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SOYBEAN MEAL ALTERNATIVES IN RABBIT DIETS – A REVIEW OF CENTRAL EUROPEAN RESEARCH

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Abstract

Soybean meal (SBM) is a by-product of soybean processing, and it is widely used as a component of diets for various livestock species, including rabbits. However, at the beginning of the 21st century, researchers began to search for alternative high-protein feeds that could replace SBM in rabbit diets. The aim of the present study was to review, in chronological order, the literature on alternative feed ingredients as substitutes for SBM in rabbit diets in Central Europe in the 21st century. The authors reviewed studies investigating the replacement of SBM in rabbit diets with plant-based protein sources such as maize and wheat distillers' dried grains with solubles (DDGS), rapeseed meal, rapeseed cake, white lupine seeds, peas and silkworm pupae and mealworm larvae meals.

The analysis revealed that SBM in rabbit diets can be completely or partially replaced with other high-protein plant ingredients and insect meals without compromising the performance of animals.

The soybean (*Glycine max*) is an annual plant of the family Fabaceae. Its most productive part is the seed pod containing up to four seeds. The soybean was first domesticated in China in the 11th century BCE, and this crop was introduced to both Americas and Europe only in the 18th century CE. At present, the soybean is one of the leading crops in the global economy, and the interest in this plant species continues to increase (Anderson et al. 2019). The world's leading producers and exporters of soybeans are the United States, Brazil, Argentina, India, China,

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Canada, and Paraguay (Lagos and Stein 2017, Ibáñez et al. 2020). Soybean production is still low in Europe, mainly due to unfavorable climatic conditions, but its cultivation has increased in recent years. Genetically modified (GM) soybeans were introduced to the global market in the 1990s. The distinguishing feature of GM soybeans was their resistance to the Roundup herbicide. New GM soybean varieties that are resistant to other plant protection products and pests were developed in the following years. At present, more than 80% of soybeans cultivated worldwide are GM plants, and GM soybeans occupied 50% of the global area under modified crops in 2018 (Sieradzki et al. 2021). In the European Union, genetic modification of crops for food and feed production continues to stir considerable controversy. However, conventional (non-GM) soybeans are more expensive to produce, and they are cultivated mainly in the more affluent European countries and in Japan (Guilpart et al. 2022).

The global popularity of soybeans can be attributed to their high protein content. On average, soybeans contain 35–38% of protein with a highly favorable amino acid profile for feed production (Karr-Lilienthal et al. 2004). This crop is also cultivated for the production of food, and it can be used as a replacement for animal protein sources in vegetarian and vegan diets. Soybeans contain approximately 18% of fat rich in essential unsaturated fatty acids such as linoleic, oleic and linolenic acids. Soybean oil is used in the food processing industry and in the production of lubricants and biofuels. Soybean oil is also incorporated into animal diets to enhance their energy value and fatty acid content (Güzeler and Yildirim 2016, Anderson et al. 2019).

The by-products of soybean oil extraction are used in animal nutrition, including in rabbit diets. These include soybean meal (SBM), soybean hulls, and soy protein concentrates. Soybean meal is the most popular by-product of soybean oil processing. It is a rich source of protein and exogenous amino acids for fast-growing farm animals during intensive fattening and for high-yielding livestock. The protein content of SBM ranges from 42% to 50%, and it is usually determined at 45.0–49.5%, depending on the soybean cultivation method, variety, and geographic origin. For example, SBM produced in the US sometimes contains more crude protein, fewer oligosaccharides, and is characterized by lower trypsin inhibitor activity than SBM produced in Argentina or Brazil, which results in higher apparent ileal digestibility of nitrogen and higher energy value. It should also be noted that thermal processing reduces the content of anti-nutritional factors in soybeans (Karr-Lilienthal et al. 2004, De Coca-Sinova et al. 2008, Ravindran et al. 2014, Lagos and Stein 2017, Ibáñez et al. 2020).

The chemical composition and energy value of SBM fed to rabbits in experiments conducted in Central Europe are shown in Table 1. In all tables, the results are presented on a dry-matter (DM) or a fresh-matter (FM) basis, and energy value is expressed as gross energy (GE) or digestible energy (DE), as in the cited studies. All abbreviations are spelled out under the tables. The protein content of SBM ranged from 36.82% (STRYCHALSKI et al. 2020) to 47.10% (VOLEK et al. 2018b) on a FM basis, and from 50.26% (KOWALSKA et al. 2020b, KOWALSKA et al. 2021, STRYCHALSKI et al. 2021) to 53.20% (ZWOLIŃSKI et al. 2017) on a DM basis.

Table 1

Chemical composition and energy value of soybean meal (according to the authors cited in the study

DM	CP	EE	CF	NFE	NDF	ADF	ADL	GE	Authors
[%]								[MJ/kg]	
86.80	43.80	2.30	–	–	10.80	6.70	2.50	–	VOLEK and MAROUNEK (2009)** VOLEK et al. (2014)**
88.24	45.93	2.46	–	–	16.97	7.41	–	18.11	STRYCHALSKI et al. (2014)**
88.20	53.20	2.30	4.20	–	19.20	8.40	–	17.10	GUGOŁEK et al. (2015)*
90.11	50.15	2.05	–	35.70	15.67	6.92	5.56	19.45	GUGOŁEK et al. (2017)*
89.66	50.40	20.64	–	–	15.41	7.56	4.23	14.53	ZWOLIŃSKI et al. (2017)*
87.30	47.10	1.90	–	–	9.90	5.80	1.40	–	VOLEK et al. (2018b)**
90.10	45.20	1.80	4.60	32.20	–	–	–	12.50[3)]	GUGOŁEK et al. (2018)**
88.68	46.56	1.98	4.44	34.12	10.63	6.25	1.15	17.36	GUGOŁEK et al. (2019)** GUGOŁEK et al. (2021)**
90.11	45.19	1.85	–	–	14.12	6.24	5.01	17.53	KOWALSKA et al. (2020a)**
89.92	36.82	2.17	–	–	16.57	7.36	5.08	17.13	STRYCHALSKI et al. (2020)**
89.10	46.50	2.40	–	–	11.70	7.00	–	–	VOLEK et al. (2021)**
89.35	50.26	2.15	–	–	15.02	7.84	3.96	16.38	KOWALSKA et al. (2020b)* KOWALSKA et al. (2021)* STRYCHALSKI et al. (2021)*
–	46.50	–	–	–	–	–	–	–	NOWAKOWICZ-DĘBEK et al. (2021)** WLAZŁO et al. (2021)**

* – in DM; ** – in FM; *** – digestible energy

DM – dry matter; CP – crude protein; EE – ether extract; CF – crude fiber; NFE – N-free extract; NDF – neutral detergent fiber; ADF – acid detergent fiber; ADL – acid detergent lignin; GE – gross energy; FM – fresh matter

Soybean meal is a popular protein source in complete pellets for rabbits. Most studies addressing this issue were conducted in the 1990s (Nasr et al. 1996, Prasad and Karim 1998). Previously, peanut meal and animal meals had been included in livestock diets to increase protein content (Gugołek and Kowalska 2022).

In addition to SBM from defatted flakes, soy protein concentrates are also fed to farm animals, including rabbits. Soy protein concentrates contain up to 90% of crude protein, and they are frequently added to diets for pregnant and lactating does (García et al. 1999, Gutiérrez et al. 2003, Chamorro et al. 2007).

Soybean hulls are yet another by-product of soybean oil extraction. Soybean hulls contain approximately 12–13% of crude protein and 2–3% of crude fat. They also contain around 36% of crude fiber, and can be used as a crude fiber source in rabbit diets (García et al. 1999, Nicodemus et al. 2007).

The by-products of the extraction of oil from soybean seeds, in particular SBM, are widely used as components of diets for broiler rabbits. However, at the beginning of the 21st century, researchers and breeders began to search for alternative high-protein feeds that could replace SBM in rabbit diets. This is because the production of SBM is expensive outside countries that are the world's leading soybean suppliers, including in Central Europe. Genetically modified (GM) soybeans also raise numerous concerns. Moreover, some countries have announced their plans to ban soybean cultivation for the production of feedstuffs (Christiansen et al. 2019, Jiang 2020, Scheitrum et al. 2020).

Numerous studies have been conducted in Central Europe, i.e. in Poland and Czechia, to test other vegetable protein sources as potential SBM substitutes in rabbit diets, such as oilseed meals (Strychalski et al. 2014, Gugołek et al. 2015, Gugołek et al. 2017, Zwoliński et al. 2017, Volek et al. 2018b, Nowakowicz-Dębek et al. 2021, Wlazło et al. 2021), DDGS (Chełmińska and Kowalska 2013, Strychalski et al. 2014, Gugołek et al. 2015), legume seeds (Volek and Marounek 2009, Volek et al. 2014, Gugołek et al. 2017, Zwoliński et al. 2017, Volek et al. 2018a, Volek et al. 2018b, Uhlířová and Volek 2019, Strychalski et al. 2020), and insect meals (Gugołek et al. 2019, Kowalska et al. 2020b, Kowalska et al. 2021, Gugołek et al. 2021, Strychalski et al. 2021, Volek et al. 2021). The chemical composition and energy value of feed components used as SBM alternatives in rabbit diets, described in the above studies, are presented in Table 2.

Table 2

Chemical composition and energy value of feed components used as substitutes for soybean meal

Feed	DM	CP	EE	CF	NFE	NDF	ADF	ADL	GE	Authors
	[%]								[MJ/kg]	
Maize DDGS	88.88	23.59	12.63	5.45	–	–	–	–	–	CHEŁMIŃSKA and KOWALSKA (2013)**
Wheat DDGS	93.53	29.13	7.36	–	–	39.98	3.42	–	20.46	STRYCHALSKI et al. (2014)**
	93.50	39.30	7.80	8.50	–	42.80	3.60	–	18.50	GUGOŁEK et al. (2015)*
DWLS	88.70	43.00	11.50	–	–	12.70	10.80	3.80	–	VOLEK et al. (2018a)**
FRM	87.87	36.15	1.63	14.16	–	–	–	–	–	NOWAKOWICZ-DĘBEK et al. (2021)** WLAZŁO et al. (2021)**
MLM	94.30	51.34	27.95	–	–	11.42	7.59	1.26	22.50	KOWALSKA et al. (2020b)* KOWALSKA et al. (2021)* STRYCHALSKI et al. (2021*
	59.40	40.00	15.00	–	–	11.50	8.30	–	–	VOLEK et al. (2021)**
PS	88.14	25.25	0.96	–	63.51	12.77	7.9	5.34	18.83	GUGOŁEK et al. (2017)*
	88.85	24.29	1.29	–	–	11.71	7.35	4.12	12.09	ZWOLIŃSKI et al. (2017)*
	88.10	22.30	0.90	5.70	55.80	–	–		12.30[3)]	GUGOŁEK et al. (2018)**
	88.14	22.26	0.85	–	–	6.96	11.26	4.71	16.60	KOWALSKA et al. (2020a)**
	88.85	29.61	1.26	–	–	14.63	7.72	4.60	16.48	STRYCHALSKI et al. (2020)**
RPM	91.02	37.98	3.99	–	33.35	26.29	14.62	6.42	17.48	GUGOŁEK et al. (2017)*
	90.11	36.46	4.20	–	–	24.07	14.25	4.98	11.79	ZWOLIŃSKI et al. (2017)*
	91.00	34.60	3.60	15.20	30.40	–	–	–	9.90[3)]	GUGOŁEK et al. (2018)**
	87.80	34.50	–	–	–	28.30	20.10	8.50	–	VOLEK et al. (2018b)**
	91.02	34.57	3.63	–	–	23.93	13.31	5.84	15.91	KOWALSKA et al. (2020a)**
RSC	90.28	31.58	10.84	–	–	22.19	12.61	–	20.25	STRYCHALSKI et al. (2014)**
	90.20	35.50	12.00	13.40	–	24.60	14.00	–	18.90	GUGOŁEK et al. (2015)*
SFM	88.70	27.50	2.80	–	–	38.60	28.00	9.50	–	VOLEK and MAROUNEK (2009)** VOLEK et al. (2014)**
	88.50	27.30				39.90	28.70	9.80	–	VOLEK et al. (2018b)**
SPM	93.19	51.58	26.49	3.73	7.46	31.35	9.34	2.95	24.69	GUGOŁEK et al. (2019)** GUGOŁEK et al. (2021)**
	94.40	51.75	24.19	–	–	6.49	5.49	2.46	23.94	KOWALSKA et al. (2020b)* KOWALSKA et al. (2021)* STRYCHALSKI et al. (2021)*
WLS	88.30	29.70	11.40	–	–	33.00	23.00	5.90	–	VOLEK and MAROUNEK (2009)** VOLEK et al. (2014)**
	88.79	46.28	2.27		31.64	31.41	22.12	5.99	18.77	GUGOŁEK et al. (2017)**
	90.34	43.37	4.45	–	–	29.32	21.68	5.09	12.34	ZWOLIŃSKI et al. (2017)**
	88.80	41.10	5.00	13.50	25.10	–	–	–	10.30[3)]	GUGOŁEK et al. (2018)**
	89.00	34.90	–	–	–	22.70	17.00	6.50	–	VOLEK et al. (2018b)**
	88.79	41.09	2.02	–	–	27.89	19.64	5.32	16.67	KOWALSKA et al. (2020a)**
	90.13	29.61	2.64	–	–	28.85	16.93	5.52	16.65	STRYCHALSKI et al. (2020)**

* – in DM; ** – in FM; *** – digestible energy

DM – dry matter; CP – crude protein; EE – ether extract; CF – crude fiber; NFE – N–free extract; NDF – neutral detergent fiber; ADF – acid detergent fiber; ADL – acid detergent lignin; GE – gross energy; FM – fresh matter; DDGS – distillers' dried grains with solubles; DWLS – dehulled white lupine seeds; FRSM – fermented rapeseed meal; MLM – mealworm larvae meal; PS – pea seeds; RPM – rapeseed meal; RSC – rapeseed cake; SBM – soybean meal; SFM – sunflower meal; SPM – silkworm pupae meal; WLS – white lupine seeds

The aim of the present study was to review, in chronological order, the literature on alternative feed ingredients as substitutes for SBM in rabbit diets in Central Europe (Poland, Czech Republic) in the 21st century. Studies investigating SBM substitution in rabbit diets and substitution levels are listed in Table 3. The main findings and conclusions from these studies are discussed chronologically in subsequent sections.

Table 3

Studies investigating soybean meal substitution in rabbit diets and substitution levels

SBM in diet [%]	SBM substitution with other feed components [%]	Authors
10.0	1) WLS 15.0 2) SFM 17.0	Volek and Marounek (2009)
12.0	1) SBM 7.0+maize DDGS 5.0 2) SBM 2.0+maize DDGS 10.0	Chełmińska and Kowalska (2013)
1) SBM 13.0+SFM 5.0 2) 7.0	1) WLS 25.0 2) WLS 12.0	Volek et al. (2014)
5.0	1) wheat DDGS 5.0 2) RSC 5.0 3) wheat DDGS 2.5+RSC 2.5	Strychalski et al. (2014) Gugołek et al. (2015)
15.0	1) SBM 7.5+RSC 5.0+WLS 4.0+PS 3.0 2) RSC 10.0+WLS 8.0+PS 6.0	Gugołek et al. (2017) Zwoliński et al. (2017) Gugołek et al. (2018)
7.0	1) DWLS 7.0	Volek et al. (2018a)
1) SBM 13.0+SFM 5.0 2) 7.0	1) RPM 10.0+WLS 14.0 2) RPM 6.0+WLS 4.0	Volek et al. (2018b)
1) SBM13.0+SFM 5.0 2) 7.0	1) DWLS 18.0 2) DWLS 7.0	Uhlířová and Volek (2019)
10.0	1) SBM 5.0+SPM 5.0 2) SPM 10.0	Gugołek et al. (2019)
10.0	1) SBM 5.0+WLS 3.5+PS 1.5 2) WLS 7.0+PS 3.0	Strychalski et al. (2020)
15.0	1) SBM 7.0+RPM 5.0+WLS 4.0+PS 3.0 2) RPM 10.0+WLS 8.0+PS 6.0	Kowalska et al. (2020a)
10.0	1) SBM 5.0+SPM 4.0 2) SBM 5.0+MLM 4.0	Kowalska et al. (2020b) Kowalska et al. (2021) Strychalski et al. (2021)
6.0	1) MLM 3.0	Volek et al. (2021)
10.0	1) SBM 5.0+SPM 5.0 2) SPM 10.0	Gugołek et al. (2021)
10.85	1) SBM 7.85+FRSM 4.0 2) SBM 4.88+FRSM 8.0 3) SBM 1.90+FRSM 12.0	Wlazło et al. (2021) Nowakowicz-Dębek et al. (2021)

SBM – soybean meal; WLS – white lupine seeds; SFM – sunflower meal; DDGS – distillers' dried grains with solubles; RSC – rapeseed cake; PS – pea seeds; DWLS – dehulled white lupine seeds; RPM – rapeseed meal; SPM – silkworm pupae meal; MLM – mealworm larvae meal; FRSM – fermented rapeseed meal

VOLEK and MAROUNEK (2009) were the first Central European researchers to explore SBM replacement in rabbit diets. They analyzed whether white lupine seeds or sunflower meal could be effective dietary protein sources for broiler rabbits. Three diets were prepared: a control diet containing SBM, and two experimental diets where SBM was replaced with white lupine seeds (first experimental diet) and sunflower meal (second experimental diet). No significant differences in body weight gain or the feed conversion ratio (FCR) were found between the groups, but feed intake was higher in the sunflower meal group. Carcass yield was higher in rabbits receiving white lupine seeds, compared with the other two groups. The digestibility of DM and crude protein was not affected by the dietary treatments. However, the digestibility coefficient of neutral detergent fiber was significantly lower, and the digestibility coefficients of acid detergent fiber and energy were lower (non-significant differences) in rabbits fed sunflower meal, relative to the other two diets. Increased cecal concentration of lactic acid was observed in rabbits fed white lupine seeds. The study demonstrated that both white lupine seeds and sunflower meal can effectively replace SBM in diets for growing rabbits raised for meat. The next study by VOLEK and MAROUNEK (2011) did not focus on SBM substitution, but its results are worth mentioning. The authors compared the effects of white lupine seeds (15%) and sunflower meal (12%) added to rabbit diets on the fatty acid composition of hind leg meat and perirenal fat. The diet containing white lupine seeds had a beneficial influence on the fatty acid profile of both hind leg meat and perirenal fat. These tissues had higher concentrations of monounsaturated fatty acids than the tissues of rabbits fed sunflower meal.

CHEŁMIŃSKA and KOWALSKA (2013) determined the effect of two inclusion levels of maize DDGS in rabbit diets. The addition of DDGS at 5% had no negative influence on body weight gain, feed intake or meat quality. However, a diet containing 10% of DDGS was not safe for rabbits due to its high mycotoxin content. Mycotoxin concentrations remained high in this diet, despite the use of detoxifiers, which considerably deteriorated meat quality. The study has shown that maize DDGS fed to rabbits should be analyzed to establish safe mycotoxin levels.

In their experiment, VOLEK et al. (2014) examined the effect of white lupine seeds fed to lactating does on the yield and fatty acid composition of milk, and the growth rate and health status of their offspring. No significant differences in feed intake or litter weight gain were noted between the groups. However, does fed a diet with white lupine seeds were characterized by higher milk yields and a more favorable fatty acid profile of milk. Morbidity and mortality rates due to digestive diseases were lower in the group receiving white lupine seeds, compared with the groups fed SBM and sunflower meal. It was found that white lupine seeds can be a viable alternative to conventional protein sources in diets for lactating does, and that they can improve the fatty acid profile of milk.

STRYCHALSKI et al. (2014) investigated the efficacy of rapeseed cake and wheat DDGS fed to growing Californian rabbits. Four diets were analyzed: a control diet containing 5% SBM, a diet containing 5% rapeseed cake, a diet containing 5% wheat DDGS, and a diet containing 2.5% rapeseed cake and 2.5% wheat DDGS. No significant differences in rabbit performance were found between the groups. Nutrient and energy digestibility was highest in the control group, and lowest in the group fed a diet with 5% wheat DDGS. The relative weight of the small intestine and digesta was highest in the latter group. The coefficients of cecal digesta hydration and bulking as well as pH values were highest, and the cecal concentrations of volatile fatty acids were lowest in rabbits fed a diet with 5% addition of rapeseed cake. Enhanced enzyme activity of colonic microbiota, which increased nutrient digestibility, was noted in rabbits receiving a diet with 2.5% rapeseed cake and 2.5% wheat DDGS, relative to the group fed 5% wheat DDGS. The study demonstrated that SBM can be effectively replaced with 5% rapeseed cake as well as 2.5% rapeseed cake combined with 2.5% wheat DDGS in diets for young rabbits.

In a study by MATUSEVIČIUS et al. (2014), sunflower meal was partially replaced with rapeseed meal in diets for growing rabbits to determine their gastrointestinal tract response and growth performance. The results of this study are interesting because both meals can also be used as SMB substitutes. Desirable changes were noted in the gastrointestinal tract of rabbits fed diets containing 5% and 10% rapeseed meal, including a decrease in pH and ammonia concentration, and an increase in DM digestibility, compared with the control group. However, rapeseed meal had no significant effect on feed intake and utilization or live weight gain. It was found that the addition of rapeseed meal to rabbit diets can minimize the negative effect of sunflower meal on fermentation processes in the gastrointestinal tract, but it does not improve the growth performance of animals.

GUGOŁEK et al. (2015) evaluated the productivity and gastrointestinal tract response of meat-type rabbits fed diets containing rapeseed cake and wheat DDGS. The administered diets were identical to those described by STRYCHALSKI et al. (2014). Productivity was highest in the control group, and lowest in the group receiving a diet with 5% wheat DDGS. Similar tendencies were noted for nutrient digestibility and nitrogen retention. No significant differences in carcass dressing percentage were observed between the groups. Animals fed 5% wheat DDGS were characterized by undesirable gut responses, including excess digesta hydration in the small intestine, increased ammonia concentration in the cecum and colon and enhanced activity of potentially pathogenic bacteria. Such responses were not noted in rabbits fed other diets. A decrease in DM concentration in the small intestine was observed only in the group receiving a diet with the addition of 2.5% rapeseed cake and 2.5% wheat DDGS. The results of this experiment indicate that SBM can be replaced with rapeseed cake in rabbit diets. Since the animals receiving 2.5% rapeseed cake and 2.5% wheat DDGS were characterized by comparable productivity, such a combination is also possible. However, the dietary inclusion of 5% wheat DDGS negatively affected most of performance parameters in growing rabbits.

In their later study, GUGOŁEK et al. (2017) analyzed whether SBM could be replaced with rapeseed meal and legume seeds in rabbit diets. The influence of such a substitution on productivity and gastrointestinal function was evaluated. Three diets were formulated: a control diet containing 15% SBM, experimental diet 1 containing 7.5% SBM, 5% rapeseed meal, 4% white lupine seeds and 3% pea seeds, and experimental diet 2 where SBM was completely replaced with 10% rapeseed meal, 8% white lupine seeds and 6% pea seeds. Productivity was comparable in all groups. Changes were noted in the enzyme activity of large gut microbiota, in particular increased secretion of glycoside hydrolases by bacterial cells, in rabbits fed a diet without SBM, which probably contributed to their high growth performance. The study revealed that SBM can be replaced, partially or completely, with a mixture of rapeseed meal, white lupine seeds and pea seeds.

ZWOLIŃSKI et al. (2017) also evaluated the effect of a mixture of rapeseed meal, white lupine seeds and pea seeds as a substitute for SBM on performance parameters, nutrient digestibility and nitrogen retention in rabbits. They found that animals fed diets containing rapeseed meal, white lupine seeds and pea seeds were characterized by similar productivity as those fed SBM-based diets.

VOLEK et al. (2018a) investigated the effect of dehulled white lupine seeds added to rabbit diets on carcass traits and meat quality. The control group was fed a diet containing SBM. Many quality attributes of raw and cooked meat were higher in rabbits fed a diet with dehulled white lupine seeds.

In their subsequent experiment, VOLEK et al. (2018b) analyzed whether SBM and sunflower meal can be replaced with white lupine seeds and rapeseed meal in diets for female rabbits, and whether such a substitution would affect milk yield and composition as well as the performance of their offspring. Two diets for lactating does and two diets for growing rabbits were formulated. The first lactation diet contained 13% SBM and 5% sunflower meal as the main protein sources; the second lactation contained 10% rapeseed meal and 14% white lupine seeds; the first grower diet contained 7% SBM; the second grower diet contained 6% rapeseed meal and 4% white lupine seeds. Does feeding their young received one of the two lactation diets, and kittens aged 17 to 42 days received one of the two grower diets. No significant differences in milk yield, the body weights of animals or feed intake were found between the dietary treatments. However, diets with white lupine seeds and rapeseed meal contributed to a more favorable fatty acid profile of milk, including higher concentrations of polyunsaturated fatty acids. No negative side effects of feeding the experimental diets were noted, which suggests that rabbits can be successfully fed diets with white lupine seeds and rapeseed meal.

GUGOŁEK et al. (2018) evaluated the physiological response of rabbits to diets containing rapeseed meal, white lupine seeds and pea seeds as SBM substitutes. The diets were identical to those formulated by GUGOŁEK et al. (2017). No significant differences in the growth rate of animals, selected morphological and biochemical blood parameters or carcass traits were noted between experimental and control groups. In addition, white lupine seeds exerted a beneficial influence on gastrointestinal function by improving fermentation processes in the gut. The results of this study clearly indicated that SBM can be successfully replaced with white lupine seeds, pea seeds and rapeseed meal in rabbit diets.

UHLÍŘOVÁ and VOLEK (2019) performed an experiment to determine the effect of dehulled white lupine seeds added to feed on milk production and composition in does, and on the growth performance of their litters before weaning. Two lactation diets were formulated: a control diet containing 13% SBM and 5% sunflower meal and an experimental diet containing 18% dehulled white lupine seeds. No significant differences in milk production were observed between the treatments. An increase in the concentrations of polyunsaturated fatty acids was observed in milk from does receiving dehulled white lupine seeds. Their kittens were also characterized by higher milk intake. It was found that dehulled white lupine seeds can be used as a protein source in diets for lactating does without compromising their milk performance or the growth performance of their offspring. It should also be noted that a study by VOLEK et al. (2020) revealed that narrow-leaved lupine seeds were a less effective dietary protein source for fattening rabbits than white lupine seeds.

GUGOŁEK et al. (2019) analyzed the growth performance of broiler rabbits and the chemical composition of their meat in response to different dietary levels of silkworm pupae meal. The control diet contained 10% SBM, the first experimental diet contained 5% SBM and 5% silkworm pupae meal, and the second experimental diet contained 10% silkworm pupae meal. In both experimental groups, rabbits were characterized by slightly lower final body weights, lower average daily gains, and lower feed intake, as well as lower dressing percentage and carcass weight, relative to the control group. In turn, silkworm pupae meal contributed to improving the FCR. Experimental diets had no significant influence on the chemical composition of rabbit meat, but they affected its fatty acid profile. The cited authors concluded that insect meals can constitute novel protein and fat sources for rabbit raised for meat. Moreover, the use of silkworm pupae meal for feed production can partially solve the problem of environmentally-friendly sericultural waste management.

A study by STRYCHALSKI et al. (2020) aimed to determine the effect of replacing SBM with a mixture of white lupine seeds and pea seeds on growth performance, nutrient digestibility and nitrogen retention in rabbits. The control diet contained 10% SBM, the first experimental diet contained 5% SBM and a mixture of white lupine seeds and pea seeds, whereas in the second experimental diet, SMB was completely replaced with white lupine and pea seeds. Neither partial nor complete substitution of legume seeds for SBM negatively affected the growth performance of rabbits, nutrient digestibility or nitrogen retention.

Similarly to GUGOŁEK et al. (2017), KOWALSKA et al. (2020a) investigated whether a combination of rapeseed meal, white lupine seeds and pea seeds, used as substitutes for SBM in rabbit diets, affected the growth performance of animals and the fatty acid composition of their meat and fat. The tested diets had no significant effect on the final body weights of rabbits. Rabbits fed diets containing rapeseed meal, white lupine seeds and pea seeds were characterized by higher feed efficiency and higher protein content of thigh muscle. Dressing percentage was higher in the experimental group fed a diet without SBM than in the control group. The proportion of saturated fatty acids decreased, and the proportion of polyunsaturated fatty acids increased in perirenal fat with decreasing dietary inclusion levels of SBM. The study demonstrated that SBM can be effectively replaced with a mixture of rapeseed meal, white lupine seeds and pea seeds in rabbit diets.

In another experiment, KOWALSKA et al. (2020b) evaluated the efficacy of insect meals in rabbit nutrition, including their effect on slaughter parameters and meat quality. The following diets were formulated: an SBM-based control diet, an experimental diet containing silkworm pupae meal and an experimental diet containing mealworm larvae meal. Insect meals increased the final body weights of rabbits and carcass dressing percentage. They also affected the amino acid composition of meat by modifying the levels of lysine, tryptophan and isoleucine, although the total concentrations of essential amino acids remained unchanged. The content of saturated fatty acids in meat was comparable in all groups. The meat of rabbits fed silkworm pupae meal had higher levels of polyunsaturated fatty acids and lower cholesterol levels. It was concluded that insect meal can be included in rabbit diets at 4% without compromising the growth performance of animals or meat quality.

Set out to determine whether SBM could be replaced with yellow mealworm larvae meal in rabbit diets, VOLEK et al. (2021) formulated two diets, of which one contained 6% SBM and the other contained 3% yellow mealworm larvae meal as protein sources, and their effects on average daily gains, nutrient digestibility and nitrogen retention were compared. Daily feed intake was significantly lower in rabbits fed the diet with insect meal. Average daily gains between days 32 and 53 of the experiment were lower in the experimental group than in the control group. However, at the end of the study, no significant differences in this parameter or in the final body weights of animals were found between the groups. Feed utilization, nutrient digestibility and N excretion were also comparable in both groups. Rabbits receiving yellow mealworm larvae meal were characterized by lower total nitrogen excretion, lower nitrogen losses in urine, and higher nitrogen retention. According to the cited authors, diets with the addition of yellow mealworm larvae meal can be fed to fattening rabbits with no adverse effect on the analyzed parameters.

STRYCHALSKI et al. (2021) investigated the gastrointestinal response and growth performance indicators of rabbits to the dietary replacement of SBM with insect meals. Three diets were tested: the first (control) diet contained 10% SBM, the second diet contained 5% SBM and 4% silkworm pupae meal, and the third diet contained 5% SBM and 4% mealworm larvae meal. Rabbits fed diets supplemented with insect meals were characterized by higher final body weights and higher daily body weight gains, as well as higher apparent total tract digestibility of crude fat, acid detergent fiber (ADF) and acid detergent lignin (ADL). Increased digesta viscosity, a decrease in the extracellular activity of cecal bacterial enzymes (α-glucosidase, β-glucosidase, α-arabinofuranosidase and β-xylosidase) and a decrease in the intracellular activity of β-glucuronidase were also noted in experimental groups. The addition of insect meals to rabbit diets enhanced the activity of N-acetyl-beta-D-glucosaminidase (an enzyme involved in chitin degradation) in the cecal digesta. Rabbits fed mealworm larvae meal had the lowest cecal concentrations of acetic acid, propionic acid, and total short-chain fatty acids. Animals receiving silkworm pupae meal had a lower colonic concentration of isovaleric acid. The experiment revealed that the dietary inclusion of insect meals at 4% improved rabbit productivity, with no negative effect on nutrient digestibility.

In the work of GUGOŁEK et al. (2021), rabbit diets were supplemented with silkworm pupae meal to determine its effect on gastrointestinal function, nitrogen retention and selected blood parameters. Three groups of rabbits were fed a diet containing 10% SBM, a diet containing 5% SBM and 5% silkworm pupae meal, and a diet containing 10% silkworm pupae meal, respectively. It was found that both nutrient digestibility and nitrogen retention decreased as the dietary inclusion level of silkworm pupae meal increased. The analyzed additive significantly increased gastrointestinal pH values. Rabbits receiving 10% silkworm pupae meal were characterized by the highest weight of cecal tissue and digesta. Silkworm pupae meal also contributed to a decrease in the activity of numerous bacterial enzymes in the gut and to an increase in the activity of N-acetyl-ß-D-glucosaminidase. The total cecal concentration of volatile fatty acids was lowest in rabbits fed a diet with 10% silkworm pupae meal. Blood analyses revealed that the addition of silkworm pupae meal to rabbit diets increased the plasma levels of albumins and urea. The authors concluded that rabbit diets can be supplemented with silkworm pupae meal at up to 5% since its higher inclusion rate may disturb gastrointestinal physiology.

Another study by KOWALSKA et al. (2021) aimed to evaluate the effect of insect meals on the growth performance of rabbits. The composition of three diets formulated in this experiment was identical to that described by STRYCHALSKI et al. (2021). The study demonstrated that rabbits fed diets supplemented with silkworm pupae and mealworm larvae meals had higher final body weights, better carcass characteristics, and a higher crude fat content of meat than control group animals. Therefore, insect meals can be used as partial substitutes for SBM in diets for growing rabbits.

NOWAKOWICZ-DĘBEK et al. (2021) focused on the effect of fermented rapeseed meal on meat quality and gastrointestinal morphometry in rabbits. A control diet and experimental diets containing different proportions of fermented rapeseed meal (4%, 8% and 12%) were formulated. The addition of fermented rapeseed meal caused a significant increase in the length of the cecum and the large intestine as well as in the weight of the heart. The proximate chemical composition of rabbit meat was comparable in all groups, excluding collagen content which increased in the longissimus thoracis and longissimus lumborum muscles of animals fed diets supplemented with fermented rapeseed meal. The collagen content of the biceps femoris muscle was highest in rabbits receiving 4% fermented rapeseed meal, and lowest in those receiving 12% fermented rapeseed meal. A decrease in the pH and water-holding capacity of the longissimus thoracis and longissimus lumborum muscles was also observed in animals fed diets with the addition of fermented rapeseed meal. The values of the above parameters did not decrease in the biceps femoris muscle. Changes in meat color, including increased yellowness, were also noted in experimental groups. The results of this study suggest that fermented rapeseed meal can be fed to rabbits with no negative influence on the quality of their meat.

Wlazło et al. (2021) examined the effect of fermented rapeseed meal on gut microbiota and the immune status of rabbits. The composition of experimental diets was identical to that described by Nowakowicz-Dębek et al. (2021). The counts of coliform bacteria, including *Escherichia coli,* and *Clostriduim perfringens* decreased, whereas the counts of beneficial lactic acid bacteria increased in the gastrointestinal tract of rabbits fed diets with the addition of fermented rapeseed meal. Immunoglobulin levels and the size of gut microbial populations increased with growing inclusion rates of fermented rapeseed meal. The authors reported that fermented rapeseed meal can be a valuable component of rabbit diets. It exerted a beneficial influence on their gut microbiota and immune status, thus contributing to reduced use of antibiotics in rabbit farming.

The results of studies conducted in Central Europe indicate that SBM in rabbit diets can be completely or partially replaced with other high-protein ingredients of plant and animal origin, such as oilseed meals, legume seeds, DDGS and insect meals, applied alone or in combinations, without compromising the growth rate or reproductive performance of animals.

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References

Anderson E.J., Md Liakat A., Beavis W.D., Chen P., Clemente T.E., Diers B.W., Graef G.L., Grassini P., Hyten D.L., McHale L.K., Nelson R.L., Parrott W.A., Patil G.B., Stupar R.M., Tilmon K.J. 2019. *Soybean [Glycine max (L.) Merr.] breeding: history, improvement, production and future opportunities.* In: *Advances in Plant Breeding Strategies: Legumes.* Ed. J.M. Al-Khayri, S.M. Jain, D.V. Johnson, Springer Cham, Switzerland, pp. 431–516.

Chamorro S., Gómez-Conde M.S., De Rozas A.P., Badiola I., Carabaño R., De Blas J.C. 2007. *Effect on digestion and performance of dietary protein content and of increased substitution of lucerne hay with soya-bean protein concentrate in starter diets for young rabbits.* Animal, 1(5): 651–659.

Chełmińska A., Kowalska D. 2013. *The effectiveness of maize DDGS in rabbit diets.* Ann. Anim. Sci., 13: 571–585.

Christiansen A.T., Andersen M.M., Kappel K. 2019. *Are current EU policies on GMOs ustified?* Transgenic Res., 28: 267–286.

De Coca-Sinova A., Valencia D.G., Jimenez-Moreno E., Lazaro R., Mateos G.G. 2008. *Apparent ileal digestibility of energy, nitrogen, and amino acids of soybean meals of different origin in broilers.* Poult. Sci., 87: 2613–2623.

García J., Carabaño R., De Blas J.C. 1999. *Effect of fiber source on cell wall digestibility and rate of passage in rabbits.* J. Anim. Sci., 77(4): 898–905.

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 Agrotec., 42(3): 297–306.

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.* J. Archiv. Anim. Nutr., 71: 311–326.

Gugołek A., Juśkiewicz J., Wyczling P., Kowalska D., Strychalski J., Konstantynowicz M., Zwoliński C. 2015. *Productivity results and physiological response of the gastrointestinal tract of rabbits fed diets containing rapeseed cake and wheat distillers dried grains with solubles.* Anim. Prod. Sci., 55: 777–785.

Gugołek A., Kowalska D. 2022. *Feeds of animal origin in rabbit nutrition – a review.* Ann. Anim Sci., 22(4): 1411–1429.

Gugołek A., Kowalska D., Strychalski J., Ognik K., Juśkiewicz J. 2021. *The effect of dietary supplementation with silkworm pupae meal on gastrointestinal function, nitrogen retention and blood biochemical parameters in rabbits.* BMC Vet. Res., 17: 204.

Gugołek A., Strychalski J., Kowalska D. 2019. *Growth performance and meat composition of rabbits fed diets supplemented with silkworm pupae meal.* Span. J. Agric. Res., 17: 1–9, e0607.

Guilpart N., Iizumi T., Makowski D. 2022. *Data-driven projections suggest large opportunities to improve Europe's soybean self-sufficiency under climate change.* Nat. Food, 3: 255–265.

Gutiérrez I., Espinosa A., García J., Carabaño R., De Blas, C. 2003. *Effect of protein source on digestion and growth performance of early-weaned rabbits.* Anim. Res., 52(5): 461–471.

Güzeler N., Yildirim C. 2016. *The utilization and processing of soybean and soybean products.* J. Agric. Fac. Uludag Univ., 30: 546–553.

Ibáñez M.A., de Blas C., Cámara L., Mateos G.G. 2020. *Chemical composition, protein quality and nutritive value of commercial soybean meals produced from beans from different countries: A meta-analytical study*. Anim. Feed Sci. Technol., 267: 114531.

Jiang L. 2020. *Commercialization of the gene-edited crop and morality: challenges from the liberal patent law and the strict GMO law in the EU.* New Gen. Soc., 39: 191–218.

Karr-Lilienthal L.K., Grieshop C.M., Merchen N.R., Mahan D.C., Fahey G.C. Jr. 2004. *Chemical composition and protein quality comparisons of soybeans and soybean meals from five leading soybean-producing countries.* J. Agric. Food Chem., 52: 6193–6199.

Kowalska D., Strychalski J., Zwoliński C., Gugołek A. Matusevicius P. 2020a. *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(4): 455–462.

Kowalska D., Gugołek A., Strychalski J. 2020b. *Evaluation of slaughter parameters and meat quality of rabbits fed diets with silkworm pupae and mealworm larvae meals.* Ann. Anim. Sci., 20: 551–564.

Kowalska D., Strychalski J., Gugolek A. 2021. *The effect of silkworm pupae and mealworm larvae meals as dietary protein components on performance indicators in rabbits.* Rev. Mex. Cienc. Pecuar., 12: 151–162.

Lagos L.V. Stein H.H. 2017. *Chemical composition and amino acid digestibility of soybean meal produced in the United States, China, Argentina, Brazil, or India.* J. Anim. Sci., 95: 1626–1636.

Matusevičius P., Zduńczyk Z., Juśkiewicz J., Jeroch H. 2014. *Rapeseed meal as a partial replacement for sunflower meal in diets for growing rabbits – gastrointestinal tract response and growth performance*. Eur. Poult. Sci., 78: 1–11.

Nasr A.S., Attia A.I., Rashwan A.A., Abdine A.M.M. 1996. *Growth performance of New Zealand White rabbits as affected by partial replacement of diet with Nigella sativa or soybean meals*. Egypt. J. Rabbit Sci., 6: 129–141.

Nicodemus N., García J., Carabaño R., De Blas J.C. 2007. *Effect of substitution of a soybean hull and grape seed meal mixture for traditional fiber sources on digestion and performance of growing rabbits and lactating does*. J. Anim. Sci., 85(1): 181–187.

Nowakowicz-Dębek B., Wlazło Ł., Czech A., Kowalska D., Bielański P., Ryszkowska-Siwko M., Łukaszewicz M., Florek M. 2021. *Effects of fermented rapeseed meal on gastrointestinal morphometry and meat quality of rabbits (Oryctolagus cuniculus)*. Livest. Sci., 251: 104663.

Prasad R., Karim S.A. 1998. *Effect of dietary energy and protein level on performance and digestibility parameters in pregnant and in lactating rabbit does under tropical environment*. World Rabbit Sci., 6: 271–276.

Ravindran V., Abdollahi M.R., Bootwalla S.M. 2014. *Nutrient analysis, metabolizable energy, and digestible amino acids of soybean meals of different origins for broilers*. Poult. Sci., 93: 2567–2577.

Scheitrum D., Schaefer K.A., Nes K. 2020. *Realized and potential global production effects from genetic engineering*. Food Policy, 93: 101882.

Sieradzki Z., Mazur M., Król B., Kwiatek K. 2021. *Prevalence of genetically modified soybean in animal feedingstuffs in Poland*. J. Vet. Res., 65(1): 93–99.

Strychalski J., Gugołek A., Matusevičius P. 2020. *Usability of white lupin and pea seeds in the feeding of growing New Zealand White rabbits*. Pol. J. Nat. Sci., 35(2): 151–164.

Strychalski J., Juśkiewicz J., Gugołek A., Wyczling P., Daszkiewicz T., Zwoliński C. 2014. *Usability of rapeseed cake and wheat-dried distillers' grains with solubles in the feeding of growing Californian rabbits*. Archiv. Anim. Nutr., 68: 227–244.

Strychalski J., Juśkiewicz J., Kowalska D., Gugołek A. 2021. *Performance indicators and gastrointestinal response of rabbits to dietary soybean meal replacement with silkworm pupae and mealworm larvae meals*. Archiv. Anim. Nutr., 75: 294–310.

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(3): 291–297.

Volek Z., Bureš D., Uhlířová L. 2018a. *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.

Volek Z., Ebeid T.A., Uhlířová L. 2018b. *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.

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 litters*. J. Anim. Sci., 92(5): 2041–2049.

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(4): 881–888.

Volek Z., Adámková A., Zita L., Adámek M., Plachý V., Mlček J., Marounek M. 2021.*The effects of the dietary replacement of soybean meal with yellow mealworm larvae (Tenebrio molitor) on of fattening rabbits*. Anim. Feed Sci. Technol., 280: 115048.

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.

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.

WLAZŁO Ł., KOWALSKA D., BIELAŃSKI P., CHMIELOWIEC-KORZENIOWSKA A., OSSOWSKI M., ŁUKASZEWICZ M., CZECH A., NOWAKOWICZ-DĘBEK B. 2021. *Effect of fermented rapeseed meal on the gastrointestinal microbiota and immune status of rabbit (Oryctolagus cuniculus).* Animals (Basel), 11(3): 716.

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.