acids, suggesting that supplementation reduced glycogen expenditure and increased lipid metabolism as an energy source during exercise. These show that the use of *Lepidium meyenii* can improve the activity of antioxidant enzymes and reduce the peroxidation in these tissues [46].

Benefits in sexual performance and spermatogenesis

Lepidium meyenii extracts are known to improve sexual performance. To confirm this specific traditional use of the plant, forty-five male mice were supplemented with lipid extract from *Lepidium meyenii* (40 mg.g^{-1}) for 22 days. Zheng et al., observed increased intrusions (introduction of the male sexual organ into the female sexual organ) by the male mice after 3 hours of observation and greater amount of sperm in female mice (n=90) during mating as compared to the control group [119]. In contrast, Lentz et al. [120] showed that supplementation with an aqueous solution of the *Lepidium meyenii* in concentrations of 25 and 100 mg.g^{-1} for 21 days did not have any effect on the number of intrusions group, as well as in the number of ejaculations as compared to the control group. It is difficult to compare both results straightaway since they have used different concentrations and solvents to prepare the extract. Nevertheless, it is clear that the lipidic fraction is richer in compounds related to the improvement of the sexual performance than the aqueous extract.

In an attempt to extrapolated the results for human subjects Dording et al. [121] supplemented individuals diagnosed with depression and using SSRI drugs (selective serotonin reuptake inhibitors) with *Lepidium meyenii* (1.5 g/day and 3.0 g/day) for 12 weeks. These individuals showed sexual dysfunction, exclusively after starting the medication. They showed that individuals supplemented with the highest dose of *Lepidium meyenii* (3.0 g/day) showed improved libido [121]. In a similar study, fifty men diagnosed with mild erectile dysfunction were treated with dehydrated *Lepidium meyenii* root tablets (1200 mg) twice a day for 12 weeks. They showed that individuals supplemented with *Lepidium meyenii* root tablets showed improved physical, social, and sexual performance in relation to the control group [33].

Supplementation with aqueous extract of black *Lepidium meyenii* (1.66 g/Kg/d) for 42 days increased sperm count in the epididymis of rats as compared to the control group [27]. Similarly, supplementation with the hydroalcoholic extract of black *Lepidium meyenii* (50 mg/d) for 7 days increased daily sperm production and sperm count in the epididymis of rats as compared to the control group [108]. In addition, sperm from rats treated with yellow *Lepidium meyenii* powder (20 g/d) for 60 days were evaluated and sperm samples from supplemented rats showed greater mobility, acrosome integrity and less DNA fragmentation compared to the control group [122].

Osteoporosis-preventive activity

Especially after menopause, there is an increased probability of women developing osteoporosis, especially by reducing hormone levels that are important in calcium and bone metabolism, such as estrogen [123]. To mimic this low hormone production and its consequences, Zhang et al. [38] performed ovariectomy in female rats and verified greater values of the diameter and width of the femoral bone, as well as bone mineral density in rats treated with ethanolic and hydroalcoholic extract of *Lepidium meyenii* in relation to the control group. Thus, a beneficial effect in preventing bone loss in case of estrogen deficiency was observed upon supplementation with *Lepidium meyenii* extracts.

Effects on the process of learning, depression and memory

Supplementation of aqueous extract of different *Lepidium meyenii* cultivars (yellow, red and black) for 21 days was used to assess learning skills in rats. After supplementation, rats were subjected to a field with an alcove, in which they had to enter and drink water. The rats supplemented with the three types of *Lepidium meyenii* entered the alcove, found and drank water in shorter time than the control group [124]. The same study carried out another test to assess aspects related to depression, and the rats were submitted to an antidepressant activity, which consisted of a forced swimming test. The rats supplemented with yellow, black and red *Lepidium meyenii* showed a reduction in immobility time, demonstrating that they were more active and were more stimulated to escape compared to the control group [124].

Reactive oxygen species (ROS's) are associated with the development of neuropsychiatric problems such as depression leading to oxidative stress and brain tissue damage, and high levels of corticosterone are also associated with greater symptoms of depression [125, 126].The use of petroleum ether extract from *Lepidium meyenii* (250 and 500 mg/kg) for 6 weeks reduced the activity of ROS in brain tissue and serum corticosterone levels [127].

Rats were subjected to the Moris labyrinth test, which consists of a circular pool divided into quadrants with an escape platform in one of these quadrants. Supplementation with black *Lepidium meyenii* hydroalcoholic extract (0.125, 0.25, 0.50, and 1.0 g/Kg) for 28 days reduced the time that the rats managed to escape through the platform Thus, indicating that supplementation with black *Lepidium meyenii* extracts has been shown to improve memory skills.

Protection against ultraviolet radiation

Ultraviolet (UV) radiation is a toxic environmental factor and may increase the synthesis of inflammatory and ROS mediators, cause cell lesions and DNA damage, which can subsequently generate mutations in skin cells and predispose to cancer [128]. The exposure of humans to sunlight without righ protection, such as sunscreens, is the main way of exposing themselves to this radiation [129].

Mice were submitted to topical use of the *Lepidium meyenii* hydroalcoholic extracts and then the animals were placed at 15 cm from the source of radiation. The topic use of yellow, red and black *Lepidium meyenii* hydroalcoholic extracts generated less epidermal hyperplasia, sunburn cells and leukocytic infiltration, compared to untreated irradiated [39, 130]. These results suggest a positive effect of *Lepidium meyenii* extracts treatment on skin changes caused by UV radiation. Although isolated compounds have not been tested, *Lepidium meyenii* has phenolic compounds, which are the responsible for the antioxidant activity of the plant and can justify this effect. The glucosinolates present in the extracts may also justify its antioxidant activity, since they might act as one of the defense substances of these plants against exposure to UV radiation. Therefore, products based on *Lepidium meyenii* may be another option of use for protection against UV radiation.

Concluding Remarks

Lepidium meyenii is an extremely versatile nutraceutical plant species. Here, we have demonstrated the great potential of this species for dietary supplementation in animals and humans, since *Lepidium meyenii* extracts possess great nutritional value and many important biological activities. These biological activities include antioxidant, anti-inflammatory, antimicrobial, cytotoxic, and immunomodulatory activities. The nutraceutical properties of *Lepidium meyenii* depend on the phenotype, place of cultivation, type of soil, environmental conditions, and time of harvest. Additionally, we have demonstrated that diet supplementation with *Lepidium meyenii* may exert several health prophylactics benefits. In-depth studies aiming at identifying and characterizing new bioactive compounds from *Lepidium meyenii* is crucial for the development of drugs as well as more efficient phytochemical based products.

Conflict of Interest

The authors declare no conflict of interest.

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