World Rabbit Science

World Rabbit Sci. 2024, 32: 145-160
https://doi.org/10.4995/wrs.2024.22017
WRSA, UPV, 2003

DIETARY INCLUSION OF WHITE LUPIN SEEDS AND THEIR BYPRODUCTS IN RABBITS CAN CONTRIBUTE TO EU AGRICULTURAL SUSTAINABILITY: A REVIEW

Peter Šufliarský [*,†], Zdeněk Volek [†], Tarek Amin Ebeid [‡], Lukáš Zita [§]

[*]Department of Microbiology, Nutrition and Dietetics, Czech University of Life Sciences Prague, Kamýcká, 129, 16500, Prague, Czech Republic.
[†]Department of Nutritional Physiology and Animal Product Quality, Institute of Animal Science, Přátelství 815, 104 00, Prague, Czech Republic.
[‡]Department of Animal and Poultry Production, College of Agriculture and Food, Qassim University, Buraydah 51452, Saudi Arabia.
[§]Department of Animal Science, Czech University of Life Sciences Prague, Kamýcká, 129, 16500, Prague, Czech Republic.

Abstract: This review explores the potential of white lupin seeds (*Lupinus albus*) as a sustainable protein source for rabbit nutrition and examines their effects on growth performance, carcass traits, health status, milk yield, milk composition and nutrient availability. The dietary inclusion of white lupin seeds leads to comparable or superior growth, milk yield, milk composition, nutrient digestibility and digestive health of rabbits, as well as meat quality and carcass outcomes relative to traditionally used protein sources for feeding rabbits, such as soybean meal and sunflower meal. Studies also show that it is possible to use white lupin byproducts, such as the hull and bran, for rabbit diets, which can be convenient in terms of providing an adequate supply of lignocellulose and enhancing the sustainability of rabbit feed, promoting circular economy principles. The cultivation of white lupin can contribute to environmental sustainability by reducing greenhouse gas emissions and the use of synthetic fertiliser. Future research should focus on breeding improvements and comprehensive environmental assessments of white lupin seeds to maximise the benefits of white lupin for rabbit nutrition. These findings support the role of white lupin as a viable and eco-friendly alternative to traditional protein sources, such as soybean meal, which could support productivity and sustainability in rabbit farming.

Key Words: rabbit, feeding, white lupin, self-sufficiency, sustainability.

INTRODUCTION

Agriculture is a crucial sector of the European Union (EU) economic and social system and is responsible for producing both food and feed. In 2020, there were approximately 9.1 million farms in the EU, employing 29 million people across the entire food supply chain. Among these, 4.1 million were livestock and poultry farms (Eurostat, 2024). In 2022, the EU produced 22.1 million tonnes of pig meat, 13 million tonnes of poultry meat, 6.6 million tonnes of bovine meat, 425 000 tonnes of sheep meat, and 44 000 tonnes of goat meat (Eurostat, 2024). The European Commission (EC) reported an estimated production of 168 000 tonnes of rabbit meat in 2016, indicating the presence of 4500 commercial rabbit farms and 161 000 backyard rabbit farms in the EU (EC, 2017). Spain, France and Italy have traditionally been the main producers of rabbit meat, although consumption has stagnated or decreased in recent years (Wu, 2022). Despite this decline, the commercial rabbit sector remains important for maintaining rural employment and economic stability (EC, 2017). Although the EU is self-sufficient in regard to animal production (EC, 2023), it is highly dependent on imports of protein components to feed farm animals. Soybean and soybean meal

Correspondence: Z. Volek, *volek.zdenek@vuzv.cz*. Received *July 2024 - August 2024.*
https://doi.org/10.4995/wrs.2024.22017

Cite as: Šufliarský P., Volek Z., Ebeid T.A., Zita L. 2024. Dietary inclusion of white lupin seeds and their byproducts in rabbits can contribute to EU agricultural sustainability: a review. *World Rabbit Sci., 32: 145-160.* https://doi.org/*10.4995/wrs.2024.22017*

(SBM) are traditionally used in the diets of monogastric farm animals, but they must be imported from South and North America (IDH, 2023). Most of this soybean is genetically modified (Soisontes *et al.*, 2023), which is negatively perceived by the general public (Domingo and Giné-Bordonaba, 2011). Additionally, the increasing population (UNDESA, 2022) and demand for protein sources have raised many other concerns, such as possible supply chain disruption (Reis *et al.*, 2023), economic fluctuations in global trade (Martignone *et al.*, 2022) and negative environmental impacts (Rauw *et al.*, 2023a; Rezende *et al.*, 2023). In response, EU stakeholders are committed to developing a sustainable protein strategy that balances imported and domestically produced protein components. Efforts are underway to reduce dependence on soybean imports by promoting the cultivation of domestic protein crops and transforming intensive agriculture into a more sustainable form (FEFAC, 2023). This shift aligns with the EU's transformation of its current linear economy to a circular economy (EC, 2020), driven by societal demands reflected in the EU Green Deal Objectives and the United Nations Sustainable Development Goals (FEFAC, 2023). The EU aims to reduce net greenhouse gas emissions by at least 55% by 2030 and achieve net-zero emissions by 2050 (EEA, 2023). The EU Green Deal, which includes the Farm to Fork strategy, the Biodiversity strategy and the Soil strategy for 2030, aims to unite primary producers, businesses, researchers, innovators, the public sector and consumers in the pursuit of a sustainable future. These strategies play a crucial role in mitigating climate change and promoting restoration of natural habitats (EC, 2020; Muscio and Sisto, 2020; Boix-Fayos and de Vente, 2023). Their goal is to transition the ways in which food is produced, processed, distributed and consumed (Sandström *et al.*, 2022; van Zanten *et al.*, 2023). Using alternative domestic protein sources can mitigate the negative environmental impact of soy product imports (da Silva *et al.*, 2023) and increase crop diversity (Rauw *et al.*, 2023b). Addressing land use change (LUC) and deforestation (Regulation (EU) 2023/1115) remains a primary challenge for European feed producers and suppliers (FEFAC, 2023). One of the most promising sustainable plant proteins is lupin seeds, which are suitable for both feed and food applications (Lucas *et al.*, 2015; Gresta *et al.*, 2017; Johnson *et al.*, 2017). Specifically, white lupin seeds (WLS) have shown potential as a dietary component for rabbit feeding, effectively replacing soybean meal without negatively impacting rabbit nutrition (Volek *et al.*, 2014, 2018a). This review explores the potential of WLS in rabbit feeding, highlighting relevant research findings and their implications. Tables 1-6 summarise the main results concerning the dietary inclusion of WLS and their byproducts in rabbit diets.

CHEMICAL COMPOSITION AND NUTRITIONAL PERSPECTIVES OF WHITE LUPIN SEEDS FOR RABBITS

Although WLS are considered protein crops, they contain relatively high levels of ether extract (EE), dietary fibre and bioactive compounds. Crude protein (CP) content can range from 30% (Martínez-Villaluenga *et al.*, 2006; Straková *et al.*, 2006; Volek and Marounek, 2009; Uhlířová *et al.*, 2015a) to 45% (Calabrò *et al.*, 2015; Mierlita *et al.*, 2018; Uhlířová and Volek, 2019; Panasiewicz, 2022; Ferchichi *et al.*, 2021; Heuzé *et al.*, 2022; Gresta *et al.*, 2023; Valente

Table 1: Summary of studies reporting the health status of fattening rabbits fed WLS diet.

References	Diet inclusion	Result
Volek and Marounek (2009)	100% WLS substitution for SBM or SFM	Occurrence of digestive disorders tended to be lower in rabbits fed the WLS diet than in rabbits fed the SFM and SBM diet.
Volek *et al.* (2014)	100% WLS substitution for SBM in weaning diet	Lower SRI was detected in rabbits fed the WLS diet than in rabbits fed the SBM diet.
Uhlířová *et al.* (2015a)	100% WLS substitution for SBM	Lower occurrence of digestive disorders and lower SRI were detected in rabbits fed the WLS diet than in rabbits fed the SBM diet.
Uhlířová *et al.* (2016)	100% WLS substitution for SBM	SRI tended to be lower in rabbits fed the WLS diet than in rabbits fed the SBM diet.
Volek *et al.* (2020)	100% WLS substitution for NLS	Lower SRI in rabbits fed the WLS diet than in rabbits fed the NLS

WLS: white lupine seeds, SBM: soybean meal, SFM: sunflower meal, SRI: sanitary risk index, NLS: narrow-leaved lupine seeds.

Table 2: Summary of studies reporting the meat quality of fattening rabbits fed the WLS diet.

References	Diet inclusion	Result
Volek and Marounek (2011)	100% WLS substitution for SFM	The WLS diet favourably affected FA profile or indices related to human health in the hind leg meat and adipose tissue of rabbits than in that of rabbits fed the SFM diet.
Volek *et al.* (2018b)	100% DWLS substitution for SBM	The DWLS diet favourably affected the physical and organoleptic properties, as well as SI and TI, in the hind leg meat of rabbits compared to rabbits fed the SBM diet.

WLS: white lupin seeds, SFM: sunflower meal, SBM: soybean meal, FA: fatty acid, DWLS: dehulled white lupin seeds, SI: saturation index, TI: thrombogenic index.

et al., 2023), which is comparable to the protein content of soybean (Straková *et al.*, 2006; Zaworska-Zakrzewska *et al.*, 2020). During processing, CP levels can increase due to the dehulling of seeds (Volek *et al.*, 2018b; Uhlířová and Volek, 2019). More important than the quantity of CP is its quality, which is expressed by amino acid composition. White lupin seeds contain satisfying levels of leucine, arginine, asparagine and glutamine and rather low levels of the sulphur-containing amino acids, lysine and threonine (Heuzé *et al.*, 2022). Synthetic analogues of these amino acids, however, can be added to feed to improve the protein quality (Ballester *et al.*, 1980; Taboada *et al.*, 1994; de Blas *et al.*, 1998; Volek *et al.*, 2018b). In general, WLS protein is highly digestible and of good biological value (Monteiro *et al.*, 2014; Mierlita *et al.*, 2018). The EE content ranges from 6% to almost 11.5%, with high levels of unsaturated fatty acids, particularly oleic acid, linoleic acid and α-linolenic acid (Volek and Marounek, 2011; Chiofalo *et al.*, 2012; Calabrò *et al.*, 2015; Musco *et al.*, 2017; Volek *et al.*, 2018b; Gresta *et al.*, 2023). Regarding saccharide composition, sucrose is the main low-molecular-weight (LMW) sugar, while the rest of the LMW sugars are in the form of raffinose, stachyose and verbascose; the ratio between soluble and insoluble non-cellulosic polysaccharides

Table 3: Summary of studies reporting the reproductive performance of rabbit does fed WLS diet.

References	Diet inclusion	Result
Volek *et al.* (2014)	100% WLS substitution for SBM+SFM	The WLS is a suitable dietary CP source for lactating rabbit does without negative effect on DMI, milk yield or on the growth and viability of their litters and improved milk FA profile.
Uhlířová *et al.* (2015b)	100% WLS substitution for SBM in lactation diet	The WLS diet improved FA profile of the milk and had no adverse effect on the reproductive performance of rabbit does. Growth of the litters was not affected by the dietary treatments.
Volek *et al.* (2018a)	100% WLS+RSM substitution for SBM+SFM in lactation diet	The WLS diet improved FA profile of the milk and had no adverse effect on the reproductive performance of rabbit does.
Uhlířová and Volek (2019)	100% substitution of SBM+SFM by DWLS in lactation diet	No adverse effect on live weight, feed intake and milk production in rabbit does or the performance of their litters before weaning. Greater n-3 PUFA content in milk and higher milk intake:solid feed intake ratio of their litters.

WLS: white lupin seeds, SBM: soybean meal, SFM: sunflower seeds, RSM: rapeseed meal, CP: crude protein, DMI: dry matter intake, FA: fatty acid, DWLS: dehulled white lupin seeds, PUFA: polyunsaturated fatty acids.

Table 4: Summary of studies reporting the growth performance and carcass traits of fattening rabbits fed WLS diet.

References	Diet inclusion	Result
Volek and Marounek (2009)	100% WLS substitution for SBM or SFM	Similar growth performance and carcass traits among dietary treatments.
Volek and Marounek (2011)	100% WLS substitution for SFM	Similar growth performance and carcass traits among dietary treatments.
Uhlířová *et al.* (2015a)	100% WLS substitution for SBM	No adverse effect on the performance or carcass traits of fattening rabbits fed the WLS diet *ad libitum*.
Zwoliński *et al.* (2017)	Partial or full substitution of SBM with mixture of RSM+WLS+PS in two different ratios	No differences in growth performance and carcass traits between dietary treatments.
Gugołek *et al.* (2017)	Partial or full substitution of SBM with mixture of RSM+WLS+PS in two different ratios	No differences in growth performance and carcass traits between dietary treatments.
Gugołek *et al.* (2018)	Partial and full substitution of SBM with mixture of RSM+WLS+PS in two different ratios	No differences in growth performance and carcass traits between dietary treatments.
Volek *et al.* (2018a)	100% SBM+SFM substitution by WLS+RSM	No differences in growth performance and carcass traits between dietary treatments.
Volek *et al.* (2018b)	100% substitution of SBM for DWLS	Significantly higher ADWG and better FCR in fattening rabbits and no adverse effect on carcass traits in rabbits fed the DWLS diet.
Garcia-Santos *et al.* (2021)	100% substitution of SBM by WLS or YLS	Negatively altered ADWG and FCR in rabbits fed the WLS diet.

WLS: white lupin seeds, SBM: soybean meal, SFM: sunflower meal, RSM: rapeseed meal, PS: pea seeds, DWLS: dehulled white lupin seeds, YLS: yellow lupin seeds, ADWG: average daily weight gain, FCR: feed conversion ratio.

is approximately 1 (Knudsen, 1997). The crude fibre content ranges from 8 to 15% in WLS (Calabrò *et al.*, 2015; Mierlita *et al.*, 2018; Gresta *et al.*, 2023). The WLS hulls (WLH) contain mainly insoluble dietary fibres, such as cellulose and lignin (Mohamed and Rayas-Duarte, 1995; Volek *et al.*, 2013). High levels of lignocellulose in WLH or WLS bran (WLB) could be convenient in terms of meeting the strict dietary fibre requirements of weaned rabbits with regard to digestive disorders (Gidenne, 2015). The starch content ranges from 1.3 up to 12.5% (Knudsen, 1997; Martínez-Villaluenga *et al.*, 2006; Calabrò *et al.*, 2015; Ferchichi *et al.*, 2021; Uzun and Agma, 2023). There are also significant levels of phenolic compounds, phytosterols, tocopherols or carotenoids, vitamin C and thiamine or riboflavin in WLS (Martínez-Villaluenga *et al.*, 2006; Wang *et al.*,2008; Ferchichi *et al.*, 2021; Tirdiľová *et al.*, 2022; Spina *et al.* 2022; Gresta *et al.*, 2023). The alkaloid content in modern lupin cultivars is generally low (Calabrò *et al.*, 2015; Musco *et al.*, 2017; Gresta *et al.*, 2023; Valente *et al.*, 2023), evidencing the progress of plant breeding over time. Compared to barley, wheat, rye, oats, wheat bran, SBM, sunflower meal (SFM), peas, beans or lentils, WLS had the highest phytate phosphorus content, expressed as a percentage of total phosphorus (P), and low phytate dephosphorylation activity (Marounek *et al.*, 2011). However, more than 80% of phytic acid is hydrolysed in the digestive tract of rabbits (Marounek *et al.*, 2003) as a result of phytase production by the microorganisms of the caecum (Marounek *et al.*, 2009). Through the well-known act of the digestive tract, i.e., caecotrophy, rabbits ingest soft faeces; therefore, rabbits can utilise phytate P effectively (Mateos *et al.*, 2020). In addition to the obvious differences in nutrient composition between cultivars, nutrient composition may also be affected by growing conditions (Calabrò *et al.*, 2015; Valente *et al.*, 2023).

Table 5: Summary of studies reporting the digestibility of nutrients in fattening rabbits fed WLS diet.

References	Diet inclusion	Result
Volek and Marounek (2009)	100% SBM or SFM substitution by WLS	Similar CTTADs of nutrients between dietary treatments.
Volek and Marounek (2011)	100% SFM substitution by WLS	Greater CTTAD of OM and NDF in rabbits fed the WLS diet.
Volek *et al.* (2014)	100% SBM substitution by WLS in weaning diet	Similar CTTADs of nutrients between dietary treatments, except for the EE, which was greater in rabbits fed the WLS diet.
Uhlířová *et al.* (2015a)	100% WLS substitution for SBM	CTTAD of DM, CP, NDF and GE did not differ among dietary treatments.
Zwoliński *et al.* (2017)	Partial or full substitution of SBM with mixture of RSM+WLS+PS in two different ratios	Similar CTTADs of nutrients between dietary treatments.
Gugołek *et al.* (2017)	Partial or full substitution of SBM with mixture of RSM+WLS+PS in two different ratios	Similar CTTADs of nutrients between dietary treatments.
Garcia-Santos *et al.* (2021)	100% substitution of SBM by WLS or YLS	Greater CTTAD of CP in rabbits fed the YLS diet than in rabbits fed the SBM or WLS diet.

WLS: white lupin seeds, SBM: soybean meal, SFM: sunflower meal, CTTAD: coefficient of total tract apparent digestibility, OM: organic matter, NDF: neutral detergent fibre, EE: ether extract, DM: dry matter, CP: crude protein, NDF: neutral detergent fibre, GE: gross energy, RSM: rapeseed meal, PS: pea seeds, YLS: yellow lupin seeds.

DIGESTIVE HEALTH OF WEANED RABBITS

Weaning is one of the most crucial periods for young rabbits when they are susceptible to various diseases, especially those of the digestive tract (Gidenne and Fortun-Lamothe, 2002; de Blas *et al.*, 2012). To address these issues, comprehensive scientific work has been conducted, especially concerning the nutritional requirements of dietary fibre (Gidenne, 2000, 2003, 2015). In addition to an imbalanced dietary fibre level, there are also other dietary factors, such as the dietary level and source of CP (amino acids), which are predisposed to digestive disorders (Carabaño *et al.*, 2009; de Blas *et al.*, 2012). With respect to WLS as a dietary replacement for SBM, a study by Volek and Marounek (2009) revealed an increased occurrence of diarrhoea in rabbits fed a diet supplemented with SBM compared to rabbits fed a diet supplemented with WLS (8 *vs.* 2 rabbits, respectively; 30 rabbits per group; P=0.083). Similar results were observed by Volek *et al.* (2014), who reported a lower sanitary risk index (SRI), assessed as the sum of morbidity and mortality according to the European Group on Rabbit Nutrition (Fernández-Carmona *et al.*,

Table 6: Summary of studies reporting the inclusion of lupin byproducts in fattening rabbit diets.

References	Diet inclusion	Result
Volek *et al.* (2013)	WLH inclusion 50 g/kg as partial substitution of wheat bran	No adverse effect on the digestibility of nutrients or the growth performance.
Uhlířová *et al.* (2018)	WLB inclusion at 50 g/kg and 150 g/kg as partial substitution of Alfalfa meal	Authors reported greater CTTAD of ADF in rabbits fed experimental diets than in those fed control diet and higher ADFI and worse FCR in rabbits fed experimental diets.

WLH, white lupin hulls; WLB, white lupin bran; CTTAD, coefficient of total tract apparent digestibility; ADFI, average daily feed intake; FCR, feed conversion ratio.

2005), in rabbits fed a diet based on WLS than in those fed an SBM diet (3.0 *vs.* 16.7%, respectively; 66 rabbits per group; P=0.016). A later study by Uhlířová *et al.* (2015a) showed that in rabbits with *ad libitum* feed intake, the morbidity (1 *vs.* 9 rabbits, respectively; 40 rabbits per group; P=0.014) and SRI (2 *vs.* 12 rabbits, respectively; 40 rabbits per group; P=0.006) rates of the animals fed a WLS diet were lower than those of the animals fed an SBM diet. Even in a high hygiene standard rabbit experimental unit, Uhlířová *et al.* (2016) observed a trend towards a lower SRI in the group of rabbits fed a WLS diet than in those fed an SBM diet (5 *vs.* 13 rabbits, respectively; 130 rabbits per group; P=0.085). In addition to comparison with SBM, the dietary inclusion of WLS was also compared with the dietary inclusion of narrow-leaved lupin seeds (NLS) in two experiments (Volek *et al.*, 2020). In Experiment I, SRI was greater in rabbits fed an NLS diet than in those fed a WLS diet (38.4 *vs.* 23.2%, respectively; 99 rabbits per group; P=0.031). Similarly, in Experiment II, these authors recorded an SRI greater in rabbits fed an NLS diet than in those fed a WLS diet (37.8 *vs.* 23.3%, respectively; 90 rabbits per group; P=0.052).

From the abovementioned results, it seems that the dietary inclusion of WLS can serve as a suitable tool for preventing digestive disorders. The mode of action is unclear and might arise from a variety of factors. On the one hand, CP source can play an important role in digestive health due to its anti-nutritional factors (ANF), such as its trypsin inhibitor activity, which affects ileal protein digestibility and the flow of protein towards fermentative activity (de Blas *et al.*, 2012). In this respect, trypsin inhibitor activity was not detected in WLS (Martínez-Villaluenga *et al.*, 2006), whereas this ANF is abundant in soybean (White *et al.*, 2000). The other factor that can contribute to preventing digestive disorders could be the favourable content of the oligosaccharide raffinose series in WLS. A significantly greater level of lactic acid in the caecal contents of rabbits fed a WLS diet than in those fed a diet based on SBM or sunflower meal (SFM) was observed by Volek and Marounek (2009). Oligosaccharides from WLS can be considered prebiotics that support microbial activities (Martínez-Villaluenga *et al.*, 2005; Martínez-Villaluenga and Gómez, 2007). In other species, Geigerová *et al.* (2017) reported an increased counts of lactobacilli and bifidobacteria in groups of broiler chickens or ducks with complete or partial replacement of SBM by WLS. The greater EE content in diets due to its relatively high content in WLS could also be a beneficial factor for the favourable health status of rabbits (Xiccato, 2020). Moreover, in experiments concerning the dietary effects of WLS compared to SBM on milk composition and milk yield, rabbit kits of does fed a WLS diets were nursed with milk containing higher levels of *α*-linolenic acid and eicosapentaenoic acid (EPA; Volek *et al.*, 2014; Uhlířová *et al.*, 2015b; Volek *et al.*, 2018a; Uhlířová and Volek, 2019). Maertens *et al.* (2005) observed significantly lower mortality after weaning in rabbits nursed by does fed a diet enriched in n-3 polyunsaturated fatty acids (PUFAs; extruded linseed used). The effect of higher dietary levels of n-3 PUFAs on the digestive health of fattening rabbits, however, is not consistent among different reports (Martínez-Paredes *et al.*, 2022). It has been reported that n-3 PUFAs can exert an interesting effect on mortality and/or morbidity in growing-fattening rabbits (Agradi *et al.*, 2023), most likely due to their immunomodulatory effect (Gutiérrez *et al.*, 2019). Another factor concerning the effect of the dietary inclusion of WLS on the health of fattening rabbits might be linked to intestinal mucin production. In fact, Makovický *et al.* (2018) reported greater mucin villous secretion in a group of rabbits fed a WLS diet than in a group of rabbits fed an SBM diet. Mucins (glycoproteins) that are found on the surfaces of the small intestinal mucosa have many different functions and exhibit antimicrobial properties (Tarabova *et al.*, 2016). In pigs, enhanced mucin secretion has preventive effects against challenges with either systemic *E. coli* lipopolysaccharide or enteric *Salmonella typhimurium* (Wellington *et al.*, 2020).

MEAT QUALITY

European dietary habits remain largely inconsistent with evidence-based recommendations, showing little improvement in recent years (Sioen *et al.*, 2017; Riccardi *et al.*, 2020; Markovic *et al.*, 2021). Enhancing the nutritional profile of certain foods, particularly animal-based products, could bridge this gap. Modifying animal diets is an effective strategy for creating “functional” foods that increase the consumption of bioactive substances that are beneficial to human health (Markovic *et al.*, 2021).

Rabbit meat has excellent nutritional composition and dietetic properties, and there are possibilities for further improving the functional value of rabbit meat. For instance, dietary manipulation is very effective concerning the fatty acid (FA) profile and indices related to human health in rabbit meat (Dalle Zotte and Szendrő, 2011). In this respect, Volek and Marounek (2011) focused on the effects of a diet supplemented with WLS, compared to a diet based on

SFM, on the FA profile and characteristics of hind leg meat of rabbits related to human health. These authors reported that in comparison to the SFM diet, the dietary inclusion of WLS decreased total saturated fatty acid (SFA; 1228 *vs*. 1417 mg/100 g of meat, respectively; P=0.010) and total polyunsaturated fatty acid (PUFA; 865 *vs*. 995 mg/100 g of meat, respectively; P=0.019), as well as the n-6 /n-3 ratio (4.09 *vs*. 4.98, respectively; P<0.001), saturation index (SI; 0.53 *vs*. 0.59, respectively; P<0.001), atherogenic index (AI; 0.56 *vs*. 0.62, respectively; P<0.001) and thrombogenic index (TI; 0.77 *vs*. 0.87, respectively; P<0.001) in hind leg meat of fattening rabbits. There was a significantly greater level of EPA (1.2 *vs*. 0.7 mg/100 g of meat, respectively; P<0.001) in the hind leg meat of rabbits fed the WLS diet than in that of rabbits fed the SFM diet. Similarly, Volek *et al.* (2018b), using dehulled white lupin seeds (DWLS), studied the effect of the dietary inclusion of DWLS, in comparison with an SBM diet, on the chemical, physical and sensory meat quality parameters of fattening rabbits. In rabbits fed the DWLS diet, lower Warner - Bratzler shear force values were measured in grilled loin meat samples (*longissimus lumborum* muscle) (21.3 *vs*. 24.3 N, respectively; P=0.003), and this finding was confirmed by the sensory evaluation of texture (numerical scale) in terms of greater tenderness (66.4 *vs*. 74.9, respectively; P=0.012) and fibrousness (62.3 *vs*. 72.0, respectively; P=0.003) of the meat samples (*longissimus lumborum* muscle). The hind leg meat of rabbits fed the DWLS diet contained a significantly greater total level of monounsaturated fatty acids (MUFAs, 787 *vs*. 452 mg/100 g of meat, respectively; P=0.001), with a greater level of oleic acid (636 *vs*. 349 mg/100 g of meat, respectively; P=0.001), than the hind leg meat of rabbits fed the SBM diet. A higher level of α-linolenic acid (65 *vs*. 33 mg/100 g of meat, respectively; P=0.001) was detected in the hind leg meat of rabbits fed with the DWLS diet than in those fed the SBM diet. A significantly lower n-6/n-3 ratio (5.32 *vs*. 8.73, respectively; P=0.001), and SI (0.53 *vs*. 0.59, respectively; P=0.001) and TI (0.80 *vs*. 0.93, respectively; P=0.001) were detected in the hind leg meat of rabbits fed the DWLS diet than in that of rabbits fed the SBM diet.

In a study by Kowalska *et al.* (2020), SBM in the control C diet (15% SBM) was partially or fully replaced by WLS, rapeseed meal (RSM) and pea seeds (PS; experimental diets E1: 7.5% SBM, 5% RSM, 4% WLS, and 3% PS; experimental diet E2: 0% SBM, 10% RSM, 8% WLS, and 6% PS). Both the experimental diets (E1 and E2) significantly improved the nutritional composition of the rabbit meat. It was noted that with decreasing inclusion of SBM in the diets, the level of total SFAs in hind leg meat decreased (39.9 and 38.0% and 37.0% of total FAs in rabbits fed the C, E1 or E2 diets, respectively; P<0.01) and that of PUFAs increased (29.6% and 32.0% and 34.9% of total FAs in rabbits fed the C, E1 and E2 diet, respectively; P<0.01). The n-6 /n-3 ratio did not significantly differ, although the SI was greater in rabbits fed the C diet than in those fed the E1 or E2 diet (0.66 and 0.60 and 0.57, respectively; P<0.05).

Guedes *et al.* (2022) replaced SBM in a control diet with WLS or yellow lupin seeds (YLS) in the experimental diets. These authors reported similar findings regarding the FA content and profile or indices related to human health in the loin meat of rabbits. Changes in FA composition influenced the n-6/n-3 ratio, which was the lowest in rabbits fed the WLS diet. An intermediate n-6/n-3 ratio was found in rabbits fed the SBM diet, and the highest n-6/n-3 ratio was found in rabbits fed the YLS diet (5.4 and 7.1 and 8.8, respectively; P<0.001). Furthermore, the AI was lowest in rabbits fed the WLS diet, and greater in rabbits fed the YLS diet, and the highest AI was found in rabbits fed the SBM diet (0.62, 0.69, and 0.80, respectively; P<0.001). Similarly, the TI was lowest in rabbits fed the WLS diet, greater in rabbits fed the YLS diet, and greatest in rabbits fed the SBM diet (0.89 and 1.03 and 1.19, respectively; P<0.001). Additionally, the SI was the lowest in rabbits fed the WLS diet, higher in rabbits fed the YLS diet, and highest in rabbits fed the SBM diet (0.60 and 0.65 and 0.76, respectively; P<0.001). In terms of the hypocholesterolaemic/hypercholesterolaemic index, the highest values were found in rabbits fed the YLS diet, lower values were found in rabbits fed the WLS diet, and the lowest values were found in rabbits fed the SBM diet (0.90 and 0.89 and 0.68, respectively; P<0.001).

The abovementioned results of the favourable impact of the dietary inclusion of WLS on the FA profile and composition were also observed in the meat of other farm animals such as pigs (Zralý *et al.*, 2007) and broiler chickens (Laudadio and Tufarelli, 2011), as well as in the eggs of laying hens and quail (Timová *et al.*, 2020; Struți *et al.*, 2023) and in dairy cow milk (Froidmont and Bartiaux-Thill, 2004).

PERFORMANCE OF RABBIT DOES, THEIR LITTERS AND MILK COMPOSITION

Maintaining the health of young rabbits' postweaning necessitates careful nutritional management of rabbit does (Martínez-Paredes *et al.*, 2022) to ensure high milk yield and milk quality for their kits (Ludwiczak *et al.*, 2020; Ludwiczak *et al.*, 2023). Rabbit milk is the sole source of nutrients for kits from birth until approximately Day 19 and is characterised by a high fat and energy content, essential for rapid growth, as well as highly digestible nutrients (Maertens, 1998; Maertens *et al.*, 2006; Gidenne *et al.*, 2018). Lipase activity is notably high during lactation but sharply decreases postweaning (Zita *et al.*, 2008), and higher unsaturation levels improve fat digestibility (Maertens, 1998). Volek *et al.* (2014) reported that does fed a diet supplemented with WLS had a greater daily milk yield for the whole lactation period (d 1 to 30) (255 *vs*. 230 g, respectively; P=0.094) and from d 22 to 30 (277 *vs*. 229 g, respectively; P=0.044) than did those fed a diet based on SBM+SFM. These authors observed that there was a significant modification in the FA composition of rabbit doe milk. Compared with those fed the SBM+SFM diet, the milk of does fed WLS diet contained a lower SFA content (69.9 *vs*. 64.0% of the total FAs, respectively; P<0.01), particularly caprylic acid (25.6 *vs*. 23.0% of the total FAs, respectively; P<0.01), and capric acid (23.9% *vs*. 22.0% of the total FAs, respectively; P<0.01). The MUFA content was greater (20.6 *vs*. 13.8% of the total FAs, respectively; P<0.01), and the oleic acid content was greater (18.5 *vs*. 12.1% of the total FAs, respectively; P<0.01) in the milk of rabbit does fed the WLS diet than in that of rabbit does fed the SBM+SFM diet. The PUFA content in the milk was lower (15.3 *vs*. 16.3% of the total FAs, respectively; P=0.030), with a decrease in linoleic acid (11.1 *vs.* 12.5% of the total FAs, respectively; P=0.007) and arachidonic acid (0.1 *vs*. 0.2% of the total FAs, respectively; P=0.007) in does fed the diet based on WLS than in those fed with the SBM+SFM diet. However, there was a greater content of α-linolenic acid (3.6 *vs*. 3.2% of the total FAs, respectively; P=0.032), and EPA (0.07 *vs*. 0.01% of the total FAs, respectively; P<0.01), and a greater total n-3:arachidonic acid ratio (28.7 *vs*. 14.5, respectively; P<0.01) in the milk of does fed the WLS diet than in those fed the SBM+SFM diet. Regarding litter performance, Volek *et al.* (2014) reported that litter weight at birth, at 21 days of age and at weaning, as well as the average daily weight gain (ADWG) of kits during the whole nursing period, or the average daily solid feed intake (ADFI) between days 22 and 30 of age, were not significantly affected by dietary treatments. In litters of does that were fed a WLS diet, a greater milk efficiency between days 1 and 22 of the nursing period (0.51 *vs*. 0.49, respectively; P=0.046) and a greater milk intake/solid feed intake ratio between days 22 and 30 of age (1.37 *vs*. 1.09, respectively; P=0.036) were observed compared to litters of does fed a diet supplemented with SBM+SFM. Uhlířová *et al.* (2015b), by means of two consecutive lactations, confirmed the previous findings. Over the 1st lactation period (all does were at their second parturition stage), the milk yield was greater from days 22 to 32 of the nursing period (3512 *vs.* 3171 g; P=0.016) in does fed a diet supplemented with WLS than in those fed a diet supplemented with SBM+SFM. Over the following lactation period (all does were at their third parturition stage), milk yield was significantly greater for the entire lactation period (35 d) in does fed the diet with WLS than in does fed the diet based on SBM+SFM (8626 *vs.* 9303 g; P=0.019). The levels of caprylic acid (22.3 *vs*. 25.3% of the total FAs, respectively; P=0.001), capric acid (22.1 *vs.* 26.2% of the total FAs, respectively; P=0.001) and linoleic acid (11.4 *vs*. 13.3% of the total FAs, respectively; P=0.002) were lower, and levels of oleic acid (17.6 *vs*. 10.0% of the total FAs, respectively; P=0.001), α-linolenic acid (3.6 *vs*. 2.6% of the total FAs, respectively; P=0.001), and EPA (0.08 *vs*. 0.04% of the total FAs, respectively; P=0.005) were greater in milk of rabbit does fed a diet supplemented with WLS than in those fed a diet supplemented with SBM+SFM. The average weight of litters or ADWG (g per rabbit) were not influenced by the dietary treatments in either of the lactations. The daily solid feed intake was significantly greater (from day 17 until weaning) in the litters of the does that were fed the SBM+SFM diets during both consecutive lactations. Volek *et al.* (2018a) evaluated the substitution of SBM and SFM (SSL) with WLS and RSM (RLL) in a lactation diet and fattening diet. The RLL diet had no negative effect on rabbit does' performance. There were no significant differences in terms of the content of dry matter (DM), protein or fat in the milk of the does among dietary treatments. There were higher levels of α-linolenic acid (2.4 *vs*. 2.2% of the total FAs, respectively; P=0.037), EPA (0.06 *vs*. 0.04% of the total FAs, respectively; P=0.015) and total n-3 PUFA (2.5 *vs*. 2.3% of the total FAs, respectively; P=0.030) in the milk of rabbit does fed the RLL diet than in that of those fed the SSL diet. The growth performance of the litters during the nursing period did not differ among the dietary treatments. Uhlířová and Volek (2019) studied the effect of inclusion of DWLS in a lactation diet in comparison with a lactation diet based on the SBM+SFM. No difference was observed in the content of DM, protein or fat at d 21 in milk; however, the inclusion of DWLS in the diet significantly altered the milk FA composition, with lower levels of linoleic acid (10.6 *vs.* 11.9% of the total FAs, respectively; P=0.035) and higher levels of α-linolenic acid (2.9 *vs.* 1.9% of the total FAs, respectively; P<0.001), EPA (0.09 *vs.* 0.03% of the total FAs, respectively; P<0.001) and total n-3 PUFAs (3.1 *vs.* 2.0% of the total FAs, respectively; P<0.001) were found in the milk of does fed the DWLS diet compared to does fed the SBM+SFM diet. There was no significant difference in litter live weight, ADWG or milk efficiency between the dietary treatments. However, daily solid feed intake (g per rabbit) tended to be lower (20.8 *vs.* 24.2 g, respectively; P=0.086), which correspond to a greater milk intake:solid feed intake ratio between days 17 and 32 of age (1.97 *vs.* 1.53, respectively; P=0.024) in litters of does fed the DWLS diet than in litters of does fed the SBM+SFM diet. These dietary modifications highlight the potential of WLS to enhance the milk composition and possibly support the health and growth performance of rabbits after weaning.

GROWTH PERFORMANCE AND CARCASS TRAITS OF FATTENING RABBITS

Achieving the required slaughter weight within an optimal timeframe is influenced by several factors (Dalle Zotte, 2002; Kumar *et al.*, 2023), with genotype being the most critical (Metzger *et al.*, 2006; Tůmová *et al.*, 2014). Nutrition also plays a significant role (Xiccato, 1999). High-quality protein sources with appropriate amino acid compositions, such as SBM, are essential (Carabaño *et al.*, 2009). However, animal nutritionists are increasingly seeking alternative feed components that provide quality nutrients, promote health and reduce environmental impacts. The legume family, including soybeans, offers a variety of plant species, such as WLS, which seems to be comparable to SBM as a protein source in rabbit feeds. In fact, Volek and Marounek (2009) reported that rabbits fed the experimental diet containing WLS as the main protein source exhibited growth performance and carcass traits similar to those of rabbits fed diets containing SBM or SFM as the main protein source. In addition, a greater dressing-out percentage was reported in rabbits fed the WLS diet than in rabbits fed diets supplemented with SFM or SBM (58.7 and 57.4% and 57.3%, respectively; P=0.006). Similar results were reported when rabbits were fed a diet containing WLS instead of a diet based on SFM, although there was no difference between the treatments regarding the dressing-out percentage (Volek and Marounek, 2011). The growth performance was also not negatively affected in another study by Uhlířová *et al.* (2015a) when WLS was compared with SBM. Regarding the carcass traits, these authors reported greater chilled (1889 *vs.* 1719 g, respectively; P=0.070) and reference carcass weights (1532 *vs.* 1386 g, respectively; P=0.041) in rabbits fed the WLS diet than in rabbits fed the SBM diet. The dressing-out percentage was not affected by the dietary treatments. Some differences regarding growth performance were reported by Volek *et al.* (2018b). The final live weight tended to be greater in the group of rabbits fed the DWLS diet than in the group of rabbits fed the SBM diet (3265 *vs.* 3153 g, respectively; P=0.097). Furthermore, the ADWG was greater (49.5 *vs.* 46.3 g/d, respectively; P=0.008) and the feed conversion ratio (FCR) better (3.19 *vs.* 3.40, respectively; P=0.001) in rabbits fed the DWLS diet than in those fed the SBM diet. There were no significant differences concerning growth performance or carcass traits observed in rabbits fed a diet based on SBM or diets where SBM was partially or fully replaced by WLS and other crude protein alternatives (RSM and PS; Zwoliński *et al.*, 2017). Similarly, Gugołek *et al.* (2017, 2018) did not observe any significant differences in growth performance or carcass traits comparing similar diets. Additionally, Volek *et al.* (2018a) did not observe any significant differences between groups of rabbits fed a diet based on SBM or a diet containing a mixture of RSM (60 g/kg as fed basis) and WLS (40 g/kg as fed basis) as the main crude protein source in terms of the growth performance or carcass traits of fattening rabbits. In fact, only one study by Garcia-Santos *et al.* (2021) described a significantly lower ADWG (42.8 and 42.1 and 48.1 g/d, respectively; P<0.05) and worse FCR (3.5 and 3.6 and 3.1, respectively; P<0.05) for the entire fattening period in rabbits fed diets containing WLS or YLS in comparison to rabbits fed a diet containing SBM as the main crude protein source. In their study, however, no significant differences were reported for the live weight of the rabbits during the entire fattening period between dietary treatments.

TOTAL TRACT APPARENT DIGESTIBILITY OF DIETS BASED ON THE WLS

Nutrient excretion data serve as the basis for important regulations and strategies crucial to mitigating environmental pollution (Xiccato *et al.*, 2005; Velthof *et al.*, 2015). In terms of maximising the digestibility and utilisation of nutrients in animals, including rabbits, it is not only a productive and economical matter but also an environmental concern (Méda *et al.*, 2014; Gidenne *et al.*, 2017; Cesari *et al.*, 2018).

In this respect, Volek and Marounek (2009) reported that rabbits fed a diet with WLS exhibited similar coefficients of total tract apparent digestibility (CTTAD) of CP, organic matter (OM), starch or EE compared to the other rabbits fed diets containing SBM or SFM as the main crude protein sources. Volek and Marounek (2011) reported significantly greater CTTAD of OM (0.667 *vs*. 0.640, respectively; P=0.017) and NDF (0.455 *vs*. 0.416, respectively; P=0.029) in rabbits fed the WLS diet than in rabbits fed the SFM diet. Additionally, Volek *et al.* (2014) showed that the CTTAD of nutrients did not differ between treatments, except for the CTTAD of EE, which was greater in rabbits fed a WLS diet than in rabbits fed a diet based on SBM (0.89 *vs*. 0.85, respectively; P=0.006). Uhlířová *et al.* (2015a) observed significantly lower CTTAD of starch in rabbits fed a WLS diet than in rabbits fed an SBM-based diet (0.963 *vs*. 0.974, respectively; P=0.005), whereas the CTTAD of DM, CP, NDF and gross energy (GE) did not differ between dietary treatments. Similarly, other authors did not find a significant difference between dietary treatments (dietary SBM replaced by a mixture of WLS, RSM, and PS) concerning the CTTAD of nutrients or GE in rabbits (Gugołek *et al.* 2017; Zwoliński *et al.* 2017). Garcia-Santos *et al.* (2021) reported lower CTTAD of OM (0.596 and 0.600 and 0.622, respectively; P=0.032) in rabbits fed a WLS or YLS diet than in rabbits fed an SBM diet. In addition, CTTAD of CP was greater in rabbits fed the YLS diet than in rabbits fed the SBM or WLS diet (0.738 and 0.715 and 0.714, respectively; P=0.021). Except for the results of the study by Garcia-Santos *et al.* (2021), the studies cited are in agreement with the early study of Fekete and Gippert (1986), who compared the digestibility and nutritive value of a diet based on WLS with those of 18 other different feedstuffs.

LUPIN BYPRODUCTS IN RABBIT NUTRITION

The agri-food sector generates vast quantities of byproducts annually, which are often unsuitable for human consumption but contain significant levels of nutrients that can be used as feed components for farm animals (FEFAC, 2022). While many of these byproducts are high in fibre and unsuitable for monogastric animals such as pigs and poultry, rabbits, despite being monogastric, can digest large amounts of fibre (e.g., Gidenne, 2015). The WLH or WLB are an example of such byproducts generated during flour production for humans (Zhong *et al.*, 2020) or feed production for pigs and poultry, as removing the hulls results in increasing nutritive value for these animal species (Nalle *et al.*, 2010).

Lupin hulls are the outer shell or husk of white lupin seeds. They contain dietary fibre and some residual protein. In rabbit diets, WLH can be used as a source of dietary fibre, which aids in digestive health and regulates gut function. Lupin hulls can also contribute to the bulkiness and texture of rabbit feed, promoting natural foraging behaviours and improving palatability. The inclusion of 50 g/kg (as fed basis) WLH in the diet of growing-fattening rabbits had no negative effect on nutrient digestibility or growth performance (Volek *et al.*, 2013).

Lupin bran consists of the outer layers of white lupin seeds, including the seed coat and aleurone layer. In rabbit diets, WLB can serve as a supplementary source of fibre and micronutrients. Its inclusion can help diversify the nutrient profile of rabbit feed and support overall digestive health. Uhlířová *et al.* (2018) studied the dietary incorporation of WLB at 50 (WLB5) or 150 (WLB15) g/kg (as fed basis) at the expense of alfalfa meal (control diet) in rabbit feed formulations. In general, there was no negative effect on the CTTAD of the diets. A significantly greater CTTAD was found for the acid detergent fibre (ADF) of the WLB15 and WLB5 diets than in the control diet (0.210 and 0.200 and 0.147, respectively, P<0.001). Concerning growth performance, no significant difference was observed for the final live weight or the ADWG of the rabbits among dietary treatments. The ADFI was greater (157.1 and 157.6 and 127.4 g/d, respectively; P<0.001) and the FCR was worse (3.05 and 3.03 and 2.62, respectively; P<0.001) in rabbits fed the WLB15 and WLB5 diets than in rabbits fed the control diet. Feeding rabbits with the WLB15 diet led to a significantly lower dressing-out percentage (57.5 and 58.6% and 59.6%, respectively; P=0.024) and a greater drip loss percentage (3.18 and 2.61% and 2.46%, respectively; P<0.001) than did feeding rabbits with the WLB5 or control diet. Similar findings were observed in a study by Laudadio *et al.* (2009).

Overall, WLH and WLB are valuable nutritional components that can be incorporated into rabbit feeds to enhance sustainability and optimise nutrient utilisation.

FUTURE PERSPECTIVES AND DIRECTION OF LUPIN RESEARCH

The introduction of native protein sources such as white lupin into the diets of farm animals in the EU aligns with ambitious plans to decrease carbon footprints and improve environmental sustainability. Compared to conventional protein sources such as soybean meal, the cultivation and processing of white lupin might result in lower greenhouse gas emissions per unit of protein produced. This reduction is primarily due to reduced reliance on synthetic fertilisers and lower energy inputs during cultivation and processing. These findings should be proven by means of life cycle assessments and carbon footprint analyses, which will provide quantitative insights into the environmental performance of white lupin-based animal feeds compared to that of conventional alternatives (Stagnari *et al.*, 2017; Costa *et al.*, 2020; Divéky-Ertsey *et al.*, 2022; Rebolledo-Leiva *et al.*, 2022). Breeding efforts to date have significantly reduced the alkaloid content in lupin, resulting in modern varieties with low alkaloid levels. Current lupin breeding goals include stabilising yields, enhancing resilience to biotic and abiotic stresses, improving seed quality-related biochemical properties, and extending maturity periods. Seed quality is particularly crucial for animal feed. However, lupin breeding is ongoing, and future efforts will focus on improving other seed quality traits, such as the content of non-starch polysaccharides and oligosaccharides (Abraham *et al.*, 2019).

Since 1990, the cultivation of lupins has gradually increased. In 2022, the acreage of lupin in the EU reached almost 260,000 hectares, representing a year-on-year increase of approximately 26% from 205,000 hectares in 2021. The largest areas of lupin cultivation in the EU are found in Poland and Germany, which together account for approximately 88% of the total lupin area in the EU (Faostat, 2024).

White lupin cultivation can provide habitat and forage resources for beneficial insects, birds and small mammals, supporting biodiversity in agricultural landscapes (Messéan *et al.*, 2021; Reckling *et al.*, 2022; Brannan *et al.*, 2023). By diversifying crop rotations and incorporating white lupin into agroecosystems, farmers can enhance ecosystem resilience and contribute to the conservation of native plants and animal species (Llobat and Marín-García, 2022; Rauw *et al.*, 2023b; Marada *et al.*, 2023; Marín-García *et al.*, 2023).

CONCLUSIONS

The integration of white lupin into rabbit (and other livestock) feeds in the EU might present a promising opportunity to enhance environmental sustainability, improve farm animal diets and support agricultural biodiversity. Ongoing research and breeding efforts, combined with supportive policies and market acceptance, will be crucial for realising the full potential of white lupin in sustainable agriculture.

Acknowledgements: This study was supported by the Ministry of Agriculture of the Czech Republic (Prague, Czech Republic), institutional support MZE-RO0723. The support of the Ministry of Education, Youth and Sports of the Czech Republic (Prague, Czech Republic) ["S" Grant] is also acknowledged.

Authors contribution: Šufliarský P.: data curation, writing – original draft and writing – review & editing. Volek Z.: conceptualization, methodology, investigation, writing – review & editing and supervision. Ebeid T.A.: investigation and writing – review & editing. Zita L.: data curation and writing – review & editing.

REFERENCES

Abraham E., Ganopoulos I., Madesis P., Mavromatis A., Mylona P., Nianiou-Obeidat I., Parissi Z., Polidoros A., Tani E., Vlachostergios D. 2019. The use of lupin as a source of protein in animal feeding: Genomic tools and breeding approaches. *Int. J. Mol. Sci., 20: 851. https://doi.org/10.3390/ijms20040851*

Agradi S., Sulce M., Menchetti L., Vigo D., Castrica M., Barbato O., Andoni E., Quattrone A., Munga A., Marongiu M.L., Curone G., Brecchia G. 2023. Dietary supplementation with n-3 polyunsaturated fatty acids: Effects on reproductive and productive performance and meat quality in rabbit breeding. *Anim. Nutr., 14: 70-78. https://doi.org/10.1016/j.aninu.2023.03.009*

Ballester D., Yañez E., García R., Erazo S., López F., Haardt E., Cornejo S., López A., Pokniak J., Chichester C.O. 1980. Chemical composition, nutritive value, and toxicological evaluation of two species of sweet lupine (*Lupinus albus* and *Lupinus luteus*). *Journal of Agricultural and Food Chemistry, 28(2), 402-405. https://doi.org/10.1021/jf60228a056*

Boix-Fayos C., de Vente J. 2023. Challenges and potential pathways towards sustainable agriculture within the European Green Deal. *Agric. Systems, 207. https://doi.org/10.1016/j.agsy.2023.103634*

Brannan T., Bickler C., Hansson H., Karley A., Weih M., Manevska-Tasevska G. 2023. Overcoming barriers to crop diversification uptake in Europe: A mini review. *Front. Sustain. Food Syst., 7. https://doi.org/10.3389/fsufs.2023.1107700*

Calabrò S., Cutrignelli M.I., Lo Presti V., Tudisco R., Chiofalo V., Grossi M., Infascelli F., Chiofalo B. 2015. Characterization and effect of year of harvest on the nutritional properties of three varieties of white lupine (*Lupinus albus* L.). *J. Sci. Food Agric., 95: 3127-3136. https://doi.org/10.1002/jsfa.7049*

Carabaño R., Villamide M.J., García J., Nicodemus N., Llorente A., Chamorro S., Menoyo D. 2009. New concepts and objectives for protein-amino acid nutrition in rabbits: a review. *World Rabbit Sc., 17: 01-14. https://doi.org/10.4995/wrs.2009.664*

Cesari V., Zucali M., Bava L., Gislon G., Tamburini A., Toschi I. 2018. Environmental impact of rabbit meat: The effect of production efficiency. *Meat Sci., 145: 447-454. https://doi.org/10.1016/j.meatsci.2018.07.011*

Chiofalo B., Presti V.L., Chiofalo V., Gresta F. 2012. The productive traits, fatty acid profile and nutritional indices of three lupin (*Lupinus* spp.) species cultivated in a Mediterranean environment for the livestock. *Anim. Feed Sci. Technol., 171: 230-239. https://doi.org/10.1016/j.anifeedsci.2011.11.005*

Costa M.P., Chadwick D., Saget S., Rees R.M., Williams M., Styles D. 2020. Representing crop rotations in life cycle assessment: a review of legume LCA studies. *Int. J. Life Cycle Assess., 25: 1942-1956. https://doi.org/10.1007/s11367-020-01812-x*

da Silva R.F.B., Moran E.F., Millington J.D.A., Viña A., Liu J. 2023. Complex relationships between soybean trade destination and tropical deforestation. *Sci. Rep., 13. https://doi.org/10.1038/s41598-023-38405-1*

Dalle Zotte A. 2002. Perception of rabbit meat quality and major factors influencing the rabbit carcass and meat quality. *Livest. Prod. Sci., 75: 11-32. https://doi.org/*10.1016/S0301-6226(01)00308-6

Dalle Zotte A., Szendrő Z. 2011. The role of rabbit meat as functional food. *Meat Science, 88: 319-331. https://doi.org/10.1016/j.meatsci.2011.02.017*

de Blas J.C., Taboada E., Nicodemus N., Campos R., Piquer J., Méndez J. 1998. Performance response of lactating and growing rabbits to dietary threonine content. *Anim. Feed Sci. Technol., 70: 151-160. https://doi.org/10.1016/S0377-8401(97)00063-1*

de Blas J.C., Chamorro S., García-Alonso J., García-Rebollar P., García-Ruiz A.I., Gómez-Conde M.S., Menoyo D., Nicodemus N., Romero C., Carabaño R. 2012. Nutritional digestive disturbances in weaner rabbits. *Anim. Feed Sci. Technol., 173: 102-110. https://doi.org/10.1016/j.anifeedsci.2011.12.016*

Divéky-Ertsey A., Gál I., Madaras K., Pusztai P., Csambalik L. 2022. Contribution of pulses to agrobiodiversity in the view of EU protein strategy. *Stresses, 2: 90-112. https://doi.org/10.3390/stresses2010008*

Domingo J.L., Giné-Bordonaba J. 2011. A literature review on the safety assessment of genetically modified plants. *Environ. Int., 37: 734-742. https://doi.org/10.1016/j.envint.2011.01.003*

EEA. 2023. European environment agency. Trends and projections in Europe 2023. Luxembourg: *Publications Office of the European Union, p. 85. https://data.europa.eu/doi/10.2800/595102*

European Commission. 2017. Directorate-General for Health and Food Safety, Commercial rabbit farming in the European Union – Overview report. *Publications Office of the European Union, p. 23. https://data.europa.eu/doi/10.2772/62174*

European Commission. 2020. Directorate-General for Communication, Circular economy action plan – For a cleaner and more competitive Europe. *Publications Office of the European Union.* https://data.europa.eu*/doi/10.2779/05068*

European Commission. 2023. EU agricultural outlook for markets, 2023-2035. European Commission. *DG Agriculture and Rural Development, Brussels. p. 85.*

Eurostat. 2024. Key figures on the European food chain – 2023 edition. Cook E. editor, *Publications Office of the European Union. p. 102.* https://data.europa.eu*/doi/10.2785/265789*

Faostat. 2024. Lupine acreage and production in the EU. *https://www.fao.org/faostat/en/#data/QCL/visualize. Accessed May 2024.*

FEFAC. 2022. The European Feed Manufacturers' Federation – Circular feed: Optimised nutrient recovery through animal nutrition. *Belgium, p. 26*.

FEFAC. 2023. The European Feed Manufacturers' Federation. Feed sustainability charter. Progress report 2023. *Belgium. p. 19*.

Fekete S., Gippert T. 1986. Digestibility and nutritive value of nineteen important feedstuffs for rabbits. *J. Appl. Rabbit Res., 9: 103-108*.

Ferchichi N., Toukabri W., Vrhovsek U., Nouairi I., Angeli A., Masuero D., Mhamdi R., Trabelsi D. 2021. Proximate composition, lipid and phenolic profiles, and antioxidant activity of different ecotypes of *Lupinus albus*, *Lupinus luteus* and *lupinus angustifolius*. *J. Food Measure. Charact., 15: 1241-1257. https://doi.org/10.1007/s11694-020-00722-8*

Fernández-Carmona J., Blas E., Pascual J.J., Maertens L., Gidenne T., Xiccato G., García. 2005. Recommendations and guidelines for applied nutrition experiments in rabbits. *World Rabbit Sci., 13: 209-228. https://doi.org/10.4995/wrs.2005.516*

Froidmont E., Bartiaux-Thill N. 2004. Suitability of lupin and pea seeds as a substitute for soybean meal in high-producing dairy cow feed. *Anim. Res., 53: 475-487. https://doi.org/10.1051/animres:2004034*

Garcia-Santos S., Almeida M., Closson M., Guedes C.M., Barros A., Ferreira L.M., Trindade H., Pinheiro V. 2021. Effect of total replacement of the soya bean meal by lupine seeds (*L. albus* and *L. luteus*) on performance and digestion characteristics of growing rabbits. *Anim. Feed Sci. Technol., 278. https://doi.org/10.1016/j.anifeedsci.2021.114996*

Geigerová M., Švejstil R., Skřivanová E., Straková E., Suchý P. 2017. Effect of dietary lupin (*Lupinus albus*) on the gastrointestinal microbiota composition in broiler chickens and ducks. *Czech J. Anim. Sci., 62: 369-376. https://doi.org/10.17221/42/2017-CJAS*

Gidenne T. 2000. Recent advances in rabbit nutrition: emphasis on fibre requirements. A review. *World Rabbit Sci., 8: 23-32. https://doi.org/10.4995/wrs.2000.414*

Gidenne T. 2003. Fibres in rabbit feeding for digestive troubles prevention: respective role of low-digested and digestible fibre. *Livest. Prod. Sci., 81: 105-117. https://doi.org/10.1016/S0301-6226(02)00301-9*

Gidenne T. 2015. Dietary fibres in the nutrition of the growing rabbit and recommendations to preserve digestive health: a review. *Animal, 9: 227-242. https://doi.org/10.1017/S1751731114002729*

Gidenne T., Fortun-Lamothe L. 2002. Feeding strategy for young rabbits around weaning: a review of digestive capacity and nutritional needs. *Anim. Sci., 75: 169-184. https://doi.org/10.1017/S1357729800052942*

Gidenne T., Garreau H., Drouilhet L., Aubert C., Maertens L. 2017. Improving feed efficiency in rabbit production, a review on nutritional, technico-economical, genetic and environmental aspects. *Animal Feed Science and Technology, 225: 109-122. https://doi.org/10.1016/j.anifeedsci.2017.01.016*

Gidenne T., Bannelier C., Gallois M., Segura M., Lambrecht V. 2018. Milk digestion in the young rabbit: methodology and first results. *World Rabbit Sci., 26: 269-276. https://doi.org/10.4995/wrs.2018.10061*

Gresta F., Wink M., Prins U., Abberton M., Capraro J., Scarafoni A., Hill G. 2017. Lupins in European cropping systems. *In: D. Murphy-Bokern F.L. Stoddard C.A. Watson (Eds.), Legumes in cropping systems. CAB International, 88-108. https://doi.org/10.1079/9781780644981.0088*

Gresta F., Oteri M., Scordia D., Costale A., Armone R., Meineri G., Chiofalo B. 2023. White Lupin (*Lupinus albus* L.), an Alternative Legume for Animal Feeding in the Mediterranean Area. *Agriculture, 13: 434. https://doi.org/10.3390/agriculture13020434*

Guedes C.M., Almeida M., Closson M., Garcia-Santos S., Lorenzo J.M., Domínguez R., Ferreira L., Trindade H., Silva S., Pinheiro V. 2022. Effect of total replacement of soya bean meal by whole lupine seeds and of gender on the meat quality and fatty acids profile of growing rabbits. *Foods, 11: 2411. https://doi.org/10.3390/foods11162411*

Gugołek A., Juśkiewicz J., Strychalski J., Zwoliński C., Żary-Sikorska E., Konstantynowicz M. 2017. The effects of rapeseed meal and legume seeds as substitutes for soybean meal on productivity and gastrointestinal function in rabbits. *Archiv. Anim. Nutr., 71: 311-326. https://doi.org/10.1080/1745039X.2017.1322796*

Gugołek A., Juśkiewicz J., Kowalska D., Zwoliński C., Sobiech P., Strychalski J. 2018. Physiological responses of rabbits fed with diets containing rapeseed meal, white lupine and pea seeds as soybean meal substitutes. *Ciência e Agrotecnologia, 42: 297-306. https://doi.org/10.1590/1413-70542018423003318*

Gutiérrez S., Svahn S.L., Johansson M.E. 2019. Effects of omega-3 fatty acids on immune cells. *Int. J. Mol. Sci., 20: 5028. https://doi.org/10.3390/ijms20205028*

Heuzé V., Thiollet H., Tran G., Nozière P., Lessire M., Lebas F. 2022. White lupin (*Lupinus albus*) seeds. *Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. https://www.feedipedia.org/node/279.* Accessed May 2024.

IDH. 2023. European Soy Monitor; Insights on European uptake of certified, responsible, deforestation, and conversion-free soy in 2021. *September 2023. Prepared by Schuttelaar & Partners: the Hague, the Netherlands.*

Johnson S.K., Clements J., Villarino C.B.J., Coorey R. 2017. Lupins: Their unique nutritional and health-promoting attributes. *In: Gluten-Free Ancient Grains. Elsevier, 179-221. https://doi.org/10.1016/B978-0-08-100866-9.00008-X*

Knudsen K.E.B. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. *Anim. Feed Sci. Technol., 67: 319-338. https://doi.org/10.1016/S0377-8401(97)00009-6*

Kowalska D., Strycharski J., Zwoliński C., Gugołek A., Matusevicius P. 2020. The effect of mixture of rapeseed meal, white lupin seed, and pea seed in rabbit diets on performance indicators and fatty acid profile of meat and fat. *Kafkas Univ. Vet. Fak. Derg., 26: 455-462.* https://doi.org/10.9775/kvfd.2019.23222

Kumar S.A., Kim H.J., Jayasena D.D., Jo C. 2023. On-farm and processing factors affecting rabbit carcass and meat quality attributes. *Food Sci. Anim. Res., 43: 197-219. https://doi.org/10.5851/kosfa.2023.e5*

Laudadio V., Dario M., Addonizio F., Tufarelli V. 2009. Effect of inclusion of hard versus soft wheat bran with different particle size on diet digestibility, growth performance and carcass traits of fattening rabbits. *Asian-Austral. J. Anim. Sci., 22: 1377-1385. https://doi.org/10.5713/ajas.2009.90218*

Laudadio V., Tufarelli V. 2011. Dehulled-micronised lupin (*Lupinus albus* L. *cv*. Multitalia) as the main protein source for broilers: influence on growth performance, carcass traits and meat fatty acid composition. *J. Sci. Food Agric., 91: 2081-2087. https://doi.org/10.1002/jsfa.4426*

Llobat L., Marín-García P.J. 2022. Application of protein nutrition in natural ecosystem management for European rabbit (*Oryctolagus cuniculus*) conservation. *Biodiv. Cons., 31: 1435-1444. https://doi.org/*10.1007/s10531-022-02426-5

Lucas M.M., Stoddard F.L., Annicchiarico P., Frías J., Martínez-Villaluenga C., Sussmann D., Duranti M., Seger A., Zander P.M., Pueyo J.J. 2015. The future of lupin as a protein crop in Europe. *Front. Plant Sci., 6. https://doi.org/10.3389/fpls.2015.00705*

Ludwiczak A., Składanowska-Baryza J., Kuczyńska B., Stanisz M. 2020. Hycole doe milk properties and kit growth. *Animals, 10: 214. https://doi.org/10.3390/ani10020214*

Ludwiczak A., Składanowska-Baryza J., Kuczyńska B., Sell-Kubiak E., Stanisz M., Skrzypczak E. 2023. Unveiling the attributes of rabbit milk. *Animal, 17: 100848. https://doi.org/10.1016/j.animal.2023.100848*

Maertens L. 1998. Fats in rabbit nutrition: A review. *World Rabbit Sci., 6: 341-348. https://doi.org/10.4995/wrs.1998.366*

Maertens L., Aerts J.M., De Brabander D.L. 2005. Effet d´un aliment riche en acides gras omega-3 sur les performances et la composition du lait des lapines et la viabilité de leur descendance. *In Proc.: 11 èmes Journées de la Recherche Cunicole, 29 to 30 November 2005, Paris, France, 205-208.*

Maertens L., Lebas F., Szendrő, Zs. 2006. Rabbit milk: A review of quantity, quality and non-dietary affecting factors. *World Rabbit Sci., 14: 205-230. https://doi.org/10.4995/wrs.2006.565*

Makovický, P, Volek, Z, Uhlířová, L, Makovický P. 2018. The influences of dried Chicory root and White lupine added to food on jejunal morphology: experimental study. *Gastroenterol. Hepatol. Bed Bench., 11: 233-238. https://doi.org/10.22037/ghfbb.v0i0.1248*

Marada P., Cukor J., Kuběnka M., Linda R., Vacek Z., Vacek S. 2023. New agri-environmental measures have a direct effect on wildlife and economy on conventional agricultural land. *PeerJ., 11. https://doi.org/10.7717/peerj.15000*

Marín-García P.J., Llobat L., Aguayo-Adán J.A., Franch J., Cambra-López M., Blas E., Pascual J.J., Rouco C. 2023. Nutritional ecology of European rabbit (*Oryctolagus cuniculus*): Factors affecting chemical composition of gastric content. *J. Anim. Physiol. Anim. Nutrit., 107: 1495-1501. https://doi.org/10.1111/jpn.13849*

Markovic R., Baltic M.Z., Radulovic S., Peric D., Jovanovic D., Starcevic M., Sefer D. 2021. From designing diets for animals to designing food of animal origin – overview. *IOP Conference Series: Earth and Environmental Science, 854. https://doi.org/10.1088/1755-1315/854/1/012056*

Marounek M., Dušková D., Skřivanová V. 2003. Hydrolysis of phytic acid and its availability in rabbits. *British Journal of Nutrition, 89: 287-294. https://doi.org/10.1079/BJN2002785*

Marounek M., Břeňová N., Suchorská O., Mrázek J. 2009. Phytase activity in rabbit cecal bacteria. *Folia Microbiologica, 54: 111-114. https://doi.org/10.1007/s12223-009-0016-7*

Marounek M., Bubancová I., Podsedníček M., Lukešová D., Ramadan M. 2011. Activity of phytate dephosphorylation in cereals, legumes and oilseeds determined by colourimetric and isotachophoretic method. *J. Anim. Feed Sci., 20: 472-479. https://doi.org/10.22358/jafs/66201/2011*

Martignone B., Gustavo K.B., Dimitrios P. 2022. Price Transmission Analysis of the International Soybean Market in a Trade War Context. *Economies, 10: 203. https://doi.org/10.3390/economies10080203*

Martínez-Paredes E., Nicodemus N., Pascual J.J., García J. 2022. Challenges in rabbit doe feeding, including the young doe. *World Rabbit Sci., 30: 13-34. https://doi.org/10.4995/wrs.2022.15562*

Martínez-Villaluenga C., Frías J., Vidal-Valverde C. 2006. Functional lupin seeds (*Lupinus albus L.* and *Lupinus luteus L.*) after extraction of α-galactosides. *Food Chemistry, 98: 291-299. https://doi.org/10.1016/j.foodchem.2005.05.074*

Martínez-Villaluenga C., Frías J., Vidal-Valverde C., Gómez R. 2005. Raffinose Family of Oligosaccharides from Lupin Seeds as Prebiotics: Application in Dairy Products. *J. Food Protect., 68: 1246-1252. https://doi.org/10.4315/0362-028X-68.6.1246*

Martínez-Villaluenga C., Gómez R. 2007. Characterization of bifidobacteria as starters in fermented milk containing raffinose family of oligosaccharides from lupin as prebiotic. *Int. Dairy J., 17: 116-122. https://doi.org/10.1016/j.idairyj.2006.02.003*

Mateos G.G., García-Rebollar P., de Blas C. 2020. Minerals, vitamins and additives*. In: C. de Blas J. Wiseman (Eds.), Nutrition of the rabbit (3rd ed.). CAB International, 126-158. https://doi.org/10.1079/9781789241273.0126*

Méda B., Fortun-Lamothe L., Hassouna M. 2014. Prediction of nutrient flows with potential impacts on the environment in a rabbit farm: a modelling approach. *Anim. Prod. Sci., 54: 2042-2051. https://doi.org/10.1071/AN14530*

Messéan A., Viguier L., Paresys L., Aubertot J.N., Canali S., Iannetta P., Justes E., Karley A., Keillor B., Kemper L., Muel F., Pancino B., Stilmant D., Watson C., Willer H., Zornoza R. 2021. Enabling crop diversification to support transition toward more sustainable European agrifood systems. *Front. Agric. Sci. Engin. https://doi.org/10.15302/J-FASE-2021406*

Metzger, Sz., Odermatt M., Szendrő, Zs., Mohaupt M., Romvári R., Makai A., Biró-Németh E. 2006. A study of the carcass traits of different rabbit genotypes. *World Rabbit Sci., 14: 107-114. https://doi.org/*10.4995/wrs.2006.550

Mierlita D., Simeanu D., Pop I.M., Criste F., Pop C., Simeanu C., Lup F. 2018. Chemical composition and nutritional evaluation of the lupine seeds (*Lupinus albus L.*) from low-alkaloid varieties. *Revista de Chimie, 69: 453-458. https://doi.org/10.37358/RC.18.2.6126*

Mohamed A.A., Rayas-Duarte P. 1995. Nonstarchy polysaccharide analysis of cotyledon and hull of *Lupinus albus*. *Cereal Chem., 72: 648-651.*

Monteiro P.R.M., Costa B.P.A., Campos F.S., Silva R.M., da Silva O.C., Martino S.D.H., Silvestre P.C.M. 2014. Evaluation of the chemical composition, protein quality and digestibility of lupin (*Lupinus albus* and *Lupinus angustifolius*). *O Mundo da Saúde, 38: 251-259. https://doi.org/10.15343/0104-7809.20143803251259*

Muscio A., Sisto R. 2020. Are agri-food systems really switching to a circular economy model? Implications for European research and innovation policy. *Sustainability, 12: 5554. https://doi.org/10.3390/su12145554*

Musco N., Cutrignelli M.I., Calabrò S., Tudisco R., Infascelli F., Grazioli R., Lo Presti V., Gresta F., Chiofalo B. 2017. Comparison of nutritional and antinutritional traits among different species (*Lupinus albus L.*, *Lupinus luteus* L., *Lupinus angustifolius L.*) and varieties of lupin seeds. *J. Anim. Physiol. Anim. Nutr., 101: 1227-1241. https://doi.org/10.1111/jpn.12643*

Nalle C.L., Ravindran G., Ravindran V. 2010. Influence of dehulling on the apparent metabolisable energy and ileal amino acid digestibility of grain legumes for broilers. *J. Sci. Food Agric., 90: 1227-1231. https://doi.org/10.1002/jsfa.3953*

Panasiewicz K. 2022. Chemical Composition of Lupin (*Lupinus* spp.) as influenced by variety and tillage system. *Agriculture, 12: 263. https://doi.org/10.3390/agriculture12020263*

Rauw W.M., Gómez I.E., Torres O., García G.M., de Miguel B.E., Rey B.J.M., Gomez-Raya L. 2023a. Future farming: protein production for livestock feed in the EU. *Sustain. Earth Rev., 6. https://doi.org/10.1186/s42055-023-00052-9*

Rauw W.M., Gomez-Raya L., Star L., Øverland M., Delezie E., Grivins M., Hamann K.T., Pietropaoli M., Klaassen M.T., Klemetsdal G., Gil M.G., Torres O., Dvergedal H., Formato G. 2023b. Sustainable development in circular agriculture: An illustrative bee↺legume↺poultry example. *Sustain. Dev., 31: 639-648. https://doi.org/10.1002/sd.2435*

Rebolledo-Leiva R., Almeida-García F., Pereira-Lorenzo S., Ruíz-Nogueira B., Moreira M.T., González-García S. 2022. Determining the environmental and economic implications of lupin cultivation in wheat-based organic rotation systems in Galicia, Spain. *Sci. Total Environ., 845. https://doi.org/10.1016/j.scitotenv.2022.157342*

Reckling M., Albertsson J., Vermue A., Carlsson G., Watson C.A., Justes E., Bergkvist G., Jensen E.S., Topp C.F.E. 2022. Diversification improves the performance of cereals in European cropping systems. *Agron. Sustain. Dev., 42: 118. https://doi.org/10.1007/s13593-022-00850-z*

Regulation (EU) 2023/1115. 2023. Regulation of the European Parliament and of the Council (EU) 2023/1115. On the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010. 2023. *Official journal of the European Union.2023: 206-242. http://data.europa.eu/eli/reg/2023/1115/oj*

Reis T.N.P. dos, Ribeiro V., Garrett R.D., Kuemmerle T., Rufin P., Guidotti V., Amaral P.C., Meyfroidt P. 2023. Explaining the stickiness of supply chain relations in the Brazilian soybean trade. *Global Environ. Change, 78. https://doi.org/10.1016/j.gloenvcha.2022.102633*

Rezende V.T., Ali S., Bonaudo T., Gameiro A.H. 2023. Brazilian soybeans as feed for livestock in Europe: an insight into the nitrogen flows. *Reg. Environ. Change, 23: 33. https://doi.org/10.1007/s10113-023-02034-1*

Riccardi G., Vitale M., Vaccaro O. 2020. Are Europeans moving towards dietary habits more suitable for reducing cardiovascular disease risk? *Nutrition, Metabolism and Cardiovascular Diseases, 30: 1857-1860. https://doi.org/10.1016/j.numecd.2020.07.018*

Sandström V., Chrysafi A., Lamminen M., Troell M., Jalava M., Piipponen J., Siebert S., van Hal O., Virkki V., Kummu M. 2022. Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. *Nature Food, 3: 729-740. https://doi.org/10.1038/s43016-022-00589-6*

Sioen I., van Lieshout L., Eilander A., Fleith M., Lohner S., Szommer A., Petisca C., Eussen S., Forsyth S., Calder P.C., Campoy C., Mensink R.P. 2017. Systematic review on N-3 and N-6 polyunsaturated fatty acid intake in European countries in light of the current recommendations - focus on specific population groups. *Ann. Nutr. Metabol., 70: 39-50. https://doi.org/10.1159/000456723*

Soisontes S., Freund F., Laquai V. 2023. The future of protein feed: a case study of sustainable substitutes in the German livestock industry. *Environm. Dev. Sustain., 28. https://doi.org/10.1007/s10668-023-03676-1*

Spina A., Saletti R., Fabroni S., Natalello A., Cunsolo V., Scarangella M., Rapisarda P., Canale M., Muccilli V. 2022. Multielemental, nutritional, and proteomic characterization of different *Lupinus* spp. genotypes: A source of nutrients for dietary use. *Molecules, 27: 8771. https://doi.org/10.3390/molecules27248771*

Stagnari F., Maggio A., Galieni A., Pisante M. 2017. Multiple benefits of legumes for agriculture sustainability: an overview. *Chem. Biol. Technol. Agric., 4. https://doi.org/10.1186/s40538-016-0085-1*

Straková E., Suchý P., Večerek V., Šerman V., Mas N., Jůzl M. 2006. Nutritional composition of seeds of the genus *Lupinus*. *Acta Vet. Brno, 75: 489-493. https://doi.org/10.2754/avb200675040489*

Struți D.I., Mierlita D., Bunea A. 2023. Improving the use of white lupine in the laying quail feeding by enzymes addition: effects on productive performances, digestion, blood biochemical indices and eggs quality. *Agriculture, 13: 575. https://doi.org/10.3390/agriculture13030575*

Taboada E., Mendez J., Mateos G.G., De Blas J.C. 1994. The response of highly productive rabbits to dietary lysine content. *Livest. Prod. Sci., 40: 329-337. https://doi.org/10.1016/0301-6226(94)90099-X*

Tarabova L., Makova Z., Piesova E., Szaboova R., Faixova Z. 2016. Intestinal mucus layer and mucins (a review). *Folia Vet., 60: 21-25. https://doi.org/10.1515/fv-2016-0003*

Timová I., Straková E., Všetičková L., Suchý P. 2020. Impact of feeding mixture containing lupin meal on improvement of polyunsaturated fatty acids in egg yolk. *Czech J. Anim. Sci., 65: 311-321. https://doi.org/*10.17221/87/2020-CJAS

Tirdiľová I., Vollmannová A., Čéryová S., Obtulovič P., Árvay J., Zetochová E. 2022. Impact of 3-year period as a factor on the content of biologically valuable substances in seeds of white lupin. *Plants, 11: 2087. https://doi.org/10.3390/plants11162087*

Tůmová E., Bízková Z., Skřivanová V., Chodová D., Martinec M., Volek Z. 2014. Comparisons of carcass and meat quality among rabbit breeds of different sizes, and hybrid rabbits. *Livest. Sci., 165: 8-14. https://doi.org/10.1016/j.livsci.2014.04.019*

Uhlířová L., Volek Z. 2019. Effect of dehulled white lupine seeds on the milk production and milk composition in rabbit does and the growth performance of their litters before weaning. *J. Anim. Feed Sci., 28: 291-297. https://doi.org/10.22358/jafs/110371/2019*

Uhlířová L., Volek Z., Marounek M., Tůmová E. 2015a. Effect of feed restriction and different crude protein sources on the performance, health status and carcass traits of growing rabbits. *World Rabbit Sci., 23: 263-272. https://doi.org/10.4995/wrs.2015.3229*

Uhlířová L., Volek Z., Marounek M., Skřivanová V. 2015b. Replacement of soybean meal with white lupin in the nutrition of rabbit does: effect on milk yield, milk composition and growth performance of their litters over two lactation periods. *In Proc.: 14th International Lupin Conference, 21-26 June 2015, Milan, Italy, p. 128.*

Uhlířová L., Volek Z., Marounek M., Skřivanová E. 2016. The effect of a diet based on whole lupin seed (*Lupinus albus cv.* Amiga) on sanitary risk index and the growth of growing-fattening rabbits. *In Proc.: 11th World Rabbit Congress - June 15-18, 2016 - Qingdao - China, 459-462.*

Uhlířová L., Volek Z., Marounek M. 2018. White lupin bran and its effects on the growth performance, carcass characteristics and digestibility of nutrients in fattening rabbits. *World Rabbit Sci., 26: 1-6. https://doi.org/*10.4995/wrs.2018.8781

UNDESA. 2022. United Nations Department of Economic and Social Affairs, Population Division. World population prospects 2022: *Summary of Results. UN DESA/POP/2022/TR/NO. 3. p. 54.*

Uzun T., Agma Okur A. 2023. Impacts of different processes on the nutritional and antinutritional contents of white and blue lupin seeds and usage possibilities for sustainable poultry production. *Animals, 13: 3496. https://doi.org/10.3390/ani13223496*

Valente I.M., Sousa C., Almeida M., Miranda C., Pinheiro V., Garcia-Santos S., Ferreira L.M.M., Guedes C.M., Maia M.R.G., Cabrita A.R.J., Fonseca A.J.M., Trindade H. 2023. Insights from the yield, protein production, and detailed alkaloid composition of white (*Lupinus albus*), narrow-leafed (*Lupinus angustifolius*), and yellow (*Lupinus luteus*) lupin cultivars in the Mediterranean region. *Front. Plant Sci., 14. https://doi.org/10.3389/fpls.2023.1231777*

van Zanten H.H.E., Simon W., van Selm B., Wacker J., Maindl T.I., Frehner A., Hijbeek R., van Ittersum M.K., Herrero M. 2023. Circularity in Europe strengthens the sustainability of the global food system. *Nat. Food, 4: 320-330. https://doi.org/10.1038/s43016-023-00734-9*

Velthof G.L., Hou Y., Oenema O. 2015. Nitrogen excretion factors of livestock in the European Union: a review. *J. Sci. Food Agric., 95: 3004-3014. https://doi.org/10.1002/jsfa.7248*

Volek Z., Marounek M. 2009. Whole white lupin (*Lupinus albus* cv. Amiga) seeds as a source of protein for growing-fattening rabbits. *Anim. Feed Sci. Technol., 152: 322-329. https://doi.org/10.1016/j.anifeedsci.2009.05.003*

Volek Z., Marounek M. 2011. Effect of feeding growing–fattening rabbits a diet supplemented with whole white lupin (*Lupinus albus* cv. Amiga) seeds on fatty acid composition and indexes related to human health in hind leg meat and perirenal fat. *Meat Sci., 87: 40-45. https://doi.org/10.1016/j.meatsci.2010.08.015*

Volek Z., Volková L., Marounek M. 2013. Effect of a diet containing white lupin hulls (*Lupinus albus* cv. Amiga) on total tract apparent digestibility of nutrients and growth performance of rabbits. *World Rabbit Sci., 21: 17-21. https://doi.org/10.4995/wrs.2013.1191*

Volek Z., Marounek M., Volková L., Kudrnová E. 2014. Effect of diets containing whole white lupin seeds on rabbit doe milk yield and milk fatty acid composition as well as the growth and health of their litters1. *J. Anim. Sci., 92: 2041-2049. https://doi.org/10.2527/jas.2013-7120*

Volek Z., Ebeid T.A., Uhlířová L. 2018a. The impact of substituting soybean meal and sunflower meal with a mixture of white lupine seeds and rapeseed meal on rabbit doe milk yield and composition, and the growth performance and carcass traits of their litters. *Anim. Feed Sci. Technol., 236: 187-195. https://doi.org/10.1016/j.anifeedsci.2017.12.011*

Volek Z., Bureš D., Uhlířová L. 2018b. Effect of dietary dehulled white lupine seed supplementation on the growth, carcass traits and chemical, physical and sensory meat quality parameters of growing-fattening rabbits. *Meat Sci., 141: 50-56. https://doi.org/10.1016/j.meatsci.2018.03.013*

Volek Z., Uhlířová L., Zita L. 2020. Narrow-leaved lupine seeds as a dietary protein source for fattening rabbits: a comparison with white lupine seeds. Animal, 14: 881-888. *https://doi.org/*10.1017/S1751731119002350

Wang S., Errington S., Yap H.H. 2008. Studies on carotenoids from lupine seeds. *In: J.A. Palta J.B. Berger (eds). 'Lupins for Health and Wealth' Proceedings of the 12th International Lupin Conference, 14-18 Sept. 2008, Fremantle, Western Australia. International Lupin Association, Canterbury, New Zealand.*

Wellington M.O., Hamonic K., Krone J.E.C., Htoo J.K., Van Kessel A.G., Columbus D.A. 2020. Effect of dietary fiber and threonine content on intestinal barrier function in pigs challenged with either systemic *E. coli* lipopolysaccharide or enteric *Salmonella* Typhimurium. *J. Anim. Sci. Biotechnol., 11: 38. https://doi.org/10.1186/s40104-020-00444-3*

White C.E., Campbell D.R., McDowell L.R. 2000. Effects of dry matter content on trypsin inhibitors and urease activity in heat treated soya beans fed to weaned piglets. *Anim. Feed Scie. Technol., 87: 105-115. https://doi.org/10.1016/S0377-8401(00)00168-1*

Wu L. 2022. Rabbit meat trade of major countries: regional pattern and driving forces. *World Rabbit Sci., 30: 69-82. https://doi.org/10.4995/wrs.2022.13390*

Xiccato G. 1999. Feeding and meat quality in rabbits: A review. *World Rabbit Sci., 7: 75-86. https://doi.org/10.4995/wrs.1999.383*

Xiccato G. 2020. Fat digestion. *In: C. de Blas J. Wiseman (Eds.), Nutrition of the rabbit (3rd ed.). CAB International, 58-68. https://doi.org/10.1079/9781789241273.0058*

Xiccato G., Schiavon S., Gallo L., Bailoni L., Bittante G. 2005. Nitrogen excretion in dairy cow, beef and veal cattle, pig, and rabbit farms in Northern Italy. *It. J. Anim. Sci., 4: 103-111. https://doi.org/10.4081/ijas.2005.3s.103*

Zaworska-Zakrzewska A., Kasprowicz-Potocka M., Twarużek M., Kosicki R., Grajewski J., Wiśniewska Z., Rutkowski A. 2020. A comparison of the composition and contamination of soybean cultivated in Europe and limitation of raw soy seed content in weaned pigs' diets. *Animals, 10: 1972. https://doi.org/10.3390/ani10111972*

Zhong L., Ali H., Fang Z., Wahlqvist M.L., Hodgson J.M., Johnson S.K. 2020. Lupin seed coat as a promising food ingredient: physicochemical, nutritional, antioxidant properties, and effect of genotype and environment. *International Journal of Food Science & Technology, 55: 1816-1824. https://doi.org/*10.1111/ijfs.14460

Zita L., Fučíková A., Marounek M., Tůmová E. Skřivanová V. 2008. Lipase activity till 35 days of age in broiler rabbits. In: Xiccato G., Trocino A., Lukefahr S.D. *In Proc.: 9th World Rabbit Congress, 10-13 June 2008, Verona, Italy, 869-872.*

Zralý Z., Písaříková B., Trčková M., Herzig I., Juzl M., Simeonovová J. 2007. The effect of white lupine on the performance, health, carcass characteristics and meat quality of market pigs. *Veterinární Medicína, 52: 29-41. https://doi.org/10.17221/2008-VETMED*

Zwoliński C., Gugołek A., Strychalski J., Kowalska D., Chwastowska-Siwiecka I., Konstantynowicz M. 2017. The effect of substitution of soybean meal with a mixture of rapeseed meal, white lupin grain, and pea grain on performance indicators, nutrient digestibility, and nitrogen retention in Popielno White rabbits. *J. Appl. Anim. Res., 45: 570-576. https://doi.org/10.1080/09712119.2016.1233107*