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White Lupin (*Lupinus albus* L.) – Nutritional and Health Values in Human Nutrition – a Review

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Abstract

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White lupin seeds have been used in human nutrition and treatment for several thousand years. Nowadays the use of white lupin seeds is limited by a small scale of their production. However, in the last 20 years quite new properties of white lupin have been discovered for the application in the production of different kinds of functional food. Unique traits of protein, fatty acids with a desirable ratio of omega-6 to omega-3 acids, and fibre as well as other specific components, for example oligosaccharides and antioxidants or non-starch carbohydrates, make white lupin an excellent component in many healthy diets. The effects of white lupin components concern the physiological condition of the human body, including diabetes, hypertension, obesity, cardiovascular diseases, lipid concentration, glycaemia, appetite, insulin resistance, and colorectal cancer. Seeds are used among others for the production of gluten-free flour, bacterial and fungal fermented products, noodle and pasta products, as substitutes of meat, egg protein and sausages, also are cooked, roasted and ground and mixed with cereal flour in the production of bread, crisps and pasta, crisps and dietary dishes.

Keywords: health benefits; chemical composition; effects on human health

Many researchers state that the use of lupin seeds for consumption and medicinal purposes has been the subject of interest for more than 3000 years around the Mediterranean Sea. White lupin is the longest known crop species in the history of the genus *Lupinus* – it was known among Aegean farmers at least 400 years B.C. Until the beginning of the 19th century in Europe – in the Mediterranean Sea region it was the most often cultivated lupin species for green manure and for seeds, which were used in animal and human nutrition. However, because of high alkaloid content, the seeds could not be considered as a safe food component (Prusinski 2015). A traditional way to avoid bitter taste caused by the presence of alkaloids in the lupin seeds was their very fine grinding, and next multiple rinsing with water, which however caused a decrease in the nutritive value as a result of removing soluble proteins, free amino acids, carbohydrates, and minerals. Nevertheless, this method was commonly used by societies in Mediterranean Europe and Andean countries (Petterson 1998).

After a significant success in qualitative cultivation in the 20th century (Prusinski 2015) a significantly increased interest was observed concerning white lupin among feed and food producers, and also, among others, in medicine, food processing, and even in cosmetic industry, in the production of ecological pesticides, etc. Laboratory tests were very promising, however, the commercial use of white lupin seeds for the above-mentioned purposes is still insufficient and limited (Swan 2000). Meanwhile, due to the development of lifestyle diseases caused by an improper diet, i.e. cardiovascular diseases,

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obesity, and diabetes, special attention is paid to healthy nutrition. White lupin seeds provide numerous health benefits counteracting the problems which are also connected with high blood pressure, insulin resistance, or higher cholesterol level. Taking into consideration predictions concerning a continuously growing number of deaths as a result of lifestyle diseases, functional food, including the use of lupin seeds, will have a greater and greater importance (Martins & Bento 2007; Martirosyan & Singh 2015). In many countries of Europe, the conservative attitude of consumers towards genetically modified organisms inhibited work on the popularisation of GMO in a significant way, and caused aversion towards importing products obtained from GMO cultivars (Sweetingham & Kingwell 2008). In the future, the lack of GMO lupin may lead to a significant development of a functionally varied food, mainly from white lupin seeds.

Basic seed composition and properties of its constituents

White lupin may be cultivated on almost all continents, however, chemical composition of seeds and their nutritive value depend on plant response to environmental conditions. Only the protein content does not significantly depend on the place of cultivation, while the proportion of other components in seeds is significantly dependent on the cultivation region (Bhardwaj *et al.* 1998).

Protein. Owing to symbiosis with rhizobia, white lupin has an ability to fix N_2 with the use of atmospheric nitrogen for the production of protein and other nitrogenous substances in seeds, which contain hardly any starch at the same time (Kurlovich *et al.* 2002).

The average protein content in the seeds of white lupin is from 32.9% (Martinez-Villaluenga *et al.* 2006; Strakova *et al.* 2006) up to more than 36.0% (Sujak *et al.* 2006), or even 38.0% (Vecerek *et al.* 2008; Saastomoinen *et al.* 2013). Storage proteins in lupin consist of 85% globulins and 15% albumins (Petterson 1998). The globulin fraction contains 3 main proteins of varied amino acid composition: α-, ß-, and γ-conglutin. γ-Conglutin containing more methionine, cysteine, and valine is a sulphur-containing amino acid that constitutes about 4% of the protein composition (Duranti *et al.* 1981). Some of them may have an allergenic effect (Guillamon *et al.* 2010), however, compared to other legumes (peas, soybean, bean), white lupin seeds have a minimum content of proteins with anti-nutritive properties (Kurlovich *et al.* 2002) and a higher content of arginine, lysine, leucine, and phenylalanine than for example soybean, which makes white lupin seeds more valuable than other species regarding nutrition standards (Table 1). White lupin contains more amino acids (AA), including essential amino acids (EAA), and is also characterised by a higher index of essential amino acids (EAAI) and protein efficiency ratio (PER), as well as a higher nutritive value of protein isolates (CS) than the other two lupin species (yellow and narrow-leafed) cultivated in Europe (Sujak *et al.* 2006). Such composition indicates a high suitability of white lupin protein for vegans or for those on ovo-lacto vegetarian diet or on gluten-free diet for people with the celiac disease (Arnoldi & Greco 2011).

Dehulling of white lupin seeds increases crude protein content and contents of most amino acids (except alanine) (Straková *et al.* 2006) leading to an increase of their biological value both for human nutrition and for animal feeding. On the other hand, extrusion of seeds leads to a decrease of amino acid content and the value of EAA (Kiczorowska & Lipiec 2002).

High-protein diet may play an important role in ageing processes, pregnancy and lactation, growth of youth and athletes, as well as in recovery. Some white lupin proteins or their parts *per se* may positively affect the physiological condition of human body under a wide range of unfavourable conditions, including diabetes, hypertension, obesity, cardiovascular diseases, or they may control glucose content in diabetics or pre-diabetics (Duranti 2011).

Lupin flour contains approximately 30–40% protein, and effectiveness of its utilization is slightly lower than that of animal protein, though still satisfactory. The human diet which is high in lupin proteins affects a significant decrease in serum cholesterol, including the LDL (low-density lipoprotein, bad cholesterol) level, and also the level of triglycerides and glucose, and it also lowers the blood pressure (Arnoldi 2005; Nowicka *et al.* 2006). According to Naruszewicz *et al.* (2006), thanks to white lupin addition to food, a decrease in glucose content in the blood was 6.7%, homocysteine 11.8%, and high-sensitivity C-reactive protein (Hs-CRP) up to 18.3%.

The favourable effect of soybean protein is already known, it can systematically decrease cholesterol

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Table 1. Amino acid composition of white lupin seeds (g/16 g N)

Specification	Sujak *et al.* (2006) (Europe)	Petterson & Fairbrother (1996) (Australia)	Bhardwaj (2002) (USA)
Essential amino acids			
Lysine	4.9	4.31	1.19
Methionine + cysteine	2.5	1.96	
Cysteine	1.9	0.63	
Threonine	3.5	3.16	0.83
Isoleucine	4.3	3.69	1.26
Tryptophan	0.6	0.97	
Valine	4.1	3.55	1.06
Leucine	7.8	6.05	1.92
Histidine	3.3	1.74	0.51
Phenylalanine	5.6	3.33	1.02
Phenylalanine + tyrosine	5.6	8.68	
Tyrosine	1.7		1.32
Non-essential amino acids			
Arginine	11.4		2.98
Asparagine	10.5		2.96
Serine	4.5		0.99
Glutamine	23.5		6.08
Proline	3.5		1.31
Glycine	4.3		0.92
Alanine	3.2		0.83
Nutritional values			
Amino acids participation (g/16 g N)	97.7		
Essential amino acid participation (g/16 g N)	33.5		
Chemical score of restrictive amino acid(s)	73.8		
Essential amino acids index	85.0		
Protein efficiency ratio	2.87		

content in humans and animals, and also reduce the risk of the ischaemic heart disease. However, modern industry is searching for products of specific properties: technological and sensory ones, without phytoestrogens and affordably priced. Clinical tests proved capabilities of protein isolated from white lupin to reduce cholesterol content to the same extent as it is observed in the case of other legumes (Sirtori *et al.* 2004). The absence of phytoestrogens in white lupin seeds makes this species better for the young (Sirtori & Naruszewicz 2005).

Fat. Total fat content in white lupin seeds is from about 8% (Straková *et al.* 2006; Uzun *et al.* 2007; Vecerek *et al.* 2008; Andrzejewska *et al.* 2016) to 11.5% (Sujak *et al.* 2006). In the subcontinental climate white lupin seeds are characterised by an approximately 8% lower fat content than in the Mediterranean climate (Annicchiarico *et al.* 2014).

White lupin seeds are an interesting source of favourable ratios of important fatty acids used in the prophylaxis of circulatory system diseases (Simopoulos 2003). In their development, people have consumed fats in which the ratio of ω-6 to ω-3 acids was similar, whereas now in the diet of highly-developed countries it is up to 15 to 1. Excess ω-6 acids in the diet constitute a risk factor, while the 2 : 1 ratio, which is observed in white lupin seeds, has an enormous effect and decreases mortality associated with circulatory system diseases. According to Green and Oram (1983), Arnoldi and Greco (2011), and Andrzejewska *et al.* (2016) oleic acid (mostly > 50%) prevails in the fat of white lupin seeds, which indicates a high suitability of lupin oil for consumption purposes (Table 2). In the seeds of bitter white lupin cultivars (spp. *termis*) the proportion of oleic acid is significantly higher (52.2 ±

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Table 2. Triglyceride composition in the seeds of white lupin (%)

Fatty acids	Andrzejewska *et al.* (2015) (Europe)	Alamri (2010) (Asia)	Bhardwaj (2002) (USA)
Oleic acid (18:1) (n-9)	54.3	44.9	50.9
Linoleic acid (18:2) (n-6)	14.9	26.2	23.5
Palmitic acid (16:0)	8.57	7.71	6.60
Linolenic acid (18:3) (n-3)	7.22	15.8	9.68
Gadoleic acid (C20:1) (n-9)	4.14		
Erucic acid	1.59		
Stearic acid (18:0)	1.57	1.71	0.78
Arachidic acids (20:0) and erucic acid (22:1)	0.81 + 1.59	2.74	
Σ SFA (saturated fatty acids)	16.1	9.63	11.3
Σ MUFA (monosaturated fatty acids)	58.8		55.4
Σ PUFA (polyunsaturated fatty acids)	15.0	9.38	33.3
Total n-6	15.0		
Total n-3	7.22		
n-6/n-3	2.11		

2.32%) than in sweet cultivars (spp. *albus*) (44.9 ± 2.16%) (Alamri 2012). Andrzejewska *et al.* (2016) identified in white lupin seeds also the following acids: myristic, pentadecanoic, palmitoleic, margaric, arachidic, eicosadienoic, eicosatrienoic, docosadienoic, and lignoceric at a content not higher than 1% each. Fatty acid forms (S) in Turkey (Erbas *et al.* 2005) were similar to those obtained by Bhardwaj (2002) in the USA.

Carbohydrates. Lupin seeds and seed coats contain various types of carbohydrates, mainly non-starch carbohydrates (Khan *et al.* 2015), which are the most abundant in seeds. In the seed coat, apart from a small amount of proteins and fats, structural polysaccharides prevail: cellulose, hemicellulose, and pectins, while in the cotyledons – non-structural polysaccharides of cell walls (Straková *et al.* 2006; Vecerek *et al.* 2008), with the major proportion of galactose, arabinose, and uronic acid (Mohamed & Rayas-Duarte 1995; Petterson 1998). Most carbohydrates represent soluble or insoluble fibre up to about 2.83 g/100 g dry matter (Martinez-Villaluenga *et al.* 2006).

Table 3. Content of starch in white lupin seeds (g/kg)

Source	Content
Mohamed & Ryas Duarte (1995)	30.0
Petterson (1998)	not detected
Strakova *et al.* (2006)	81.5–85.7
Martinez-Villaluenga *et al.* (2006)	30.4
Vecerek *et al.* (2008)	72.6–86.5
Borek *et al.* (2011)	not detected

Lupin starch is slowly digested and thus gradually releases glucose into the blood. However, according to some authors, mature air-dried white lupin seeds do not contain any starch (Petterson 1998; Borek *et al.* 2011) or its content is very low (Mohamed & Ryas Duarte 1995; Martinez-Villaluenga *et al.* 2006) (Table 3). As a result, lupin seeds indicate a low glycaemic index (Gullion & Champ 2002) and can prevent diseases related to insulin resistance. In Czech studies starch content in white lupin seeds was at least twice higher (Straková *et al.* 2006; Vecerek *et al.* 2008), which is however still very low compared to starch content e.g. in pea seeds (53.6–57.2%) (Dostálová *et al.* 2009).

Crude fibre. White lupin seeds are a valuable source of dietary fibre (mostly insoluble), which is higher than in soybean seeds (Pisarikova & Zraly 2010). In most *Fabaceae* plants the content of crude fibre ranges from 8% to 27.5%, and that of soluble fibre from 3.3% to 13.8% (Guillon & Champ 2002). The average content of total fibre is from 101 g/kg (Tizazu & Emire 2010) to 367 g/kg (Martinez-Villaluenga *et al.* 2006) (Table 4).

The seed coat in white lupin, which constitutes usually less than 20% of seed weight (Tizazu & Emire 2010), is mainly composed of cellulose with a small proportion of lignins. According to Pet-

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Table 4. Content of crude fibre in white lupin seeds (g/kg)

Source	Content
Martinez-Villaluenga *et al.* (2006)	367
Sujak *et al.* (2006)	144
Straková *et al.* (2006)	107
Vecerek *et al.* (2008)	134
Tizazu & Emire (2010)	101

terson (1998), there is up to 95 g of fibre in 100 g of the seed coat of white lupin. Thus, the dehulling of white lupin seeds decreases the total fibre content and increases the soluble dietary fibre content (Pisarikova & Zraly 2010). Fibre contained in the cotyledons constituting about 30–40% of the germ weight consists of insoluble materials of the cell walls of a structure similar to pectins, which are soluble fibre known for its favourable effect on lowering the total cholesterol level as well as reducing susceptibility to the ischaemic heart disease (Hall *et al.* 2005).

Ash. White lupin seeds are a rich source of macro and microelements (Table 5); their total content is 30–40 mg/kg (Straková *et al.* 2006; Sujak *et al.* 2006; Saastamoinen *et al.* 2013). Among macroelements K, Mn, and Mg definitely prevail and among microelements Ca, Fe, and Na are dominant (Ka & Chandravanshi 2014). Lower Ca content improves culinary properties of seeds and reduces the time of their overcooking (Tizazu & Emire 2010).

Table 5. Content of macro and minor elements of ash in white lupin seeds (g/kg)

Element	Ka & Chandravanshi (2014) (Africa)	Petterson & Fairbrother (1999) (Australia)
K	5.142–6.215	4.1–12.0
Na	0.0319–0.0501	0.1–1.1
P		2.8–4.9
Mg	1.739–2.159	0.96–1.6
Ca	0.502–0.967	1.2–2.5
Cr	0.0113–0.0176	
Mn	1.675–4.095	0.019–3.800
Fe	0.078–0.093	0.020–0.042
Co	0.0162–0.0166	0.0003
Ni	0.0120–0.0156	
Cu	0.0048–0.0099	0.0031–0.0081
Zn	0.0403–0.0536	0.0021–0.0038
Pb	0.0108–0.0164	
Cd	not detected	

Compounds of favourable/unfavourable effect on human health

Anti-nutritional compounds. The negative effect of unfavourable compounds in white lupin seeds which is often cited in literature is outdated to a significant extent now. As distinguished from other legumes (peas, soybean, and bean), white lupin seeds are characterised by a low or very low content of anti-nutritive substances (Muzquiz *et al.* 1998; Enneking & Wink 2000). Their removal is possible either through selection of genotypes with a low content of these components or through post-harvest treatments, e.g. germinating, cooking, soaking, fermentation, extraction, etc.

Quinolizidine alkaloids (QAs) are a family of about 100 bitter components – secondary metabolites of a bicyclic, tricyclic, and tetracyclic structure (Petterson 1998). Seeds of wild lupin species may even contain over 10 000 mg/kg alkaloids. The primary role of alkaloids was to protect plants against herbivorous animals. In their development, the alkaloid concentration in different plant parts (leaves, roots, stems) changes, reaching the highest value in the flowering stage. In Australian studies on white lupin the occurrence of 4 alkaloids was observed: albine (15%), 13-hydroxylupanine (8%), lupanine (70%), and multiflorine (3%) in the total amount not reaching over 0.01% (Petterson & Fairbrother 1996), while in Spanish studies additional a-isolupanine (Muzquiz *et al.* 1994) as well as 13-α-angeloyloxylupanine and 13-tigloyloxylupanine were reported (Muzquiz *et al.* 1998). Total alkaloid content in sweet white lupin cultivars has been significantly reduced in the process of domestication and breeding and does not currently exceed 0.02% (Prusinski 2015).

Most alkaloids may cause cramps, vomiting, and even death as a result of the respiratory system paralysis. Alkaloids also negatively affect the central nervous system in mammals, though in very low doses they may have a stimulating effect, while in high doses an inhibiting effect (McKnickiene & Asakaqviciute 2008). In humans too high dosage, especially of lupanine and sparteine, may also cause trembling, arousal, and convulsions leading to blurred vision, dry mouth, nervousness, and bad mood (Arnoldi & Greco 2011). In many countries, among others in France, Great Britain, Australia, and New Zealand, the maximum alkaloid content in flour and lupin products was established on the level up to 200 mg/kg seeds (Resta *et al.* 2008). In

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Australia and New Zealand, an acceptable alkaloid dose for human consumption is up to 0.035 mg/kg/day (Arnoldi & Greco 2011). White lupin lines of low alkaloid content are characterised by a higher lysine content than high-alkaloid lines (Green & Oram 1983). According to Annicchiarico *et al.* (2014), in the subcontinental climate, the alkaloid content in white lupin seeds may even be by 85% higher than in the Mediterranean climate. White lupin alkaloids present in seeds are also used for the control of the occurrence of skin parasites in humans (Yeheyis *et al.* 2010). In South America, bitter seeds of white lupin are commonly used in medicine to reduce the content of uronic acid and cholesterol in the blood and fibre from white lupin seeds is used in a balanced human diet (Torterolo *et al.* 2011).

Oligosaccharides. Seeds of sweet lines of white lupin from California contained 5.3% of oligosaccharides, including stachiosis (2.8%), sucrose (1.8%), raffinose (0.4%), and verbascose (0.3%) (Mohamed & rayas-duarte 1995), while in Australian cultivars they constituted 5.85–7.41% in total (Petterson & Fairbrother 1996). The content of oligosaccharides depends on cultivar and also on the place of lupin cultivation – more oligosaccharides were found in Germany (10.3%) than in Argentina (8.6%) or California (5.3%) (mohamed & Rayas-duarte 1995). The enzyme α-galactosidase, which is necessary for the hydrolysis of α-1,6 bonds, is unavailable in the small intestine of animals and humans. As a consequence, these components pass to the large intestine, where they undergo fermentation and gas production – CO_2, methane, and H_2, giving well-known symptoms of stomach ache and flatulence, from which people can suffer after consuming a greater amount of legume seeds (Petterson 1998). The anti-nutritive character of soluble carbohydrates in lupin seeds also results from their viscosity and their effect on bowel transit time as well as on changes in hormone regulation and different absorption of nutrients. In order to remove them, seed germination is used, which is commonly used in case of soybean (Enneking & Wink 2000).

It should be highlighted that recently these compounds have been used more and more frequently for the production of probiotics and prebiotics (Arnoldi & Greco 2011). Oligosaccharides have a potential value for the immune system, i.e. antioxidative activity and antitumor activity, as well as lowering the cholesterol level (Rochfort & Pannozo 2007). The extraction of oligosaccharides from white lupin seeds may affect a decrease in the content of γ-conglutin and lipoxygenase (even by 37%), which however may be beneficial due to their potential unfavourable allergenic effect, and the effect deteriorating organoleptic traits of flour (Martinez-Villaluenga *et al.* 2006). Oligosaccharide content in pasta prepared with the use (10–30%) of white lupin flour was significantly lower than the expected one resulting from calculations, and after cooking it decreased by 30% (Lampart-Szczapa *et al.* 1997).

Inhibitors of protease. These are proteins which strongly bind with digestive enzymes such as trypsin, reduce their digestibility, and lead to malnutrition or other disorders in animals. Inhibitors also have a different function in plants, they are a source of storage proteins which undergo breakdown at the start of seed germination (Enneking & Wink 2000). Inhibitors of trypsin may be deactivated through high temperature treatment, which significantly improves PER. White lupin seeds do not contain them at all (they are mostly undetectable, i.e. less than 0.1 mg/g) (Petterson & Fairbrother 1996).

Lectins. Also classified as glycoproteins, they are capable of clumping red blood cells and they prevent the absorption of nutrients. Lupin seeds contain small amounts of lectins (3×10^{-5} HU, i.e. hemaglutination activity units) compared to e.g. common bean (840×10^{-5} HU) (Nachbar & Oppenheim 1980) or they are not detectable at all (Petterson & Fairbrother 1996).

Phytic acid. It may reduce the bioavailability of mineral components in monogastric animals through cation chelation (Zn, Mg, Ca, Fe, K, and Mg) to non-absorbable phytynians (Petterson & Fairbrother 1996; Petterson 1998). It should be highlighted that phytic acid content in white lupin seeds (0.03%) is significantly lower than e.g. in soybean – from 1.54% (Mohamed & Rayas-Duarte 1995) to 1.89–2.27% (Saastomoinen *et al.* 2013). In the studies of Martinez-Villaluenga *et al.* (2006) 0.025–0.044% of phytic acid was found in white lupin seeds, while according to Saastomoinen *et al.* (2013) – 0.063%. Its content may be reduced even further through fermentation or extrusion of seeds.

Phytochemicals

Tannins. Phenolic compounds produced at the end of plant maturity and accumulated mainly in seed coats constitute natural protection against diseases and pests, and show antioxidative, antifungal, and an-

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tibacterial properties; however, Khan *et al.* (2015) did not show any correlation between antioxidant activity and phenolic contents. Petterson & Fairbrother (1996) found small amounts of them in white lupin seeds (0.23–0.52%), while Lampart-Szczapa *et al.* (2009) detected slightly above 2 mg/100 g in dehulled raw seeds. During seed fermentation, tannin content increased significantly up to about 8 mg/100 g, whereas after extrusion it slightly decreased.

Isoflavones. They have a protective function in plants and seeds and are synthesised in response to biotic and abiotic stresses (phytoalexins). They have been recognised as useful substances preventing the occurrence of breast cancer, osteoporosis, and hot flashes during menopause, they show hypocholesterolaemic properties (Khan *et al.* 2015), whereas cholesterol content reduction is connected with the stimulation of LDL fraction receptors (Sirtori *et al.* 2004), most likely due to the reabsorption of bile acids, which affects reduction in solubility and in LDL cholesterol fractions (Martins & Bento 2007). The highest content of isoflavones in seeds is characteristic of soybean. All green parts of white lupin plants contain these compounds, and in seeds (in the cell walls) their synthesis begins only in the germination stage, while dry seeds are almost entirely free of them (Katagiri *et al.* 2000).

Saponins. They are glycosides found in many plants giving them bitter taste. White lupin seeds do not contain them at all (Petterson & Fairbrother 1996) or they were not detected (Muzquiz *et al.* 1993), as distinguished from yellow lupin seeds (55.0 to 68.3 mg/kg), especially blue lupin (270.1–469.5 mg/kg) (Muzquiz *et al.* 1993), and even 480–730 mg/kg in Australian cultivars (Ruiz *et al.* 1995). In pea seeds, their content is 1800 mg/kg, while in soybean seeds up to 3500 mg/kg (Allen 1998). Saponins produce complex compounds with bile acids and cholesterol catching and removing their excess from the body.

Antioxidants. White lupin seeds in Saudi Arabia are characterised by the highest content of tocopherols – 63.6 mg/100 g (α – 4.96 mg/100 g, δ – 4.10 mg/100 g, and γ – 54.5 mg/100 g, and β fraction was not detected) (Alamri 2012), while in Australia 0.19 mg/100 g, 0.25 mg/100 g, and 20.1 mg/100 g, respectively (Frias *et al.* 2005). The total amount of tocopherols in Europe according to Annicchiarico *et al.* (2014) was 12.1–13.3 g/100 g. In food products enriched with lupin flour, tocopherols protect against free radicals through inhibiting the oxidation of body lipids and fats in the food. However, the cooking of white lupin seeds causes a significant loss of tocopherols (Kalogeropoulos *et al.* 2010).

Forms of white lupin seeds used in the human diet

In the literature, information can be found on the sensitivity of some people to lupin products (seeds, flour, and dust) manifesting itself for example in an anaphylactic shock in some individuals (Radcliffe *et al.* 2005), urticaria, asthma, conjunctivitis, swelling, or allergy of the mouth cavity (Sanz *et al.* 2010) as well as bloating, diarrhoea, and blurred vision mainly in children after the consumption of raw or roasted bitter white lupin seeds (Yeheyis *et al.* 2010). Allergens are the main cause of allergic reactions: Lup-1, which is a conglutin b (vicilin-like protein) and Lup-2 corresponding to the conglutin α fraction (legumin-like protein) (Guillamon *et al.* 2010). The problem of the allergenic effect of alkaloids in white lupin seeds does not practically exist now due to biological development and obtaining sweet cultivars. The latest research has also indicated that allergenic properties of lupin are significantly lower than those of other leguminous species, e.g. of soybean or peanuts, and concern only a small percentage of the human population. However, the European Commission included white lupin in the list of allergens (Arnoldi & Greco 2011).

Nevertheless, white lupin seeds and their constituents used in different ways become an important mean to meet or improve the health status and quality of life not only in developing countries (Martirosyan & Singh 2015). In Europe, mainly the seeds of white lupin and partly blue lupin are used for consumption purposes; the latter is commonly used in Australia. White lupin was accepted for consumption purposes by the Australian government in 1987 and by the British one in 1996 (Swan 2000).

Sweethingham and Kingwell (2008) indicated the most important areas of the use of lupin by humans, including the white lupin: whole seeds or those without seed coats used in the traditional fermentation of food in Asia, gluten-free lupin flour, and protein fractions in the production of milk without saturated fat, noodle and pasta products, as substitutes of meat, egg protein, and sausages, etc. Cooked, roasted, and ground into powder seeds are also mixed with cereal flour in bread, crisps, and pasta (Erbas *et al.* 2005). Roasted seeds may be used

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as snacks in the same way as e.g. peanuts. In roasted and cooked seeds, alkaloid content is significantly lower, and their dehulling decreases the content of anti-nutritive compounds (Getachew *et al.* 2012). Kalogeropoulos *et al.* (2010) observed a significant decrease in total phenolic contents during cooking. The addition of lupin flour to wheat flour allows for obtaining more nutritive bread as far as protein and dietary fibre is concerned. Mixing wheat and lupin flour may help obtain the proper amino acid balance, giving as a result a more complete food (Petterson & Fairbrother 1996). Due to the better distribution of water in dough, the obtained products have better rheological properties, including better resistance to freezing and thawing, the preparation of bread dough can be easier, and shrinking can be limited. White lupin seeds are also a perfect substrate for the production of both bacterial and fungal fermented products, e.g. tempe, miso, tofu, traditional sauces, as well as dairy products (milk or yoghurt probiotics similar to those produced from soybean seeds) in Asia (Petterson & Fairbrother 1996; Petterson 1998; Swan 2000) and Australia (Uauy *et al.* 1995). Lupin seeds subjected to extrusion mixed with cereals are also used for the production of crisps and dietary dishes (Kiczorowska & Lipiec 2002). White lupin sprouts contain about 41% protein and 8% fat, and are a perfect potential source of food (Bhardwaj & Hamama 2012a). From 1 kg of seeds you can obtain even 7.5 kg of fresh sprout weight, and the sprouts are practically free of lateral roots as distinguished from e.g. soybean sprouts. The sprouts are also rich in isoflavones as well as macro- and microelements, especially Mn (139 mg/kg dry matter), and phytosterols increasing the nutritional value of white lupin.

Also germination is used as a process to increase the nutritional value of many legumes (Khan *et al.* 2015). Seed germination causes a reduction in the content of alkaloids, phytynians, and oligosaccharides (Dagnia *et al.* 1992). On the other hand, the extrusion of white lupin seeds decreases the content of fibre and crude fat, and slightly the content of most amino acids (mainly methionine and cysteine) and EAA value (Kiczorowska & Lipiec 2002). Owing to the increased breakdown of proteins and complex carbohydrates into simple and more digestible structures of white lupin seeds, they were proved to be better for fermentation than soybean seeds. The completely new food applications of white lupin include the use of immature seeds like in the case of green peas or soybean (Bhardwaj & Hamama 2012b). The yield of immature white lupin pods of a French cultivar Ludet was over 18 t/ha with the protein content of 33%. Fermented white lupin seeds for tinned fruit and vegetables are used in order to increase pectin content (Golovchenko 2008), which contain 4.5–5.5 g/100 g of the product, e.g. much more than those obtained with other additives (e.g. apple or beets) (Yeheyis *et al.* 2010).

The use of white lupin seeds by food companies in Europe and Australia is, however, significantly reduced, among other things, due to uncertainty of the continuity of supplies of a sufficient amount and quality of seeds, reduced access to knowledge concerning their processing, and the risk of occurrence of allergic reactions in a certain population (Uauy *et al.* 1995; Sweetingham & Kingwell 2008).

CONCLUSION

White lupin is the oldest crop species of the kind and may constitute a potential source of protein without gluten. Despite valuable properties and wide use, white lupin rather does not have a potential of being a global species. However, in the last 20 years, numerous properties of white lupin have been discovered for the application in the production of different kinds of functional food due to the properties of seed components, which makes white lupin seeds, regarding nutrition standards, more valuable than other species of legumes.

The high biological value of proteins and important sources of amino acids positively affect the physiological condition of the human body, especially of those suffering from diabetes, hypertension, obesity, and cardiovascular diseases; they may also control glucose content in diabetics or pre-diabetics, and are especially suitable for vegans or for those on an ovo-lacto vegetarian diet, or on a gluten-free diet for people with the celiac disease. Human diet with high lupin proteins affects a significant decrease in serum cholesterol, including the LDL level, and it also lowers the blood pressure. Lupin oil has desirable ratios of omega-6 to omega-3 acids for consumption purposes. White lupin seeds are also a valuable source of dietary fibre, both soluble and insoluble, with its well-known beneficial effect on reducing the cholesterol level and on susceptibility to the ischaemic heart disease. Food containing white lupin may also suppress appetite, control glycaemia, improve the lipid concentration in blood, and prevent colorectal

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cancer; a low glycaemic index can prevent diseases related to insulin resistance.

Part of specific substances contained in seeds may have an unwanted effect (possibly the excessive alkaloid content), but many of them have the potential value for the immune system (e.g. oligosaccharides with their antioxidative and antitumor activity, or lowering the cholesterol content), others in turn occur in minimum amounts (inhibitors of proteases, saponins), or there is significantly less of them (phytic acid, lectins, isoflavones) than e.g. in soybean seeds. The problem of allergenic effects of white lupin seeds concerns only some kinds of protein, and much less alkaloids.

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