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REVIEW PAPER

LEGUMES – USE FOR NUTRITIONAL AND FEEDING PURPOSES*

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Abstract

This work aims to identify possibilities of using legume seeds as food for humans and feed for animals. The family *Fabaceae* encompasses multiple species, some of which are highly valuable owing to their nutritional value, as indicated by the high content of amino acids, minerals, vitamins, and bioactive compounds. The cropping area, yielding, and supply of legume seeds in Poland, the European Union, and the world varies but tends to grow, which creates various opportunities for their use. They are a good raw material for the production of feeds and food, including functional food. Protein and amino acids available in seeds of these plants are important in human nutrition and animal feeding. Legume species differ in the content and type of dietary fiber as well as in concentrations of starch, protein, minerals, and vitamins. Legume seeds contain bioactive compounds, enzyme inhibitors, lectins, phytoestrogens, oligosaccharides, saponins, and phenolic compounds. Dietary inclusion of legumes has a positive effect on the human body, as it reduces the incidence of civilization diseases. The use of legume seeds in moderate doses or as alternatives to other protein-rich feedstuffs, including GM soybean meal, has a positive effect on production performance, fattening and slaughter results of farm animals as well as on the quality of meat. The results of scientific research confirm that legume seeds are an important component of human diet. Legume seeds and products made from them are recommended in human and animal nutrition owing to their beneficial nutritional and health effects.

Keywords: legumes, feed and food, nutrients, nutraceutical potential, animals.

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INTRODUCTION

Few hundred species of legumes are grown across the globe, although only some are of any economic importance as protein sources in food and feeds. The *Fabaceae* family is the third largest family of flowering plants, comprising 751 genera and 19 500 species. The family legumes (Latin: *Fabaceae*) contains pulses and papilionaceous plants, including coarse-grained plants (lupine – *Lupinus*, soybean – *Glycine max* (L.) Merr., pea – *Pisum sativum* L., field bean – *Vicia faba* L., beans – *Phaseolus vulgaris* L., broad beans – *Vicia faba* L., peanuts – *Arachis hypogaea* L.) and fine-grained ones (alfalfa – *Medicago sativa* L., clover – *Trifolium* L., birdsfoot-trefoil – *Lotus corniculatus* L., tragacanth – *Astragalus christianus* L., chickling pea – *Lathyrus sativus* L., sweet clover – *Melilotus officinalis* L.). Legumes include annual and perennial, spring or winter species. They are also divided into edible legumes – intended for human consumption (peas – *P. sativum*, beans – *P. vulgaris*, broad beans – *V. faba*, chickpeas – *Cicer arietinum* L., cowpea – *Vigna unguiculata* L., lentils – *Lens culinaris* Medik., peanuts – *A. hypogaea*) and fodder legumes – intended for animal feeding (lupines – *Lupinus*, fodder peas – *P. sativum*, field beans – *V. faba*, soybeans – *G. max*) (Kapusta 2012).

Nutritional and feeding significance of legumes

The species abundance and variety of properties enable versatile uses of leguminous plants. Legume seeds are used mainly in human nutrition (Erbersdobler et al. 2017), but these plants have multiple applications in the agriculture (in animal feeding: seed meals as components of feed mixtures; on pastures – as green forage and as green manure for ploughing into soil; and in reclamation of degraded areas), in medicine – because of their therapeutic properties, and also in the timber industry.

Seeds of lupine (*Lupinus*), peas (*P. sativum*), soybean (*G. max*), and broad bean (*V. faba*) represent important dietary components for human populations of developing countries. The cultivation of legumes and their consumption compensate for shortages of protein from other sources (Duranti 2006, Kapusta 2012, Bouchenak, Lamri-Senhadji 2013). Protein and amino acids available in high amounts in seeds of these plants are important in human nutrition and animal feeding. Legume species differ in the content and type of dietary fiber as well as in concentrations of starch, protein, minerals, and vitamins (Tables 1, 2). In addition, they contain bioactive compounds, enzyme inhibitors, lectins, phytoestrogens, oligosaccharides, saponins, and phenolic compounds. When ingested with food or feed, the phytochemicals of legume seeds provide protection against inflammatory conditions, metabolic disorders, diabetes, atherosclerosis, and hypertension.

Legume seeds are rich in minerals, such as potassium (K), phosphorus (P), molybdenum (Mo), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn),

Table 1

Composition and nutritive value of selected legume seeds (Kunachowicz 2012)

Specification	Nutrients (g kg^{-1})			Micro- and macroelements (mg kg^{-1})				Vitamins and provitamins					
	protein	fat	dietary fiber	sodium	potassium	phosphorus	iron	A (µg kg^{-1})	β-carotene (µg kg^{-1})	E (mg kg^{-1})	B_1 (mg kg^{-1})	B_2 (mg kg^{-1})	C (mg kg^{-1})
White bean, dry seeds *Phaseolus vulgaris* L.	214.00	16.00	157.00	190.00	11880.00	4370.00	69.00	0.00	0.00	2.00	6.70	2.30	20.00
Pea, dry seeds *Pisum sativum* L.	238.00	14.00	150.00	300.00	9370.00	3880.00	47.00	200.00	1170.00	3.00	7.70	2.80	20.00
Red lentil, dry seeds *Lens culinaris* Medik.	254.00	30.00	89.00	20.00	8740.00	3010.00	58.00	100.00	600.00	2.20	10.70	4.50	30.00
Soybean, dry seeds *Glycine max* (L.) Merr	343.00	196.00	157.00	10.00	21320.00	7430.00	89.00	20.00	120.00	7.80	6.90	1.90	0.00
Green pea, fresh seeds *Pisum sativum* L.	67.00	4.00	60.00	220.00	3530.00	1220.00	19.00	680.00	4080.00	3.90	3.40	1.60	342.00
Broad bean, fresh seeds *Vicia faba* L.	71.00	4.00	58.00	70.00	2610.00	570.00	19.00	280.00	1700.00	4.60	0.90	0.60	320.00

Table 2

Chemical composition and content of selected amino acids in legume seeds (Śliwiński et al. 2010, Kasprowicz-Potocka et al. 2017)

Specification	Chemical composition (g kg^{-1})			Content of amino acids (g kg^{-1} DM)				
	total protein	crude fat	crude fiber	lysine	methionine	cysteine	tryptophan	threonine
White lupine *Lupinus albus* L.	359.00	100.00	151.00	15.90	3.10	5.60	0.00	13.00
Yellow lupine *Lupinus luteus* L.	422.00	70.00	157.00	22.00	3.20	8.40	0.00	14.50
Blue lupine *Lupinus angustifolius* L.	339.00	59.00	168.00	15.70	2.70	4.60	0.00	12.90
Pea *Pisum sativum* L.	241.00	11.00	71.00	17.50	2.90	3.90	2.60	9.60
Field bean *Vicia faba* L.	309.00	10.00	98.00	18.10	2.10	3.40	2.50	9.80
Domestic soybean *Glycine max* (L.) Merr	375.00	159.00	82.00	22.30	5.80	6.40	0.00	14.70

calcium (Ca), and magnesium (Mg) (Erbersdobler et al. 2017), of which the most important ones are Fe, Ca, and Zn. The consumption of *ca* 85 g kg^{-1} of dry bean (*P. vulgaris*) seeds by an adult man may cover 22% of the demand for Fe, 54% for Ca, and 29% for Zn. Bean (*P. vulgaris*) seeds can also provide copper (Cu), phosphorus (P), manganese (Mn), and magnesium (Mg). In addition, legume seeds represent an excellent source of water--soluble vitamins. When included into a diet, they alleviate mineral deficiencies, improve life comfort, and - in extreme cases – minimize the risk of death. According to data provided by the America Department of Agriculture, a cup of dry bean (*P. vulgaris*) seeds satisfies the daily demand of a human for thiamine (45-107% of the demand), riboflavin (20-27%), and niacin (11-27%) (United States Department of Agriculture 2015).

The synergistic and/or antagonistic effects of a mixture of legume phytochemicals, their interactions with other dietary constituents, and mechanisms of their action pose a challenge to scientists who attempt to determine their role in both human and animal organisms, both healthy and ill. According to Bouchenak and Lamri-Senhadji (2013), legume seeds are good raw material for the production of feeds and food, including functional food.

Legumes in scientific research

Medical books published in the previous centuries lack information about the use of legume seeds as therapeutic agents. Some information can be found in books from the Far East (China, India), where local species of legumes used in medicine are mentioned. Their phytotherapeutic effects have been known for centuries also in the Mediterranean region. They have been used for prophylactic and therapeutic purposes in addition to being dietary components (Guarrera 2005). Nowadays, they serve to produce nutraceuticals, which in turn are used in the prevention of civilization diseases in humans (Duranti 2006). They represent a source of nutrients, have traits and properties of pharmaceuticals, and produce a positive effect on energy balance, concentrations of blood glucose and lipids, arterial blood pressure, peristalsis, and defecation. Active substances of legume seeds are used in the treatment of pathological conditions, e.g. visceral obesity, elevated level of triglycerides, hypertension, and hyperglycemia. Dietary administration of lupine (*Lupinus*) additives demonstrated their beneficial effect on the health of patients with obesity, hypertension, and hypercholesterolemia.

Bartkiene et al. (2013) conducted an experiment on model Wistar rats to determine the effect of their diet's supplementation with unprocessed or lacto-fermented flours from soybean (*G. max*), flaxseed (*Linum usitatissimum* L.), and lupine (yellow and white lupine (*Lupinus luteus* L., *Lupinus albus* L.)) on their intestine condition. The specific goal was to elucidate the effect of the type of flour on intestinal epithelium, considering its protective effect against pathogenic bacteria. The study demonstrated the impact of the type of a diet on body weight of the animals. The rats fed diets containing fermented plant products were significantly larger than ones receiving diets with unprocessed seeds. The diet with fermented yellow lupine (*L. luteus*) enhanced activities of α-glucosidase and β-galactosidase, which reduced postprandial glycemia. Analyses of the small intestine, cecum, and colon of rats fed a diet with fermented yellow lupine (*L. luteus*) demonstrated high levels of lactic acid bacteria, *Bifidobacteria*, enterococci. Fermentation of plant products contributed to a significant decrease in the number of *E. coli* in rat cecum compared to the groups fed diets with unprocessed seeds. The diet with fermented yellow lupine (*L. luteus*) seeds was conducive to the richness of *Bifidobacterie* and anaerobes in the colon. It seems justified to advocate the implementation of these research results into production practice, especially when rearing young grower pigs which often show disorders in the coli/lacto bacteria ratio.

Consumption of legume seeds is believed to prevent cancer development, including a colorectal cancer. Seeds ingested with a food ration accelerate the passage of digesta through the gastrointestinal tract, which facilitates excretion. This, in turn, results in diminished absorption of cholesterol, incomplete digestion of starch and less intense fermentation processes, all being important for health (Probert et al. 1995). These benefits of legume seed consumption are mainly viewed from the persepctive of advantages human health, but they are also important for the well-being and homeostasis of animals. Despite high concentrations of lipids, starch and proteins, legumes can help to maintain the right body weight. They induce the feeling of satiety, hence reducing the daily intake of other foods (Duranti 2006). As reported by Lee et al. (2006), bread enrichment with lupine seed (*Lupinus*) flour diminished appetite and reduced energy intake, having caused the sensation of satiety. Interesting observations were also made by Archer et al. (2004), who included dietary fiber from lupine seeds (*Lupinus*) into a diet. The addition of dietary fiber ensured the feeling of satiety which lasted up to 4.5 h after food ingestions and allowed reducing the daily energy intake by 15%. These findings can be useful and practical in human nutrition and in maintenance of gestating sows.

Frequent intake of dry legume seeds and a diet poor in saturated fats can help to regulate lipid homeostasis in the body and thereby reduce the risk of cardiovascular diseases. The contributing factors are a high content of dietary fiber, low glycemic index and the content of saponins, phytosterols and oligosaccharides (Duranti 2006). Lupine (*Lupinus*) varieties with a low content of alkaloids are characterized by very low allergenicity and lead to a decreased incidence of cardiovascular diseases, hence their increased use in food is highly advisable. An experiment on model animals and a clinical trial were conducted to determine the effect of lupine proteins on health (Arnoldi et al. 2015). The addition of proteins of white lupine (*L. albus*) and blue lupine (*L. angustifolius*) (experimental group) to rats' diet reduced blood cholesterol and triglycerides compared to the control animals not receiving this protein. The inclusion of whole lupine seeds (*Lupinus*) into a diet for monogastric animals was reported to reduce blood cholesterol in chickens (Viveros et al. 2007) and pigs (Martins et al. 2005). The positive effect of lupine protein isolates and dietary fiber on the lipid concentration in blood serum was also demonstrated by Sirtori et al. (2004), who reported blood cholesterol decreasing by 21% in model animals upon their use. Dietary inclusion of legume seeds can reduce the level of the LDL cholesterol fraction due to changes in the entero-hepatic circulation of bile salts and enhanced cholesterol secretion by the liver (Shahwar et al. 2017). Kapravelou et al. (2013) evaluated the effect of white lupine (*L. albus*) protein hydrolysate given with or without insoluble dietary fiber of lupine on various blood, hepatic and renal markers as well as on the colon of model animals. They used Wistar rats in the experimental model of hypercholesterolemia induced *in vivo* by a diet. The administration of the experimental diet decreased the concentration of triglycerides in blood plasma and liver, had a positive effect on glucose metabolism and a protective effect on kidneys. In the groups fed the high-fat diet, the lupine protein hydrolysate produced a protective effect at the early stage of hypercholesterolemia. Insoluble residues of dietary fiber increased fat excretion with feces as well as improved physiological parameters of the colon and capabilities for fermentation and water retention Kapravelou et al. (2013).

Dietary inclusion of legume seeds decreases arterial blood pressure (Benisi-Kohansal et al. 2016). Bean seeds (*P. vulgaris*) have a beneficial dietary fiber to protein ratio and a high content of folic acid, which positively affects blood vessel tension (Safaeiyan et al. 2015). Investigations conducted on salt-sensitive rats (a model predisposed for hypertension) demonstrated mitigation of hypertension and improvement in functions of blood vessel endothelium upon inclusion of lupine protein into a diet for experimental animals (Pilvi et al. 2006). Lupine proteins are characterized by a relatively high content of arginine, a precursor of nitrogen oxide synthesis. Therefore, the observed blood pressure decrease may be due to the improvement in blood vessel tension (Vasdev, Gill 2008). Legumes are also rich in potassium, magnesium and dietary fiber, which positively affect blood pressure. As evidenced in scientific research, consumption of legumes can contribute to the reduction of systolic and average blood pressure (Jayalath et al. 2014).

Legume seeds are also rich sources of lutein and zeaxanthin. Their inclusion into a diet can retard the onset and development of macular degeneration. Macular carotenoids contained in legumes are unable to cure this disease but they can slow down its progression (Kang, Kim 2019).

Isoflavones from legume seeds regulate the endocrine metabolism, protect against breast and endometrium cancer, alleviate menopausal ailments, and regulate the calcium-phosphorus balance and bone mass (Wawryk, Zdrojewicz 2016). In Europe, the intake of isoflavones is low (0.2-5 mg/day), being significantly higher in Asian countries (25-45 mg/day), which Wawryk and Zdrojewicz (2016) claim can be attributed, among other factors, to a milder course of the menopause in Asian women than in women from other parts of the world.

Scarafoni et al. (2008) and Clemente et al. (2011) confirmed legume seeds to contain a biologically active protein molecule called a serine inhibitor (Bowman-Birk proteinase). Interest in this protein is owed to its capability of preventing or inhibiting pathological processes, including inflammatory conditions which accompany cancers and rheumatoid arthritis, as well as neurodegenerative and cardiovascular diseases (Scarafoni et al. 2008). The Bowman-Birk inhibitor exerts a health-promoting effect on the gastrointestinal tract. It can resist effects of acids and proteolytic enzymes in the stomach and small intestine. By escaping digestion, it exhibits anti-inflammatory and anti-carcinogenic properties in the colon (Clemente et al. 2011).

γ-Globulin of lupine seeds (*Lupinus*) reduces the blood level of glucose, which was confirmed in experiments on animal models (Lovati et al. 2012). Today, studies are in progress to confirm this effect in humans. Increasing the consumption of beans has been shown to reduce tissue insulin resistance in patients with type 2 diabetes. This is mainly due to a high content of complex saccharides, which are more slowly absorbed in the gastrointestinal tract. Owing to this, the pancreas produced less postprandial insulin, which allows for its longer retention in the region of the Langerhans islets (Jenkins et al. 2012). Schopen et al. (2017) tested short-time effects of lupine protein and whey protein on glucose and insulin levels in the body. They demonstrated that both additives reduced postprandial glycemia to the same extent, which offers the possibility of using lupine protein as an alternative to whey protein. In addition, they found the lupine protein extract to be 10-fold more potent than a standard antidiabetic drug. A low glycemic index and a high content of non-digestible dietary fiber in dry legume seeds can help control glycemia in diabetic patients (Duranti 2006). Dietary inclusion of legume seeds and products made from them may prevent the development of resistance to insulin, which is a frequent problem in patients suffering from type 2 diabetes.

According to Amarowicz and Pegg (2008) and to Zhao et al. (2014), legumes are natural sources of antioxidants. Amarowicz and Pegg (2008) confirmed that oxidative stress is strongly associated with the development of neoplasmic and cardiovascular diseases, and thus legume seeds are highly recommended in nutrition and prophylaxis in both human and animal patients. Technological processes and germination of seeds can affect the content of endogenous antioxidants, e.g. phenols, tocopherols and vitamin C. The content of phenolic antioxidants in seed coats is high and can by modified by heat treatment (Amarowicz, Pegg 2008). This type of treatment, however, has an adverse effect on many compounds exhibiting nutraceutical properties, which is an argument in favour of using unprocessed seeds, for example in animal feeding. The heat treatment can minimize, eliminate or enhance the allergenic potential of legumes. Most investigations have demonstrated alleviation of allergenic effects of leguminous seeds after thermal treatment (VERMA et al. 2012), which is beneficial, especially considering their use in human diet.

Legume plants in animal production

Breeders and producers of slaughter animals increasingly often reach for domestic sources of protein, like sweet lupines (*Lupinus*), pea (*P. sativum*) or field bean (*V. faba*). Both scientific research and production practice have confirmed the lack of any negative effects of moderate amounts of legume seeds used in diets for animals on their basic production traits (SOŃTA, REKIEL 2017). However, the continuously changing quality of protein feedstuffs available on the market suggests it is advisable to determine effects of various legumes not only on the production performance of animals but also on the body homeostasis and quality of animal products (meat, milk, eggs). Breeding advances in plant production enable us to use seeds of yellow and blue lupine (*L. luteus* and *L. angustifolius*), pea (*P. sativum*), field bean (*V. faba*), rape (in the form of cake or extracted meal), and soybean (*G. max.*) of domestic cultivars, in the feeding of monogastric animals. The current possibilities in the field of production and quality assurance of domestic legumes were presented by FIEDOROWICZ and SOBOTKA (2013), HANCZAKOWSKA and ŚWIĄTKIEWICZ (2015), and by KASPROWICZ-POTOCKA et al. (2017). The introduction of new cultivars into cultivation practice has turned out to be nutritionally beneficial owing to the increased nutritive value and reduced content of anti-nutrients in their seeds.

Seeds of pea (*P. sativum*), lupine (*Lupinus*) and field bean (*V. faba*) contain anti-nutrients, which curbs their applicability in animal feeding. Although they can restrain the utilization of dietary ingredients and even adversely affect animal health, they are still used in animal feeding, but in lesser amounts (DIAZ et al. 2006). The anti-nutrients contained in legume seeds include phytates, tannins, inhibitors of proteolytic enzymes and alkaloids. The usability of legume seeds for feed production may also be improved by various technological treatments, like dehulling, extrusion, toasting, micronization, as well as soaking or fermentation (MILCZAREK, OSEK 2016*a*, MILCZAREK et al. 2017).

The use of unprocessed and processed legume seeds in the feeding of various species and production groups of animals has been researched at numerous national and foreign research centers. The usability of the aforementioned protein feeds as partial substitutes of soybean meal has been confirmed in experiments on model animals (SOBOTKA et al. 2016, ZAWORSKA et al. 2016) and described in a review paper (SOŃTA, REKIEL 2017). Extensive investigations have also been conducted on farm animals, including pigs (MORDENTI et al. 2012, SOŃTA et al. 2015, MILCZAREK, OSEK 2016*b*, HANCZAKOWSKA et al. 2017, TUŚNIO et al. 2017, DEGOLA, JONKUS 2018, HANCZAKOWSKA et al. 2019) and poultry (layer hens, broiler chickens, turkeys) (SUCHÝ et al. 2010, Drażbo et al. 2014, Zduńczyk et al. 2014, Krawczyk et al. 2015, Juodka et al. 2017, Milczarek et al., 2017, Tomaszewska et al., 2018), as well as rabbits (Volek et al. 2013, Gugołek et al. 2017, Zwoliński et al. 2017), cattle fatteners (Melicharová et al. 2008, Tufarelli et al. 2012), dairy cows (Melicharová et al. 2008, Tufarelli et al. 2012, Barchiesi et al. 2018), and fish (Mazurkiewicz et al. 2007, Hernández, Roman 2016). Results achieved in these research projects as well as findings from previous experiments (Martins et al. 2005, Viveros et al. 2007) lead to a general conclusion, namely the feeding materials used, that is legume seeds instead of GM soybean meal, had no significant negative effect on fattening and slaughter parameters of various species of livestock.

Legume seeds can affect the quality of products obtained from farm animals. Investigations conducted by Zralý et al. (2006), Zijlstra et al. (2008), and by Sońta et al. (2015) showed no statistically significant differences in the quality of fatteners' meat between groups administered feed mixtures with various concentrations of yellow, blue and white lupine (*L. luteus, L. angustifolius, L. albus)* as well as field bean (*V. faba*) and the groups fed diets without their addition. Inclusion of pea seeds (*P. sativum*) to diets for dairy cows had no negative impact on the chemical composition of their milk (Melicharova et al. 2008, Tufarelli et al. 2012). Volek and Marounek (2011) demonstrated a positive effect of white lupine (*L. albus*) seeds on the quality of rabbit meat. They determined a decrease in SFAs and PUFAs levels and an increase in MUFAs. Furthermore, Drażbo et al. (2014) and Krawczyk et al. (2015) demonstrated decreased levels of SFAs and MUFAs and an increased content of PUFAs in egg yolk of layer hens fed diets supplemented with blue and yellow lupine seeds (*L. angustifolius, L. luteus*). In turn, Przywitowski el al. (2016) used yellow lupine (*L. luteus*) in feed mixtures for turkeys, and demonstrated a reduced content of SFAs and an increased or decreased content of PUFAs in their breast muscles. Suchý et al. (2010) and Osek et al. (2013) used legume seeds (lupine, pea or field bean (*Lupinus, P. sativum, V. faba*)) in feed mixtures for broiler chickens, and showed differences in the chemical composition of their breast and thigh muscles, although – according to these researchers - the feed mixtures used in the experiment had no negative effect of the quality of meat.

CONCLUSION

The abundance of legumes throughout the globe and the production of legume seeds for food and feeds make them a very good, practical source of protein, minerals, vitamins and bioactive compounds for humans and animals. Legume seeds can be a valuable substitute for GM soybean meal in the feeding of various farm animals, primarily monogastric ones, such as pigs and poultry. Numerous scientific studies justify recommending them as an important component of human diet or animal feeding, owing to their beneficial nutritional and health effects.

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