Chapter 7

Antioxidants in Maca (*Lepidium meyenii*) as a Supplement in Nutrition

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Additional information is available at the end of the chapter

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Abstract

Maca plant belongs to Brassicaceae such as broccoli, cabbage and radish, and has a tuberous root. With the declaration of The Food and Agriculture Organization (FAO) that maca is a forgotten and disappearing plant, the fresh, dried, powder and organic forms of it take part in nutrition as a food supplement world-wide. Studies have focused on antioxidant effects depending on its bioactive components such as phenols, glucosinolates, alkamides and polysaccharides. Antioxidant enzymes and their ability of inhibition the free radicals in blood and tissues were measured to determine the antioxidant effects. The research results have suggested that these compounds present the antioxidant effect by increasing enzyme activity and scavenging free radicals. Yet further experiments are needed to understand this relation between antioxidant activity and maca's antioxidants. The objective of this chapter is to carry out the possible antioxidant activity of maca in human and animal nutrition related to its active compounds such as: phenols, glucosinolates, alkamides and polysaccharides.

Keywords: antioxidant, human and animal nutrition, *Lepidium meyenii*, maca, macamide, polysaccharide

1. Introduction

Antioxidant effects of plants used in daily nutrition are investigated, their bioactive contents are analyzed and its mechanisms are revealed. Recently, bioactive compounds with antioxidant effects have been found in many plants traditionally used. These plants cross their local region, cultivated in many parts of the world, and take place in markets as various supplement products. Plants are linked to bioactive compounds in which they contain antioxidant effects. These compounds act alone or synergistically and are consumed in plants or extractions in various forms. The antioxidant effect produced by plants in metabolism is measured by various methods. The most common methods are to determine the levels of antioxidant enzymes and free radicals. In addition, measurement methods such as physical performance and health score give information about antioxidant status. Like many plants known to have antioxidant activity, Maca contains antioxidant compounds. Due to its chemical composition, pharmacological effects and positive effects on various metabolisms, The South American maca plant has attracted both the consumers and the researchers in great demand all over the world recently. The aim of this chapter is to establish an analysis of the properties related to antioxidant activity of different kinds of maca plant and its contents from active compounds such as: phenols, glucosinolates, alkamides and polysaccharides.

2. Maca (*Lepidium meyenii*)

Maca is a plant which has tuber roots underground and belongs to Brassicaceae family including also plants such as broccoli, radish, turnip, cabbage. It is supplemented in pudding, jam, beverage and yogurt based on its aromatic flavor and odor. It is traditionally consumed in daily meals by local people because of its high nutritional value, aphrodisiac, energizer and increasing fertility of them and their farm animals. The root colors are varies such red, yellow, brown, purple, black etc. (**Figure 1**). Maca is endemic in the South America. It is cultivated at high altitudes of Andes Mountains and dried in the sun and freezing cold in the natural environment to store for a long time. The dried maca is boiled in water and softened, and the water is consumed with its roots. Maca powder are added to drinks as energy source and aromatic sweetener [1]. Besides increasing interest in maca [2], and the International Plant Genetic Resources Institute announced that this local plant is neglected, under the danger of disappearing and must be protected [3]. It has positive effects on various metabolisms in laboratory animals and clinical studies. In addition, these effects and the mechanism of action have been confirmed by in vitro studies. Studies suggest that its impacts originate from antioxidant compounds such as phenols, glucosinolates, alkamides and polysaccharides. These compounds are determined by different extraction and analysis methods. Their antioxidant effects is established with factors such as free radical scavenging and cell viability invitro. In

Figure 1. Some ecotypes of maca [2].

clinic nutrition studies, the effects of maca on antioxidant status was determined by measuring the antioxidant enzyme activity, free radical scavenging, anti-fatigue effect and health score.

3. Antioxidants in maca

Like many other plants, maca plant contains various antioxidant compounds. The quantities of these substances vary according to the soil composition, maca ecotype, the time of harvest, the drying process and the extraction method [4]. In spite of the quantity differences, maca contains several and substantial amount of antioxidant compounds. These are especially phenols, glucosinolates, alkamides and polysaccharides. They have various functions on metabolism and antioxidant effects in scientific researches. In vitro studies, their antioxidant effects are mostly established by several methods such as the measurements of ferric reducing antioxidant potential (FRAP), hydroxyl radical scavenging ability (HRSA), lipid peroxidation inhibition ability (LPIA), 11,1-difenil-2-pikrilhidrazil (DPPH) and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid (ABTS) radical scavenging abilities of bioactive compounds.

3.1. Phenols

Depending on the structure elements and phenol rings they contain, phenols are termed. Phenolic compounds are divided into groups such as phenolic acids, flavonoids, tannins, resveratrol and lignans. They are found in the structure of many plants as nature antioxidant. They represent an antioxidant activity by, breaking chains, chelating metal ion, decomposing products of oxidation and scavenging free radicals [5]. Maca contains phenols in different quantities based on ecotype and extraction method. Total phenolic compounds in maca were mostly analyzed according to the Folin–Ciocalteu method by using gallic acid standard. The results of measurement are expressed as mg gallic acid equivalent (GAE) per gram of dried maca.

The ecotypes (hypocotyl colors) of maca influence the phenol contents and composition. Black maca has more total phenols than red and yellow maca. Despite black maca shows more antioxidant activity than red maca, the methanol extract of yellow maca presents more DPPH scavenging activity than that of black maca [6, 7]. When compared to yellow, pink, violent and lead hypocotyls, total phenols are highest in yellow maca (**Table 1**) [8]. Besides the effect of ecotype, phenol contents are influenced by the extraction methods. Hydroalcoholic extract and its fractions (petroleum ether, chloroform, ethyl acetate, n-butanol, and aqueous) of yellow maca have various levels of total phenols. But there is a positive correlation between FRAP, HRSA, LPIA and total phenol contents [9]. Campos et al. [4] analyzed the total phenols of maca with several extraction methods and identified a standard and optimal extraction method. It has been shown that ethanol concentration is more effective on total phenol extraction than temperature, liquid/solid ratio and extraction time. In addition, cooking process affects the total phenols content and also antioxidant activity. It was reported that boiled yellow maca contains 13.6 mg GAE/g while raw yellow maca has 7.8 mg GAE/g of total phenols (**Table 1**) [10]. Some studies argue that maca has the lowest amount of total phenols (5.5–7.6 mg GAE/g) in used herbs, plants and spices in South American culinary. Because of low phenol content, its FRAP, DPPH and ABTS scavenging abilities and antioxidant activity might be seem limited when compared to the others [11, 12].

Ecotype	Form	Value (mg GAE/g maca)	Effect	Antioxidant activity	Reference
Black	Spray-dried	13.5–17.9	DPPH scavenging	15.06–18.52%	[6]
Red		11.6–13.6		14.11–16.23%	
Yellow	Methanol extract	1.85	DPPH scavenging	21.7%	[7]
Black		2.51		18.2%	
Yellow	Methanol extract	2.27–2.29	FRAP, HRSA, LPIA activities	Various	[9]
Yellow	Fresh Hypocotyl	5.65–5.85	Effects of ecotype	Nonmeasured	[8]
Pink		5.72			
Violent		4.61–5.21			
Lead		4.89–4.91			
NA	Ethanol extract	3.56–9,51	Effects of extraction, Antioxidant activity	Various	[4]
NA	Fresh Hypocotyl	5.5–7.6	Dose-dependent DPPH scavenging	>10%	[11]
NA	Aqueous	4.6	DPPH, ABTS, FRAP scavenging	0.434 mmol/100 ml	[12]
Yellow	Boiled	13.6	Effects of cooking process	Nonmeasured	[10]
	Non-boiled	7.8			

Table 1. Phenol content of maca and its antioxidant effects.

3.2. Glucosinolates

Glucosinolates (Gls) are the secondary metabolites with nitrogen and sulfur chains which many plants in Brassicaceae family contains. In the chemical structure of Gls, there are R and sulphate groups derived from amino asides. During the consumption, plant texture is damaged and myrosinase enzyme hydrolyses Gls to β-D-glucose and aglycone. By releasing sulphate, these metabolites reorganize to thiocyanate, isothiocyanate and nitrile which give the typical taste and smell of Brassicaceae plants. The main source of Gls is seeds, roots, stems and leaves of cruciferous vegetables in human diet [13–15]. The most of Gls in maca is aromatic type and glucotropaeolin. The Gls content varies by ecotype, part of maca plant, harvest time, cultivation region, drying and extraction process (**Table 2**) [8, 16–18]. Also, researchers have focused on antioxidant and anticarcinogenic effects of Gls in maca [4, 19].

The Gls content of maca is affected by harvest time, processes of drying and manufacturing. Total Gls content increases up to 90 days before harvest and 15 days after harvest. During traditional drying process in the open air, instable temperature and dehydration cause the tissue damage and decreasing myrosinase enzyme activity to generate Gls in hypocotyl [10, 20]. This process of freeze drying also decreases benzylglucosinolate and benzylisothiocyanate contents of maca (**Table 2**) [17]. Likewise, supplementing to food as a flavorant, encapsulating

Gls	Ecotype	Form	Value	Unit	Effect	Reference
Total glucosinolate	Yellow	Methanol extract	36.2	mmol/kg DW	Effects of harvest time and drying	[20]
	Red		34.9			
	Black		31.43			
Total glucosinolate	NA	Ethanol extract	4.06–17.81	mmol/kg DW	Effects of extraction method, ABTS scavenging	[4]
Benzyl glucosinolate	Yellow	Pulverized	126	mg/100 g DW	Protect the skin against UV	[10]
		Aqueous	302			
		Dried Hypocotyl	83			
Total glucosinolate	Yellow	Fresh Hypocotyl	28.42–37.23	μmol/g DW	Effects of ecotype	[8]
	Violent		33.22–34.30			
	Pink		44.1			
	Lead		54.78–56.00			
Benzyl isothiocyanate	Mix	Fresh Hypocotyl	475	μg/g DW	Effects of drying	[17]
		Dried Hypocotyl	21.5			
Benzyl glucosinolate	Mix	Fresh Hypocotyl	46.3	mg/g DW		
		Dried Hypocotyl	17.8			
Total glucosinolate	Mix	Fresh Hypocotyl	25.66	μmol/g DW	Effects of manufacturing process	[16]
		Dried Hypocotyl	4.45			
		Seed	69.45			
		Powder	4.06			
		Mayonnaise	2.69			
		Liquor Tonic	—			

Table 2. Glucosinolate and their derivates contents of maca (DW, dry weight).

or grinding influence adversely [16]. Boiling the dried maca hypocotyl before consumption increases total Gls content. Fresh hypocotyls have the highest level of Gls. The vast majority of Gls in maca is benzyl glucosinolate (>76%), also called glucotropaeolin. The other derivatives of Gls such as glucoalyssin, glucosinalbin, glucolimnanthin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin and glucoraphanin are in trace amounts [4, 8, 20].

It is questionable whether or not there is a relation of Gls with ecotype of maca. Clement et al. [8] reported that there are differences in Gls between ecotypes and the lead color ecotype of maca has higher total Gls than that of yellow, pink and violent. Supporting to this, black maca has more benzyl glucosinolate than yellow and purple macas [18]. But, other researchers found out that various ecotypes have Gls in similar quantities and there is not an influence of ecotype on Gls content in maca [20].

3.3. Alkamides

Alkamides are formed by the different amine groups and the fatty acids and are natural components of many plants. Since their chemical structures are different from other alkamides, the alkamides of maca are called as the macamide. They which are maca-specific alkamides, are thought to have antioxidant effects. Chemical structures of macamides are formed by binding the phenylamine to fatty acid with an amide bond. These fatty acids range from 12 to 24 carbon atoms. In some macamides there is a methoxy group on the benzyl ring. The R group derives the macamides according to the number of carbons and chains they contain (**Figure 2**) [21, 22]. Day by day, a new macamide, its chemical structure and pharmacological effects are introduced in scientific publications. Despite their low levels, they are important markers to measure and standardize the maca's quality [22–25].

First, Muhammed et al. [23] identified N-benzyl-5-oxo-6E, 8E-octadecadienamide and N-benzylhexadecanamide which maca-specific alkamides and named them 'macamide'. The major amount of macamides in maca forms in N-benzylhexadecanamide. In addition to these two macamides, Zhao et al. [22] isolated five new macamides not reported in other Lepidium species before (**Table 3**). N-(3,4-dimethoxybenzyl)-hexadecanamide and N-benziltetracosanamide, commonly found in cultivated maca, were also detected in wild maca [25]. The cultivation region and the drying process affect the amount of macamides but the effect of ecotype is not clear [17, 26, 27]. Compared to maca grown in Peru, China and Czechia, the most of the N-benzylhexadecanamide is in that of China, then Peru and Czehia respectively. Further, macamide was not detected in maca grown in greenhouse [18, 27, 28]. However the above-mentioned studies argue that ecotype has no effect on macamide, they were reported that violent color of hypocotyl has higher total macamide than yellow, pink and lead colors of them [8]. Among black, purple and yellow hypocotyls of maca, black one contains the highest total macamide content [29].

Macamides are believed to be FAAH (fatty acid amide hydrolase) inhibitors, and also play a role like endocannabinoids in the cannabinergic synapses. Some derivatives of macamide have shown the inhibition activity of FAAH and to be a natural alternative to FAAH inhibitors to treat the neurological diseases, such as pain, epilepsy, anxiety, depression [30, 33, 53]. But some

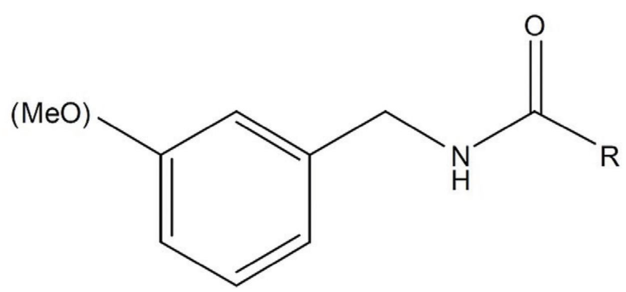

Figure 2. The main structure of macamide [21].

Macamides	Ecotype	From	Effect	Reference
N-benzyl-5-oxo-6E,8E-octadecadienamide	NA	Petroleum ether extract	First report	[13]
N-benzylhexadecanamide				
5-oxo-6E,8E-octadecadienoic acid				
N-benzyl-9-oxo-12Z-octadecenamide	NA	Ethanol extract	First report	[22]
N-benzyl-9-oxo-12Z,15Z-octadecadienamide				
N-benzyl-13-oxo-9E,11E-octadecadienamide				
N-benzyl-15Z-tetracosenamide				
N-(m-methoxybenzyl)-hexadecanamide				
N-benzylhexadecanamide	NA	Petroleum ether extract	First report	[24]
N-benzyl-9Z-octadecenamide				
N-benzyl-(9Z,12Z)-octadecadienamide				
N-benzyl-(9Z,12Z,15Z)-octadecatrienamide				
N-benzyloctadecanamide				
N-benzylhexadecanamide	Yellow	Petroleum ether extract	Antifatigue and antioxidant activities	[32, 34]
N-benzyl-5-oxo-6E,8E-octadecadienamide				
N-benzylhexadecanamide	NA	Pentane extract	FAAH inhibition	[21]
N-benzyloctadecanamide				
N-benzyl-9Z-octadecenamide				
N-benzyl-5-oxo-6E,8Eoctadecadienamide				
N-(3-methoxybenzyl) -9Zoctadecanamide				
N-benzy-(9Z,12Z)-octadecadienamide				
N-(3-methozybenzyl)-(9Z,12Z)-octadecadienamide				
N-benzy-(9Z,12Z,15Z)-octadecatrienamide				
N-(3-methozybenzyl)-(9Z,12Z,15Z)-octadecatrienamide				
N-(3-methoxybenzyl)-hexadecanamide				
N-benzyl-15Z-tetraisocenamide				
N-(4-florobenzyl)-hexadecanamide				
N-(4-chlorobenzyl)-hexadecanamide				
N-benzyl-5-oxoctadecanamide				
N-(4-chlorobenzyl)-5-oxoctadecanamide				
N-pyridine-9Z-octadecenamide				
N-(3-methoxybenzyl)-6-phenylhexanamide				
N-(3-methoxybenzyl)-6-phenylheptanamide				
N-(3-methoxybenzyl)-7-oxo-7-phenylheptanamide				
N-(3,4-dimethoxybenzyl)-hexadecanamide	Wild maca	Hexan extract	First report in wild maca	[25]
N-benzyltetracosanamide				

Macamides	Ecotype	From	Effect	Reference
N-benzyl hexadecanamide	Mix	Methanol extract	Effects of drying process	[7]
N-benzyl-(9Z,12Z)-octadecadienamide				
N-benzyl-(9Z,12Z,15Z)-octadecatrienamide				
N-benzyllinoleamide	NA	Petroleum ether extract	No effect	[31]
N-benzyloleamide			Antifatigue and antioxidant activities	
N-benzylpalmitamide			No effect	
N-benzylhexadecanamide	Black, Yellow, Purple	Petroleum ether extract	Effects of ecotype, Antioxidant activity	[29]
N-benzyl-5-oxo-6E,8E-octadecadienamide				
N-benzyl-9-oxo-(12Z,15Z)- octadecadienamide	Mix	Petroleum Ether Extract	Effects of region and greenhouse	[18, 27, 28]
N-benzyl-13-oxo-(9E,11E)-octadecadienamide				
N-benzyl-9-oxo-12Z-octadecanamide				
N-(3-methoxybenzyl)-(9Z,12Z,15Z)-octadecatrienamide				
N-benzyl-(9Z,12Z,15Z)-octadecatrienamide				
N-(3-methoxybenzyl)-(9Z,12Z)-octadecadienamide				
N-benzyl-(9Z,12Z)-octadecadienamide				
N-(3-methoxybenzyl)-hexadecanamide				
N-benzyl-hexadecanamide				
N-Benzyl-9Z-octadecanamide				
N-Benzyl-octadecanamide				
N-Benzyl-heptadecanamide				
N-benzylhexadecanamide	NA	NA	Neuroprotective activity	[33]
N-(3-methoxybenzyl)-(9Z,12Z,15Z)-octadecatrienamide				

Table 3. Macamides and macene content of maca and their effects.

macamide derivatives which has the carbonyl group do not produce the inhibition effect of the FAAH because of their interaction with the FAAH [21]. Wu et al. [30] have reported that the FAAH inhibition activity of macamides can be reversible or irreversible due to their chemical structures. When mice in exercise-induced stress was daily fed with the low (12 mg/kg) and high (40 mg/kg) doses of N-benzyloleamide, N-benzyllinoleamide and N-benzylpalmitamide, antioxidant and antifatigue effects were recorded by increasing GPx and SOD (superoxide dismutase), decreasing MDA (malondialdehyde) lactic acid, blood ammonia, LDH (lactate dehydrogenase), liver glycogen and increasing non-esterified fatty acid (NEFA) specially in N-benzyloleamide high dose group (40 mg/kg).Thus, N-benzyloleamide influences the energy metabolism and reveals antioxidant and antifatigue activities (**Table 3**) [31].

3.4. Polysaccharides

Polysaccharides are found in the structure of many plants and their major components. They are high molecular weight carbohydrates and formed by linking monosaccharides together with glycoside bonds. They have nutritive value and some pharmacological activities such as anti-fatigue, antioxidant, immunomodulator and antimicrobial etc [34–36]. Thus, polysaccharides may take a main part of components in some drugs and some food supplement [37, 38]. As a food supplement, maca also has large amount of polysaccharides which influence significant metabolism (**Table 4**). Maca polysaccharides (MP) are mostly composed of rhamnose, arabinose, glucose and galactose. Dominant components are D-GalA (D-Galacturonic Acid, 35.07%) and D-Glc (D-Glucose, 29.98%) [35]. Although the composition, the yield and the purity of MP vary according to the extraction method, the water extraction method, simple and eco-friendly, is preferred in studies to isolate them. But there are disadvantages such as the need for additional applications (ultrasonic extraction, enzymes, centrifuge, deproteinization) to increase the yield or purity of polysaccharides in maca extract [39, 26]. For example, when increasing the concentration of solvent, MP yield increases but the purity of MP decreases from 69.4 to 39.5%. Amylase and glucoamylase enzyme applications decrease both amount and purity of MP. Contrary to filtration, centrifuge enhances the yield and decrease the purity of MP [39].

The antioxidant and antifatigue activities of MP are established by measuring some biochemical parameters in blood and tissues. When fed several doses of MP (79% of glucose), hypoxia tolerance, and exercise ability of mice and muscle glycogen were enhanced. But blood lactic acid (LA) lactic dehydrogenase (LDH) and urea nitrogen (BUN) were not affected [40]. Otherwise, it was reported that increasing in swimming time and antifatigue effects of MP are based on increasing liver glycogen and decreasing urea nitrogen, BUN, LDH, and LA of mice and rats with exercise-induced stress [35, 41, 42]. In addition to these results, MP has effects on the precursor enzymes of antioxidant status such as SOD, GPx (glutathione peroxidase) and CAT (catalase). While Tang et al. [35] have introduced that a daily dose of 100 mg MP/kg body weight of mice significantly increased GPx and decreased MDA (malondialdehyde),

Species	Yields (% DM)	Dose	Unit	Effect	Reference
Mice	0.2	20–100	mg/kg/d	Antifatigue activity	[34]
Mice	0.01	25–50–100	mg/kg/d	Antifatigue and Antioxidant activities	[35]
Alcoholic Mice	NA	200–800	mg/kg/d	Antioxidant activity	[43]
Cell culture	NA	0.125–2	mg/ml	Increasing viability, hepatoprotectant	[43]
Cell culture	6	62.5–1000	μg/mL	Immunomodulator activity	[44]
Rat	2.37	50–100–200	mg/kg/d	Antioxidant activity	[42]
In vitro	0.052–0.15	2	mg/ml	Antioxidant activity, Effect of extraction	[39]
Mice	NA	0.1–0.5–1	g/kg/d	Antifatigue activity	[40]
Mice	2.37	500–2000	mg/kg/d	Antifatigue and Antioxidant activities	[41]

Table 4. Polysaccharides content of maca and their antioxidant effects (DM, dry maca).

Li et al. [41] have reported that MP has occurred a dose depend antioxidant activity by increasing SOD, GPx and CAT enzymes and decreasing MDA in liver of mice. Also, He et al. [42] have reported that antioxidant activity with a correlation between the doses and enzymes levels in muscle against the exercise-induced oxidative stress. Similar to animal experiments, MP plays the crucial roles of antioxidant and free radical scavenger in cell cultures (**Table 4**) [39, 43].

In brief, the mechanism of antifatigue and antioxidant effects of especially aqueous polysaccharides in maca originates from improving hypoxia tolerance, eliminating metabolic wastes, serving energy source with high glucose contents and reducing oxidative damage by enhancing antioxidant enzyme [38, 41].

4. Antioxidant effects of maca as a feed supplement in animal nutrition

Most scientific research has worked with laboratory animals to know the antioxidant effects of maca. Rarely, studies on farm animals have been published in recent years. In these studies, daily doses (mg /kg BW/d) of maca or its bioactive content were calculated on their body weights (**Table 5**). In order to demonstrate antioxidant effects, laboratory animals, they are exposed to exercise-induce stress and antioxidant enzyme levels of their serum and various organs (brain, liver, muscle etc.) and exercise performance is measured [31, 42]. In farm animal nutrition, the criteria such as feed efficiency, nutrition performance, viability were recorded besides antioxidant enzyme activities. Dried, milled powder form of maca is mostly used in animal experiments.

When used in rats and mice at various doses of maca or its antioxidant compounds, some effects are occurred against the stress factors. In particular, GPx, SOD and glutathione (GSH) levels in serum, liver and brain increase, MDA and ROS (reactive oxygen species) decrease [45, 46]. Choi et al. [32] determined that the lipid soluble extract of maca contained 7.8 mg/g DM of macamide and macaene while maca powder contained at the level of 0.3–0.4 mg/g DM. When this lipid soluble extract is given at 100 mg/kg BW per day, it reduces lipid peroxidation in muscles of rats, increases GSH and exercise duration (**Table 5**) [32]. Similarly macamides (N-benzyllinoleamide, N-benzyloleamide, N-benzyloleamide), isolated from maca, reduce the oxidative stress induced by exercise and eliminate the waste products in serum [31]. But Qui et al. [29] argue that maca improves the antioxidant enzyme (CAT, SOD, GPx) activity both in blood and liver independently of macamide and macaene, and there is no correlation between antioxidant effect and these bioactive compounds. When rats are daily fed with maca polysaccharides at between 20 and 100 mg/kg BW doses, serum LA, BUN and MDA are decreased, GPx and creatine kinase are increased, especially in high dose (100 mg/kg BW) [34, 43].

In other animal species, there are effects on the criteria such as sperm quality, survival, feed conversion, nutritional performance as well as antioxidant effects of maca as a feed additive [47, 48]. When there is no effect on blood parameters in horses, Aspartate transaminase (AST) and gamma-glutamyl transpeptidase (GGT) increase [49]. In fish fed the fresh hypocotyl of maca, nutritional performance and feed conversion and viability enhanced [48, 50]. While

Species	Ecotype	Form	Dose	Unit	Effect	Reference
Fish	NA	Fresh Hypocotyl	5–10–15	% of feed	Improving growth rate and survival, decreasing magnesium (not significantly)	[48]
Poultry	NA	Powder	0.5–1	% of feed	Antioxidant activity, decreasing magnesium	[51]
Horse	NA	Powder	50–75	gr/day	Increasing AST and GGT, decreasing magnesium	[49]
Horse	Yellow	Powder	20	mg/d	Effects on sperm quality	[47]
Rat	NA	Aqueous	50–100–200	mg/kg/d	Antioxidant activity	[42]
Rat	NA	Powder	1	% of feed	Antioxidant activity	[52]
Rat	Yellow	Lipid soluble extract	30–100	mg/kg/d	Antioxidant and antifatigue activities	[32]
Rat	Black	Petroleum ether extract	100	mg/kg/d	Antioxidant activity (significantly)	[29]
	Yellow				Antioxidant activity (slightly)	
	Purple				Antioxidant activity (slightly)	
Mice	NA	Powder	500–1000	mg/kg/d	Antioxidant activity	[46]
Mice	NA	Macamide	40–12	mg/kg/d	Antioxidant activity	[31]
Mice	Yellow	Polysaccharide	20–100	mg/kg/d	Antifatigue activity	[34]
Mice	NA	Petroleum ether extract	125–250–500	mg/kg/d	Antioxidant activity	[45]
Mice	NA	Polysaccharide	25–50–100	mg/kg/d	Antioxidant activity	[35]

Table 5. Antioxidant effects of maca and its compounds in animal nutirion.

laying hens fed dry maca powder at the rate of 0.5 and 1% (w/w) no effect on nutritional performance, serum parameters and reproductive hormones was determined. But serum GPx level increased depend on the ratio of maca supplementation in diet of hens [51]. Day by day, the antioxidant effect of maca as feed additive in laboratory studies has been clarifying, but not yet on the other species and more nutrition experiment is needed.

5. Antioxidant effects of maca as a food supplement in human nutrition

Maca is being both at the meals of the indigenous people and exported to the whole world. Consumers around the world are taking it as a food supplement for improving their sexual and sportive activities and energy. So researchers have similarly given priority to these issues. However, studies on antioxidant status of human are limited [54].

Stress and inflammation affect human health score in the worst way, and interleukin-6 as a marker of inflammation increases in serum. People consuming regular maca have a lower interleukin-6 level and higher health scores than those not consume it [1]. Although macamides content is higher in black maca, red one enhanced the health score of human suffered from chronic mountain illness [55]. It has been shown in women that postmenopausal symptoms such as anxiety, depression and sexual dysfunction are reduced without being dependent on reproductive hormones [56, 57]. Similar effects were also observed in men. When consumed 1.5 and 3 g/day of maca powder, men's sexual desire increases and anxiety and depression are inhibited and sperm production and quality are improved (**Table 6**) [58, 59]. These reproductive effects of maca appeared independently of the hormones [28, 60]. In addition to sexual activity, when athletes got 2 g /day, performance improved and running time was reduced [61]. By scavenging DPPH and peroxyl radicals, polysaccharides isolated from maca have protected human erythrocyte against hydrogen peroxide and inhibited the hemolysis [62]. Some studies suggested that maca consumption is well tolerated and has no adverse effect [55]. On the contrary, some studies have reported negative effects on blood pressure [57, 63, 64].

Species	Form	Dose (g/d)	Duration (day)	Effect	Reference
Men	Powder	1.5–3	84–120	Increasing spermatogenesis	[28, 58, 60]
Post menopausal women	Powder	3.5	42	Decreasing sexual dysfunction and depression	[56]
Depressed women and men	Powder	1.5–3	84	Improving sexual activities, Decreasing sexual dysfunction and depression	[65, 66]
Women and men	Powder	0.6	90	Decreasing metabolic syndrome symptoms	[64]
Sportsmen	Aqueous extract	2	98	Increasing sexual and sportive activities	[61]
Women and men	Dry hypocotyl	Consume and Nonconsume	—	Increasing interleukin-6 and health score	[63]
Post menopausal women	Powder	3.3	42	Decreasing depression, anxiety and health status	[57]
Women and men	Spray-dried	3	84	Increasing health score	[55]

Table 6. Effects of maca as a food supplement in human nutrition.

6. Conclusion

Phenols, glucosinolates, alkamides and polysaccharides, which are important antioxidant source of many plants, were above mentioned. Many scientific researchers are attempting to reveal the effects of these compounds on antioxidant metabolism. While some of these compounds are peculiar to maca, others are common in tuberous plants. The variety and proportion of the bioactive compounds in maca depend on lots of different factors, specially ecotype, cultivation region, harvest time, production process and consumption preferences. Despite the wide-consumption of maca, its antioxidant effects are still being discussed in the academic circles. So the standardization of maca plant based on antioxidants is needed to take part as a safe supplement in nutrition and diets.

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