



FEEDS OF ANIMAL ORIGIN IN RABBIT NUTRITION – A REVIEW

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Abstract

Rabbits are classified as obligate herbivores. However, under natural conditions, some members of the family Leporidae incorporate animal products into their diets. Therefore, it seems biologically justified to supplement the diets of farmed rabbits with feeds of animal origin as sources of protein, fat and minerals. The aim of this review was to describe, from a historical perspective, the use of various feeds of animal origin in rabbit nutrition. The applicability of by-products from mammal, poultry, fish and invertebrate processing for rabbit feeding was evaluated, including the future prospects for their use. A review of the available literature revealed that various animal-based feeds can be valuable protein sources in rabbit diets, but their inclusion levels should not exceed 5–10%. Studies investigating their efficacy have been conducted since the 1970s. In some regions of the world, the use of animal-derived protein in livestock feeds was prohibited due to the risk of spreading bovine spongiform encephalopathy (BSE). However, the interest in animal by-products as protein sources in livestock diets is likely to increase since the above ban has been lifted.

Key words: rabbits, nutrition, feeds of animal origin

Free-living European rabbits (*Oryctolagus cuniculus*) and domestic rabbits (*Oryctolagus cuniculus domesticus*) are classified as obligate herbivores. Under natural conditions, their diets are composed of various plant species, mostly grasses (Martins et al., 2002; Martin et al., 2007). Rabbits raised extensively in small backyard farms are fed green fodder and hay (Gugolek et al., 2008; Daszkiewicz et al., 2012). However, there is evidence to suggest that *O. cuniculus* and other representatives of the family Leporidae such as cottontail rabbits (*Sylvilagus floridanus*) and snowshoe hares (*Lepus americanus*) incorporate animal products into their diets (Smith, 1974; Bumann and Stauffer, 2002; González-Redondo and Zamora-Lozano, 2008; Clauss et al., 2016; Peers et al., 2018). Neonatal cannibalism has been observed among domestic rabbits, whereas wild leporids feed on dead animal carcasses, which may constitute a major source of food for snowshoe hares in winter. There have been reports of rabbits consuming snails and insects together with plant matter. However, no scientific studies have proven this to be true. European hares (*Lepus europaeus*) have been found to gnaw on the bones and antlers of different animal species, which are rich sources of minerals, in particular calcium (Landete-Castillejos et al., 2007). In view of the above, it seems logical and biologically justified to supplement the diets of farmed rabbits with small amounts of animal-based products as sources of protein and minerals.

Efforts have been made to replace genetically modified soybean meal (GM-SBM) with other high-protein plant-based feed components, including oilseed meals, distiller's dried grains with solubles and legume seeds in modern rabbit farming (Gasmi-Boubaker et al., 2007; Volek and Marounek, 2009; Chełmińska and Kowalska, 2013; Alagón et al., 2014; Lounaouci-Ouyed et al., 2014; Strychalski et al., 2014; Gugolek et al., 2015, 2017; Zwoliński et al., 2017). Imported SBM is expensive, and GM crops raise environmental and social concerns. The use of GM components in animal feeds is also likely to be banned in some regions of the world (Christiansen et al., 2019; Jiang, 2020; Scheitrum et al., 2020).

Numerous attempts have been made to include animal-based feed components such as meat, meat and bone meal, bone meal, blood meal, hydrolyzed feather meal, whey, sweet, dehydrated and skim milk, poultry meal, hatchery by-products, fish meal, insect meal, oyster shells and various animal fats in rabbit diets (Lebas, 2004). Such rations have been found to improve rabbit performance. However, the use of animal protein in livestock diets has been banned in many countries, in particular in the European Union member states, to prevent the spread of bovine spongiform encephalopathy (BSE) (Regulation EC, 2002; Rodehutschord et al., 2002). Nevertheless, studies investigating the efficacy of animal by-products as feed components are still conducted in Africa (Oladunjoye et al., 2013). Recent years have also

witnessed a growing global interest in edible insects as a source of protein in human and animal nutrition. Insect farming is considered to be an economical and environmentally sustainable method for producing high-quality protein and other nutrients (Oonincx et al., 2010; Nijdam et al., 2012).

The popularity of animal-based feed ingredients is expected to increase due to the implementation of Commission Regulation (EU) 2021/1372 of 17 August 2021 amending Annex IV to Regulation (EC) No. 999/2001 of the European Parliament and of the Council as regards the prohibition to feed non-ruminant farmed animals, other than fur animals, with protein derived from animals.

The inclusion of feeds of animal origin in rabbit diets still raises doubts despite their scientifically proven benefits. This review article summarizes the existing literature and available data on the use and efficacy of various animal-based feeds in rabbit nutrition, providing a historical perspective and exploring future trends and prospects. The applicability of by-products from mammal, poultry, fish and invertebrate (in particular insect) processing for rabbit feeding was evaluated, with a special emphasis on sources of dietary protein and minerals. The role of animal fats in rabbit nutrition has been described in our previous review article (Gugolek and Kowalska, 2020).

Feeds of mammalian origin in rabbit nutrition

Feed ingredients of mammalian origin can be divided into two groups. The first group includes by-products from animal slaughter and carcass processing. The other group comprises dairy products and their derivatives, mainly milk and whey products, and casein. Bone meal, used as a mineral supplement for livestock, can also be derived from mammals as well as poultry and fish, therefore it was described in a separate subsection.

Feeds from the slaughter of mammalian animals and carcass processing

Different mammalian by-products collected during the slaughter process are used in meal production for animal feeding. This category includes carcass parts not intended for human consumption, blood, inedible offal and bones. Meal with low ash content is referred to as meat meal, and meal with phosphorus content exceeding 4.5% is referred to as meat and bone meal. Apart from typical meat and bone meal, meal can also be produced from blood, hydrolyzed feathers and the ruminal contents. According to Hendriks et al. (2002), meat and bone meal is a rich source of protein and minerals in livestock diets, contributing to their protein and mineral content, and energy density.

In studies conducted by Newburgh and Squier (1920) and Newburgh and Clarkson (1923), rabbits were fed diets containing 33% and 27% dried lean beef, and wheat flour constituted the remaining portion of the feed ration. However, the aim of the cited studies was to induce ex-

perimental atherosclerosis, and not to analyze the effect of experimental diets on rabbit performance.

In the 1970s, Verita and Orlandi (1977) described feeding meat meal to growing rabbits. In a study by Niedźwiadek and Kawińska (1981), meat and bone meal was fed to control group rabbits, which indicates that this component was commonly used at that time. In the diet of experimental group rabbits, meat and bone meal was replaced with krill meal. This experiment is described in more detail in the “Invertebrates as feed for rabbits” subsection.

Sahu and Prasad (1990) fed pellets supplemented with fish meal (described in the “Fish meal in rabbit nutrition” section), 5% or 10% meat meal or 5% or 10% blood meal to chinchilla rabbits and found that both meat meal and blood meal can be included in pelleted diets at up to 10%.

Rabbit diets were more often supplemented with blood meal or blood meal combined with other ingredients than with meat meal or meat and bone meal. Blood is collected during the slaughter of different livestock species such as cattle, pigs and chickens. Generally, it is dried and turned into blood meal to facilitate handling and incorporation into animal diets. Fresh blood, hemoglobin and blood plasma can also be used as feed products. Blood meal is a rich source of protein, and it can be added to diets based on cereal grain, plant by-products and green forage. Blood meal can be an effective substitute for other protein sources in diets for dairy cattle, beef cattle, sheep, pigs, poultry, various fish species and silkworms (Batterham et al., 1986). Fanimó et al. (2002) compared the utilization of five animal protein concentrates (blood meal, fish meal, shrimp meal, hatchery by-product meal and poultry by-product meal) by rabbits and found that the animals receiving blood meal were characterized by the lowest feed intake, live weight gain and feed efficiency. Ojebiyi et al. (2006) evaluated the effect of diets supplemented with graded levels of sun-dried cassava peel-blood meal on the growth performance and organ characteristics of weaner rabbits. In turn, Adeniji (2012) investigated the efficacy of blood vegetable waste meal (BVWM) as a substitute for groundnut cake in the diets of weaner rabbits. They concluded that dietary groundnut cake can be effectively replaced with BVWM at up to 45%. It should also be noted that in the experiment performed by Oladunjoye et al. (2014), blood meal was not an experimental factor, but a feed component included in rabbit diets at a constant level of 1–2%, and the study investigated whether baobab seed meal could be fed to growing rabbits. In a study by Trung et al. (2017), blood meal as well as feather meal and fish meal were experimental factors. However, blood meal did not have a clear positive effect on the growth rate of Californian rabbits or carcass quality.

Numerous authors have analyzed the efficacy of bovine rumen, in different forms and combinations, in rabbit nutrition. Togun et al. (2009) demonstrated that the crude protein content of rumen-based diets can exceed

30%. Oladunjoye et al. (2013) found that cattle rumen epithelial tissue scrapings meal can effectively replace 80% of fish meal in diets for growing rabbits. Dried bovine rumen digesta has been most extensively researched. It remains debatable whether ruminal digesta can be regarded as feed of animal origin, but it often contains fragments of animal tissue, and therefore was classified into this category by Lebas (2004). This by-product of the slaughter process can be an inexpensive and locally available alternative feedstuff for livestock. The potential uses of bovine rumen digesta, alone and in combinations with other components (mainly blood) of rabbit diets, are presented in Table 1.

Not only bovine rumen was fed to rabbits. Mohammed et al. (2005) analyzed the performance of growing rabbits that received diets with graded levels of goat rumen contents. In another study, the above research team compared the nutrient composition, amino acid profile and microbial assays of fresh and dried cattle, camel, sheep and goat rumen contents (Mohammed et al., 2008). In a subsequent experiment, Mohammed et al. (2011 a) investigated the performance of growing rabbits fed diets with graded levels of goat blood-rumen content meal and found that the goat blood-rumen content mixture could be incorporated into rabbit diets at up to 40% without compromising their performance.

Table 1. Studies investigating bovine rumen content and its mixtures with other feed components in rabbit diets

Feed component*	Dietary inclusion level (%)	Aim of dietary supplementation**	Authors
Dry sediment of rumen liquor	10–20; 15–20	High-protein source for growing and mature rabbits	El-Adawy (1997)
Rumen content and blood rumen content mixture	10–30	Replacement of groundnut cake protein and evaluation of the effect of dietary supplementation on growing rabbit performance	Dairo et al. (2005)
Mixture of rumen content and blood meal	10–20	Replacement of maize and evaluation of the effect of dietary supplementation on growing rabbit performance	Togun et al. (2009)
Sun-dried rumen content	10–40	Evaluation of the effect of dietary supplementation on the growth performance and hematological response of growing rabbits	Okpanachi et al. (2010)
Blood-rumen content mixture	10–40	Evaluation of the effect of dietary supplementation on the growth and economic performance of rabbits	Mohammed et al. (2011 b)
Blood-rumen content mixture	10–40	Evaluation of the effect of dietary supplementation on hematological and serum biochemical indices in growing rabbits	Mohammed et al. (2012)
Spice-treated blood-rumen content mixtures	20	Evaluation of the effect of dietary supplementation on the productive performance and production economics of weaned rabbits	Nnenna and Kanayo (2013)
Dried rumen digesta	7.4–35.7	Evaluation of the effect of dietary supplementation on the reproductive performance of breeding rabbits	Alemede et al. (2014)
Rumen content-blood meal mixtures	10–20	Replacement of palm kernel cake and groundnut cake and evaluation of the effect of dietary supplementation on the performance and slaughter characteristics of growing rabbits	Ojebiyi and Saliu (2014)
Rumen content supplemented with enzyme	4.5–9	Replacement of groundnut cake in growing rabbit diets	Adeniji et al. (2015)
Rumen liquor fermented cassava peels	11–43	Replacement of maize and evaluation of the effect of dietary supplementation on the performance and health status of growing rabbits	Oloruntola et al. (2016)
Dried rumen digesta	12.5–25	Replacement of maize and evaluation of the effect of dietary supplementation on the hematological parameters of growing rabbits	Oluwafemi and Iliyasu (2016)
Enzyme supplemented dried rumen digesta	6–12	Replacement of maize in growing rabbit diets	Oluwafemi and Adeiza (2017)
Yeast-treated blood-rumen content mixture	10–40	Replacement of maize in growing rabbit diets	Mbahi et al. (2018)
Rumen liquor with poultry waste fermented cassava peels	32–43	Replacement of maize in growing rabbit diets	Oloruntola (2018)
Enzyme-supplemented rumen digesta and blood meal mixture	10–40	Replacement of groundnut cake in growing rabbit diets	Wafar et al. (2019 c)

*names of feed components as in the cited sources.

**aim of dietary supplementation as in the cited sources.

Rabbit diets were also supplemented with leather hydrolysates, which were used as a substitute for meat meal at 4% (Verita and Orlandi, 1977). In a study by Furlan et al. (1997), SBM was replaced by 25%, 50%, 75% and 100% protein hydrolyzed cattle hide scrap meal (PHCHSM) in diets for growing rabbits to determine its effect on their performance and carcass yield. A regression analysis revealed a linear decrease in daily weight gain, daily feed intake, carcass weight and yield in response to the higher levels of PHCHSM, whereas PHCHSM at up to 50% had no influence on weight gain, feed intake or carcass weight, which indicates that 50% is the maximum replacement level of SBM with PHCHSM.

It should be noted that rabbit droppings were also used as feed. In a study by Swick et al. (1978), dried rabbit manure was fed to rabbits, whereas Fekete (1985) used rabbit feces as almost the only feed for rabbits. However, according to Castillo-Rodríguez et al. (2007), such diets pose considerable sanitary risk and therefore cannot be recommended.

Feeds from dairy by-products

Major by-products of the dairy industry fed to animals, including rabbits, are skim milk and dried whey. They contain highly digestible proteins with high biological value, and are a rich source of water-soluble vitamins. Whey contains also lactic acid that supports gastrointestinal function (Schingoethe, 1976; Shiratsuchi et al., 1994). Casein was also included in rabbit diets, but often as a non-feed ingredient, which was described in the second part of this subsection.

Milk and whey products

Newburgh and Squier (1920) administered a mixture of milk, carrots and casein to induce arteriosclerosis in rabbits. The effect of feed ingredients derived from milk on rabbit performance has been studied since the 1970s. Halga (1974) added 5% dried skim milk to diets for growing rabbits, whereas Akuzawa et al. (1978) described hand-rearing of rabbits with rabbit milk and commercial milk powder for dogs and cats.

In the studies described below, *Streptococcus faecium* cultures were used as probiotics. In the experiment performed by Masoero et al. (1980 a), rabbits received dried whey that constituted 2.5% to 5% of the diet, with or without lyophilized *Streptococcus faecium* cells. The cited authors demonstrated that the addition of 5% dried whey increased mortality rates and decreased feed conversion in rabbits aged 28–70 days, relative to the control diet. In their subsequent study, Masoero et al. (1980 b) evaluated the efficacy of lactic acid bacteria in rabbit diets supplemented with dried whey. In a study by Caroppo et al. (1980), *Streptococcus faecium* was cultured on whey or soybean/casein peptones, yeast extract and lactose, spray-dried and added to basal rabbit diets. The rabbits received also 1.5 ml of yoghurt mixed with drinking water, per day per head. The study revealed that dried *S. faecium* fed to young rabbits reduced their mor-

tality rates, improved feed conversion efficiency and had a beneficial influence on their growth performance. Yoghurt also exerted a positive effect on the studied parameters in rabbits. Interactions between dietary and endogenous intestinal bacteria were also analyzed in the cited study. In their subsequent study, Masoero et al. (1982) continued their research into dried whey-supplemented rabbit diets. The control diet contained barley, and in eight experimental diets, barley was partially replaced with 2.5% or 5% dried whey, 3.2% or 6.4% hydrolyzed condensed whey, or 0.5×10^6 or 1.0×10^6 viable cells of *S. faecium*/g, with or without 5% dried whey.

Beynen et al. (1983 a) analyzed the effect of milk replacers containing skim milk powder or soybean protein concentrate on serum cholesterol levels in rabbits and calves. In another experiment performed by Colina and Coppings (1989), rabbits received fresh liquid sweet whey. This is one of very few cases where rabbits were fed liquid whey and milk, which is possible only in extensive production systems.

Blas et al. (1990) administered diets containing barley, bran and alfalfa hay, with or without 15% skim milk, to young rabbits and found no significant differences in body weight gain, feed intake or milk intake between groups. According to the above authors, milk should not be included in starter diets for rabbits because it does not improve performance. In a study by Coppings and Ekhatior (1990), dried whey (0, 5, 10 or 20%) was incorporated into isonitrogenous pelleted diets for growing rabbits. The animals administered dried whey were characterized by lower feed intake, but higher final body weights, higher daily gains and more desirable feed:gain ratios in comparison with the control group. The diet did not affect carcass yield, liver and heart weights, whereas whey-fed rabbits had heavier kidneys, higher abdominal fat content and higher mortality rates, but the noted differences were not significant. In a similar trial that involved 43-day-old rabbits, no significant differences were observed between whey-fed and control animals. It was concluded that dried whey could improve the growth performance of rabbits, but their responses varied with age.

Lovati et al. (1990) analyzed isonitrogenous purified diets containing different animal protein sources, including milk-whey protein, and concluded that they induced hypercholesterolemia in rabbits, but the underlying mechanisms were different. Aggarwal and Kansal (1991) added 16% dried skim milk to rabbit diets to determine its effect on plasma cholesterol levels. In a follow-up study, Aggarwal and Kansal (1992) investigated the effect of skim milk on the progression of atherosclerosis in cholesterol-fed rabbits.

Research into the efficacy of milk-derived products in rabbit nutrition was also conducted in the 21st century. Lyu et al. (2013) determined the effect of whey powder on the growth performance, antioxidant status and immune function of weanling laboratory rabbits. The study revealed that the optimal level of supplemental whey powder was 5%. In turn, Hassan et al. (2014) evaluated

the influence of acid whey on rabbit performance. Fresh acid whey was mixed with drinking water at 0, 100, 150, 200 and 250 ml. Body weight gain, feed intake and feed efficiency were significantly lower in rabbits receiving acid whey, which indicates that this feed additive had a significant negative effect on the growth performance of rabbits at 4 to 8 weeks of age.

Kishawy et al. (2018) evaluated the influence of dietary supplementation with graded levels of whey powder and citric acid, and reported that 22.5 g/kg whey powder contributed to the highest final body weights and body weight gain, the most favorable feed conversion ratio, the highest protein efficiency, relative growth rate, and dressed weight in growing rabbits. Optimal digestion coefficients were associated with 15 g/kg and 22.5 g/kg whey powder. Rabbits fed diets supplemented with citric acid, alone or in combination with whey powder, were characterized by significantly lower intestinal pH values than control group animals. The dietary addition of 15 g/kg and 22.5 g/kg whey powder resulted in a higher content of protein and ash in thigh muscles, relative to the control group and the group with a lower inclusion level of whey powder. The calcium content of the femur was higher in the group fed the diet with the highest whey powder content. The condition of the small intestinal wall improved in the groups receiving 15 g/kg and 22.5 g/kg whey powder, including the highest increase in the size of intestinal villi and glands, and the number of goblet cells. The cited authors concluded that the addition of whey powder at 1.5% and 2.25% to diets for growing rabbits improved their growth performance and nutrient digestibility, increased the crude protein content of thigh muscles, and improved gut health; the optimal inclusion level of whey powder was 2.25%. The addition of citric acid had no beneficial influence on the above parameters.

Ribeiro et al. (2019) evaluated the functional properties of symbiotic yoghurt fed to rabbits. The study confirmed the bifidogenic capacity of Jerusalem artichoke (*Helianthus tuberosus*) flour as a prebiotic ingredient in yoghurt, which modulated gut microbiota and delivered health benefits, including a significant decrease in cholesterol and glucose levels in rabbits, as evidenced by an analysis of serological and microbiological parameters.

Casein

Casein is the principal protein found in milk, and it accounts for more than 70% of total milk proteins. It forms micelles with calcium and phosphorus. Until the 1960s, casein was primarily used in nonfood (technical) applications, including adhesives for wood, paper coating, leather finishing, synthetic fibers and plastics. In the last few decades, casein has found numerous applications in the food industry such as enhancing the physical properties of food products (whipping, foaming, water-binding, thickening), improving their emulsifying capacity and texture. Casein also increases the nutritional value of foods (Sarode et al., 2016).

Spreadbury (1978) fed casein to New Zealand White rabbits in a study investigating their protein and amino acid requirements. Oat-based diets were supplemented with maize gluten, gelatin, groundnut meal, SBM, fish meal and casein. Kuyvenhoven et al. (1989) analyzed the digestibility of casein, formaldehyde-treated casein and soybean protein, and their effects on serum cholesterol levels in rabbits. They demonstrated that cholesterol concentrations in the blood serum and livers of rabbits increased in response to casein and formaldehyde-treated-casein diets. Fecal bile acid excretion and concentration were lower in rabbits receiving casein and formaldehyde-treated casein than in those fed soybean protein. Apparent nitrogen digestibility was lowest in rabbits fed formaldehyde-treated casein, and highest in those fed casein. It appears that protein digestibility is not a reliable indicator of serum cholesterol levels in rabbits.

Canzi et al. (2000) evaluated the modulation of the intestinal ecosystem by lactic acid bacteria and plasma cholesterol levels in rabbits fed casein diets. A microbiological analysis revealed that the diets had a significant effect on the growth and activity of various bacterial species in the intestinal ecosystem, and that lactic acid bacteria contributed to restoring intestinal microbial balance. Aribi et al. (2010) determined the effects of casein and an adapted-milk formula on the proliferation of lymphocytes, mid-cells and granulocytes and on circulating lipids in rabbits. The cited authors found that casein and the adapted-milk formula enhanced the activity of phagocytes, eosinophils and basophils, and inhibited lymphocyte proliferation. Moreover, the adapted-milk formula contributed to preventing overweight and childhood obesity, whereas high concentrations of milk casein could be an atherogenic risk factor.

In other experiments involving rabbits, casein was used as an agent inducing pathological states (hypercholesterolemia, atherosclerosis) rather than as a dietary component or an experimental factor. Many of those experiments relied on biological and biochemical analyses, and not feeding trials. The most important studies of the type are presented in Table 2.

It can be concluded that meat meal, meat and bone meal and other mammalian slaughter by-products are valuable feed additives that increase the protein content of rabbit diets. They had been included in commercial diets since the 1970s, but their use was discontinued in many countries due to the risk of BSE. The optimal inclusion level of mammalian by-products in rabbit diets is 5%, although some authors recommended higher rates. The interest in feeds of mammalian origin and other animal by-products is likely to increase since the ban on their use has been lifted.

Milk by-products are also rich sources of dietary protein for rabbits. Due to their desirable amino acid composition, they contribute to improving the performance and overall health status of rabbits. They can be combined with probiotics and prebiotics, and their optimal inclusion level is 2–2.5% of the ration. Casein is usually administered to rabbits for non-dietary purposes.

Table 2. Studies investigating casein-supplemented rabbit diets

Aim of casein supplementation	Authors
Inducing arteriosclerosis in rabbits	Newburgh and Clarkson (1922)
Analysis of the distribution of cholesterol between serum lipoprotein fractions in rabbits fed semi-purified diets containing casein and either coconut oil or corn oil	Beynen and West (1981)
Development of hypercholesterolemia in rabbits fed semi-purified diets containing casein or soybean protein	Terpstra and Sanchez-Muniz (1981)
Evaluation of the effect of cholestyramine on low-density lipoprotein binding sites on liver membranes in rabbits with endogenous hypercholesterolemia induced by a wheat starch-casein diet	Chao et al. (1982)
Inducing hypercholesterolemia in rabbits	Beynen et al. (1983 a)
Evaluation of the effect of replacing dietary soybean protein with casein on the fecal excretion of neutral steroids in rabbits	Beynen et al. (1983 b)
Analysis of the regulation of hepatic receptor-dependent degradation of LDL by mevinolin in rabbits with hypercholesterolemia induced by a wheat starch-casein diet	Chao et al. (1983)
Treatment of dietary casein with formaldehyde to reduce its hypercholesterolemic effects	West et al. (1984)
Analysis of the correlation between casein-induced hypercholesterolemia and dietary calcium levels	Van der Meer et al. (1985)
Analysis of the secretion of cholesteryl-ester-rich lipoproteins by perfused liver in rabbits fed a wheat-starch-casein diet	Chao et al. (1986)
Evaluation of the effect of soybean protein and casein on pre-established atherosclerosis	Kritchevsky et al. (1988)
Analysis of the turnover of apolipoprotein B in rabbits fed diets containing casein or soybean protein	Khosla et al. (1989)
Evaluation of the effects of dietary casein and soybean protein on the metabolism of radiolabeled low-density apolipoprotein B	Samman et al. (1989)
A comparison of the hypocholesterolemic effects of dietary soybean protein and formaldehyde-treated casein	West et al. (1989)
Evaluation of the effect of casein on feed intake and cholesterol metabolism in rabbits	Bergeron and Jacques (1990)
Evaluation of the effects of different dietary animal proteins, including casein and whey, on cholesterol metabolism	Lovati et al. (1990)
Analysis of the turnover of intermediate-density lipoprotein-apolipoprotein B in rabbits fed semi-purified diets containing casein or soybean protein	Samman et al. (1990)
Analysis of the relationship between LDL catabolism in casein-fed rabbits and increasing plasma cholesterol levels	Khosla et al. (1991)
Analysis of the comparative effects of HMG-CoA reductase inhibitors on apo B production in the casein-fed rabbit	Auerbach et al. (1995)

Feeds of poultry origin in rabbit nutrition

Feeds of poultry origin include meat meal, blood meal, feather meal, hatchery waste and eggs, and they are valuable components of animal diets. The use of various poultry by-products in rabbit nutrition is described below.

Feeds from the processing and slaughter of poultry

Poultry meal consists of milled, rendered and cleaned parts of the carcasses of slaughtered birds, i.e. inedible tissues such as the head, neck, feet, undeveloped eggs, intestines and skeletal frames following muscle removal. Poultry meal is a rich source of protein as its protein content ranges from 55% to 74%. It also contains fat (10–19%) and ash (11–23%) (Dong et al., 1993; Donadelli et al., 2019). Poultry meal is widely used as feed for aquaculture and companion animals. However, the amino acid composition of poultry meal is less desirable than that of fish meal (Nengas et al., 1999). Fanimio et al. (2002) compared poultry meal and other animal by-products in rabbit nutrition. Their work is described in more detail in subsequent subsections.

Ekpenyong and Biobaku (1986) analyzed the growth response of rabbits to dried poultry waste. A more advanced study was conducted by Fotso et al. (2000) who evaluated the nutritional value of four different protein sources, including chicken offal meal, in diets for growing rabbits raised in Cameroon. They found that rabbits fed chicken offal as the main dietary protein source were characterized by higher feed intake and a significantly higher growth rate than those receiving vegetable protein sources (cassava leaf meal and cottonseed meal). An analysis of the cost per kg meat, calculated based on feed cost, revealed that the diet containing chicken offal meal was most cost-effective, followed by that containing cottonseed meal and cassava meal.

Ahlawat et al. (2001) analyzed poultry viscera meal as a potential substitute for fish meal at 5% and 8% in feed pellets for broiler rabbits. The study demonstrated that carcass yield (%) and the weight of total edible offal were significantly higher, and chilling loss was significantly lower, in the group receiving 8% poultry viscera meal than in the control group. The yield of inedible offal (blood, skin, hind feet and lungs) was also significant-

ly higher in the experimental group than in the control group. The cited authors concluded that poultry viscera meal can be included in rabbit diets as a safe and effective substitute for fish meal. In a follow-up study by Ahlawat et al. (2003), poultry viscera meal was added to Angora rabbit diets to replace fish meal at 5% and 8% and to determine its effect on wool traits. It was found that wool yield per shear (g) and fiber length (cm) were significantly higher in the group receiving poultry viscera meal than in the control fish meal group. Other wool quality attributes (moisture percent, moisture regain, ash content, fiber diameter, fiber strength, specific gravity and pH) were not significantly affected by the dietary treatment. The results of the study indicated that poultry viscera meal had a beneficial influence on wool production and therefore could be safely included in Angora rabbit diets.

Feather meal is a by-product of poultry processing. It consists of poultry feathers that are partially ground under high heat and pressure, and then ground again and dried. Although feather meal has relatively high total nitrogen content (up to 12%), nitrogen bioavailability from this feed is low. Feather meal is fed to different livestock species (Moritz and Latshaw, 2001).

Hydrolyzed feather meal was also tested as a potential ingredient of rabbit diets. Fekete and Hegedus (1986) reported that enzymatically digested feather meal, used as a substitute for SBM at 30% of the diet, had a positive effect on growing rabbits. Ayanwale (2006) also evaluated hydrolyzed feather meal as a protein source in rabbit diets. Four types of feeds containing 0.0, 5.0, 10.0 and 15.0% feather meal were formulated. The study revealed that feather meal improved rabbit performance at a dietary inclusion level of up to 15%.

The objective of the experiment performed by Trigo et al. (2012) was to evaluate the effects of alternative dietary protein sources, namely meat meal and hydrolyzed feather meal, and two levels of crude protein, 17 and 14%, on performance and carcass quality traits in growing rabbits. The cited authors found that dietary protein sources significantly affected dry matter intake and feed cost per rabbit. Performance traits were generally not affected by the inclusion of hydrolyzed feather meal in the diet, but the expected economic results were not achieved due to higher feed intake levels. Therefore, the inclusion of feather meal in the diet appears to be the subject of the cost of this by-product. Performance traits were affected by a lower percentage of protein in the diet, although the cost of feed ingredients in the protein-restricted diets was lower.

In a study of Californian rabbits conducted by Trung et al. (2017), feather meal was one of experimental factors, together with fish meal and blood meal. Feather meal in the amount of 14.9 g per day had no clear positive effect on rabbit performance.

Feeds from hatchery waste

Hatchery waste meal is obtained from the processing of poultry hatchery waste such as the shells of hatched

eggs, infertile eggs, dead embryos, and dead or culled chicks (Al-Harhi et al., 2010).

Handa et al. (1996) fed extruded hatchery waste to growing Soviet Chinchilla rabbits at 6% of the feed ration. The hatchery waste included infertile eggs, empty shells, dead embryos in shells, weak and culled chicks, and day-old male chicks of layer breeds. Extruded hatchery waste contained more than 45% crude protein. The analyzed feed components did not compromise carcass quality, and low cost was their main advantage.

Hatchery by-product meal was also fed to weaner rabbits in the aforementioned work of Fanimo et al. (2002), where it contributed to lower feed intake and feed efficiency than fish meal.

In a study by Isaac et al. (2007), weaned rabbits were fed grower mash diets supplemented with hatchery waste meal at 0, 15, 25 and 45%. The animals were randomly allocated to five dietary treatments with four replicates per treatment to assess their performance. Grower mash without hatchery waste meal was the control diet (0%), and the inclusion levels of hatchery waste meal were determined based on 100 g that was given to the control group. Significant differences were found between treatments. According to the cited authors, hatchery waste meal has a great potential to support production and therefore it can be used as an ingredient of rabbit diets.

Another interesting study investigating hatchery waste was conducted by Ojebiyi et al. (2014) who analyzed the synergistic effects of hatchery by-products and cassava peel meal mixtures on the performance of cross-bred growing rabbits. They found that hatchery waste and cassava peel meal can be included in diets for young rabbits at up to 15%, but the highest return can be expected at the inclusion rate of 10%.

Eggs

Eggs, egg components and by-products can also be incorporated to rabbit diets. Lovati et al. (1990) analyzed dietary animal proteins, including ovalbumin, and cholesterol metabolism in rabbits. Chicken egg yolk powder was also added to rabbit diets, usually to induce atherosclerosis. For instance, Jezierski and Konecka (1994) administered 130 g of feed pellets mixed with one egg yolk to young rabbits. Moderate atherosclerosis was induced to determine the role of behavioral and emotional factors in diet-induced atherosclerosis in rabbits. Egg yolk had no significant effect on total plasma cholesterol levels. None of experimental or control group rabbits developed visible atherosclerosis. In another experiment by Konecka et al. (1996), experimental group rabbits were fed 150 g standard pelleted feed daily mixed with one egg yolk and 1.5 g cholesterol.

Srilatha et al. (1997) investigated the effects of feeding egg yolk on serum lipid concentrations in rabbits. The experimental diet had a significant influence on serum cholesterol levels which increased 15- to 30-fold, relative to the baseline value, depending on whether experimental rabbits consumed the yolk of one or two eggs

during the study. Considerable changes in low-density lipoprotein cholesterol levels were noted in experimental animals, which indicates that this method can be used for detecting the first signs of atherosclerosis in humans. The above study also provided direct evidence for the harmful effect of hen's egg yolk on serum cholesterol levels in an easily reproducible animal model.

Xing et al. (2009) used egg yolks, added at 15% to experimental diets, to examine the lipid profile of hyperlipidemic rabbits.

The effects of chicken and ostrich eggshells on bone formation in rabbits were evaluated in veterinary studies by Durmus et al. (2003, 2008), Alemi et al. (2019), Anashar and Daoud (2019), and Alhussary et al. (2020). The research findings suggest that eggshells supported bone growth and contributed to preventing bone defects, in particular with regard to the mandible.

Poultry manure and litter

Coach (1974) evaluated poultry manure as a potential ingredient of livestock diets. The author reported on the adverse effects of dried poultry manure addition exceeding 15% of the diet, resulting from the increasing levels of uric acid which is not utilized and therefore can be toxic to animals.

The first study investigating the efficacy of poultry litter in rabbit nutrition was conducted by Auxilla et al. (1982) who observed no significant differences in feed conversion efficiency between rabbits fed 8.0–25.0% poultry litter and control group animals. The use of poultry droppings in fattening rabbits was evaluated by Martina et al. (1987).

In turn, Mokhtar et al. (2002) analyzed the use of dried pigeon droppings in rabbit nutrition and concluded that pigeon manure can be included in rabbit diets at up to 12% with positive results and without compromising body gain, feed conversion or economic efficiency.

Onimisi and Omage (2006) evaluated poultry litter as a feedstuff for growing rabbits and found that poultry litter could replace up to 32% of maize and soybeans in the diets without negative effects on growth performance.

Poultry manure in rabbit diets was thoroughly investigated by Abdel-Azeem et al. (2007) who compared the efficacy of dried broiler manure and dried layer manure, supplemented with a Chinese commercial preparation containing garlic extract, hydrolytic enzymes, *Bacillus subtilis* cultures and ginseng extract. The study revealed that rabbits fed 10% dried broiler manure had significantly higher final body weights and daily gain; intermediate values of these parameters were noted in the control group, whereas the lowest values were observed in rabbits receiving 15% dried layer manure. The commercial preparation added at 2.5 g/kg of the diet led to a significant improvement in body weights, feed conversion ratio, the digestibility coefficients of dry matter, crude protein and crude fiber. It also contributed to a decrease in plasma globulin, total cholesterol, glutamic oxaloacetic transaminase (GOT) and urea concentrations, compared

with non-supplemented basal diets. The addition of the tested preparation had no significant influence on carcass traits, plasma total protein, albumin, total lipids and phosphorous levels or economic efficiency. Thus, broiler manure and layer manure supplemented with the analyzed preparation can be used as feed additives in growing rabbits.

In a study conducted in Nigeria, Ogunsipe (2011) evaluated the effect of layer litter on the performance of growing rabbits and microbial diversity in their feces. The experiment had a completely randomized design, and weaned rabbits were randomly allocated to four dietary treatments (0, 10, 20 and 30% of layer litter). Performance parameters were most satisfactory, including the highest weight gain, in rabbits fed the diet containing 20% of layer litter. No significant differences in weight gain were found between rabbits fed the reference diet and the diet with 10% of layer litter, or between those fed diets with 20% and 30% of layer litter. An analysis of relative organ weights revealed that only the weights of the liver and kidneys were not significantly affected by the dietary inclusion of layer litter. The number of bacterial isolates from rabbit feces was minimal, and bacterial concentrations had no adverse effects of on the health status of the animals, as no mortality cases were recorded throughout the experiment. Some of the bacterial isolates were highly sensitive to antibiotics (ciprofloxacin, gentamycin and ofloxacin). According to the cited authors, layer litter can replace up to 30% of maize without any negative effects on growth performance, carcass cuts, organ weights and the overall health status of rabbits.

In a subsequent study, Ogunsipe (2014) assessed the effect of poultry litter with and without exogenous enzyme (nutrase xylase) supplementation on the growth performance, nutrient digestibility and economy of rabbit production. An analysis of the chemical composition of diets revealed an improvement in the nutrient status of enzyme-supplemented diets relative to non-supplemented diets. The higher nutrient density of enzyme-supplemented diets was reflected in the higher weight gain of rabbits, compared with the animals fed non-supplemented diets, except for the 40% poultry litter treatment where no significant differences were found between rabbits fed enzyme-supplemented and non-supplemented diets. Apparent nutrient digestibility was higher in rabbits fed enzyme-supplemented diets than in those receiving non-supplemented diets at 0 to 20% and 30 to 40% poultry litter inclusion levels. An analysis of production economics showed that enzyme supplementation steadily decreased the cost of feed N/kg weight gain up to the inclusion rate of 30% poultry litter.

In experiments performed by Oloruntola et al. (2016) and Oloruntola (2018), rabbits were fed rumen liquor with poultry waste fermented cassava peels. Sun-dried layer droppings were mixed with ground cassava peels. In these experiments, the main factor was rumen liquor fermented cassava peels, which is why the findings were described in a previous subsection (Table 1).

Sayed (2019) evaluated dried poultry droppings as a feed ingredient of rabbit diets, including their influence on growth performance, nutrient digestibility, carcass characteristics and blood biochemical parameters. Significant differences in urea concentration were observed between rabbits fed a diet containing 15% dried poultry droppings and those fed the control diet. In turn, carcass dressing percentage and the weight percentages of the liver, kidneys, heart and lungs were similar in rabbits fed dried poultry droppings and control animals. In conclusion, dried poultry droppings can be included at up to 100 g/kg in rabbit diets with no adverse effects on their health or performance. Additional advantages include lower feed cost and lower pollution levels.

The efficacy of poultry meal as a source of nutrients in rabbit diets has been tested since the second half of the 20th century. A review of the relevant literature, provided above, shows that various poultry by-products can be valuable sources of dietary protein for rabbits, although their chemical composition can vary widely. Poultry manure and litter have been analyzed as cheap alternative feeds mainly in developing countries. The recommended inclusion level of poultry by-products is 6–8%, although some authors applied even 15% with no negative effects. Chicken eggs and egg by-products were added to rabbit diets mostly as part of biological trials.

Fish meal in rabbit nutrition

In a review article on rabbit nutrition, Lebas (2004) reported that fish meal is a nutrient-dense feedstuff for rabbits because it has high energy value per unit weight, and contains high-quality protein and readily digestible essential amino acids and fatty acids. Numerous studies have shown that fish meal contributes to improving the growth and performance of various animal species (Korver and Klasing, 1997; Cho and Kim, 2010). However, fish meal is expensive, which limits its wide use in animal diets. It is often replaced with cheaper high-protein feeds such as blood meal, extruded hatchery waste, meat meal and poultry viscera meal (Lebas, 2004). The most important studies investigating the efficacy of fish meal in rabbit nutrition are presented below.

Spreadbury (1978) analyzed the protein and amino acid requirements of growing rabbits. In the cited study, protein supplied by oats was supplemented with maize gluten, gelatin, groundnut meal, casein, SBM or fish meal. Amino acid balance in dietary protein was found to be an important consideration, and the dietary addition of both lysine and methionine improved the growth rates of rabbits. The minimum requirements for normal growth were estimated at 6.2 g methionine+cystine and 9.4 g lysine/kg of the diet.

Fish meal substitutes in rabbits have also been extensively researched. Omole and Sonaiya (1981) observed that rabbits were characterized by higher growth rates when fish meal rather than groundnut meal was applied as a protein supplement in diets containing cassava peel meal, pointing to the poor quality of cassava protein.

Niedźwiadek and Kawińska (1981) replaced fish meal with krill meal – this study is described in more detail in the subsequent subsection.

As already mentioned, Lovati et al. (1990) evaluated the effect of different animal protein sources, including fish meal, on cholesterol metabolism in rabbits, as compared with soybean protein.

Sahu and Prasad (1990) analyzed whether fish meal could be replaced with other animal meals in chinchilla rabbit diets. Rabbits received commercial pellets containing 5% fish meal or laboratory-made pellets containing 5% or 10% meat meal or 5% or 10% blood meal. It was concluded that both meat meal and blood meal could replace fish meal at up to 10% in rabbit diets. It should be noted that fish meal was not an experimental factor, and it was included in control diets, which suggests that already in the 1990s fish meal was regarded as a typical component of commercial rabbit diets.

The use of fish meal as an ingredient of rabbit diets was described by Indian researchers, Prasad et al. (1996 a, b), Prasad and Karim (1998). Prasad et al. (1996 a) supplemented rabbit diets with 5% to 8% fish meal to differentiate the levels of energy and protein. They found that the total amount of feed consumed throughout the experiment was highest in the low energy treatment, followed by the medium energy treatment and the high energy treatment. The digestibility coefficients of dry matter, crude protein and energy increased with a rise in the energy content of diets; an increase in the protein content of the rations was accompanied by improved protein digestibility. A regression analysis of average daily gain vs. the ratio of digestible energy and crude protein intake revealed that the above ratio had no significant effect on average daily gain. In turn, Prasad et al. (1996 b) supplemented rabbit diets with 5% fish meal in a study of the growth performance of broiler rabbits fed pelleted and traditional diets. Prasad and Karim (1998) added 5% to 8% fish meal to rabbit diets to achieve three levels of energy and protein in nine combinations. The experiment was performed under tropical conditions, on pregnant and lactating does (nine groups of six animals each) to evaluate their reproductive performance and nutrient digestibility. The findings indicate that a diet containing 18% crude protein and 2700 kcal DE/kg of feed can be considered optimal for reproductive rabbit does in the tropical environment.

In a study conducted in Cameroon, Fotso et al. (2000) evaluated the nutritional value of different protein sources including fish meal (16% of the diet) in diets for growing rabbits. Higher feed intake and a significantly higher growth rate were noted in rabbits receiving fish meal than in those fed plant protein sources. Carcass yields were similar in rabbits fed fish meal (54%) and cassava leaf meal (52.3%), and significantly higher than the value determined in rabbits fed cottonseed meal (49.92%). The diet containing fish meal was least cost-effective.

Ahlawat et al. (2001) analyzed poultry viscera meal as a potential substitute for fish meal at 5% and 8% in

feed pellets for broiler rabbits. In another study, the above authors demonstrated that poultry viscera meal could be safely included in Angora rabbit diets as a substitute for fish meal, and that it positively affected wool production (Ahlawat et al., 2003). In the cited experiments, fish meal was included in control group diets, which is why they are described in detail in the "Feeds from the processing and slaughter of poultry" subsection.

Fanimo et al. (2002) also analyzed fish meal in their aforementioned study that compared the utilization of five animal protein concentrates in rabbit diets. Biobaku et al. (2003) tested whether local Nigerian fish meal could be included in rabbit diets at 7.17% to 12.39%. The effects of groundnut cake and fish meal on the growth rate of rabbits and protein utilization were determined in the study. Control diets, which did not contain groundnut cake and local fish meal, contributed to significantly higher body weight gain, compared with experimental diets. The protein efficiency ratio was also significantly higher in the control diets. No enteritis or mortality cases were recorded in the treatment groups.

Another extensive study involving fish meal was conducted by Mbanya et al. (2005) who described seven concentrate feeds for growing rabbits, which were formulated to include one, two or three different protein sources. The dietary treatments consisted of cottonseed cake, soybean cake, fish meal, cottonseed cake and soybean cake. Diets were supplemented with 2% to 6% fish meal. Rabbits fed fish meal were characterized by the highest growth rate, due to the superior amino acid composition of this protein source, relative to cottonseed cake and soybean cake. However, this trend was not reflected in better feed conversion.

Njidda and Isidahomen (2010) evaluated the influence of replacing fish meal with grasshopper meal on the hematology, serum chemistry and carcass characteristics of growing rabbits. It was concluded that grasshopper meal could be included in the diet at 2.50% as a substitute for fish meal (50% replacement) with no adverse effects on hematological and biochemical blood parameters or carcass traits.

Fatufe et al. (2010) examined the effect of feeding bacterial protein meal (*Streptomyces* spp. containing 70% crude protein, 6.5% crude fat and 4.1% crude fiber) as a substitute for fish meal or groundnut cake meal in diets for growing rabbits over 84 days. Rabbits' responses to bacterial protein meal in terms of feed intake, body weight gain and feed conversion were not statistically significant. The inclusion of bacterial meal in rabbit diets significantly decreased skin weight and kidney fat content. The experiment confirmed that bacterial protein meal can completely replace fish meal and groundnut cake meal in diets for growing rabbits as it had no adverse effect on their growth performance or carcass quality.

Karikari et al. (2011) evaluated the nutritional value of millet residue meal combined with fish meal, SBM or fish-SBM (1:2) as protein sources in diets for domestic

rabbits. Based on the protein source, the treatments were labeled as a fish meal diet, an SBM diet and a fish-SBM diet. During the pre-breeding period, does fed the fish meal diet were characterized by a poorer daily growth rate and feed conversion ratio than those fed the SBM diet. The former delivered and weaned a lower number of kits than the latter. Does receiving the SBM diet were heaviest at mating and kindling, and they were characterized by superior values of most parameters, compared with does fed the fish meal diet. The study demonstrated that millet residue meal may be a better feed source for female rabbits when it is combined with SBM rather than fish meal or fish-SBM to increase dietary protein content.

In a study by Oladunjoye et al. (2013), an attempt was made to replace fish meal with cattle rumen epithelial tissue scrapings meal in diets for growing rabbits. It was found that this experimental factor can replace 80% of fish meal. The details of this study are provided in the section discussing feeds of mammalian origin.

Galan et al. (2013) analyzed whether Nile tilapia (*Oreochromis niloticus*) meal can be included in rabbit diets, and determined its effect on the chemical composition and resistance of bones. The study revealed that the meal of tilapia filleting residues positively affected carcass quality traits, but it had no influence on the chemical composition or resistance of bones.

Duwa et al. (2014) replaced fish meal with housefly pupae meal in diets for growing rabbits. The details of the study are provided in the subsection on invertebrate meal.

Trung et al. (2017) allocated Californian rabbits to five treatments differing in dietary protein sources, i.e. SBM, water spinach leaf meal, fish meal, feather meal and blood meal. Fish meal accounted for 2.5% of the diet. The basal diet consisted of para grass (*Brachiaria mutica*) and *Centrocema pubescens*. The crude protein and metabolizable energy content of diets were 19.0% and 11.6 MJ/kg DM, respectively. It was found that SBM and water spinach leaf meal can be fed to young rabbits to improve their meat performance and increase profits. However, the fishy smell, low palatability and digestibility of fish meal, feather meal and blood meal could limit nutrient intake, impair nutrient digestion and decrease the growth rate of rabbits.

Fish meal is a valuable feed additive in rabbit nutrition. It has been widely used since the 1970s, exerting a beneficial influence on the growth performance of animals and meat quality. Fish oil is a major dietary source of n-3 long-chain polyunsaturated fatty acids (PUFAs), docosahexaenoic acid (22:6n-3) and eicosapentaenoic acid (20:5n-3), which deliver health benefits and can modify the chemical composition of meat. Fish meal can be included in rabbit diets at up to 10% or even 15% according to some sources. However, the use of fish meal may be limited by its relatively high price.

Invertebrates as feed for rabbits

Invertebrates (*Invertebrata*) are a large group of animals, comprising more than one million species, which

can be potential sources of protein and other nutrients in livestock diets. The term “invertebrates” refers to all animals except those classified under the subphylum Vertebrata, such as mollusks, crustaceans, arachnids and insects. They differ in their nutritional value (Finke, 2002). In the 21st century, research has focused on edible insects as potential nutrient sources in diets for various livestock species (Oonincx et al., 2010; Nijdam et al., 2012).

Annelids, mollusks and crustaceans

In a study by Niedźwiadek and Kawińska (1981), krill meal was incorporated at 6% into diets for growing rabbits as a substitute for fish and meat and bone meal. Rabbits fed krill meal were characterized by the highest body weight gain and nutrient digestibility. It was concluded that krill meal can effectively replace other meals of animal origin in rabbit diets.

Orozco et al. (1988) evaluated the nutritional value of earthworm (*Eisenia foetida* and *Lumbricus rubellus*) meal as a protein feed for growing rabbits. The proximate chemical composition, amino acid composition and protein digestibility *in vitro* of earthworm meal were determined. The experimental diet, which contained 30% of total protein as earthworm meal, was compared with the control diet with SBM as the protein component. Both diets were isocaloric and isonitrogenous. No significant differences in feed intake, body weight gain, feed conversion or apparent digestibility were found between the groups. Apparent digestibility was 5.09% higher in the diet containing earthworm meal, compared with the control diet. The study demonstrated that earthworm meal can account for 30% of total protein in rabbit diets without any adverse physiological effects.

Fanimo et al. (2002) compared five animal protein concentrates, including shrimp waste meal. They found that domestic rabbits can be fed shrimp meal instead of other protein sources because shrimp meal is palatable, improves the feed conversion ratio and increases meat tenderness.

Ojiako et al. (2018) allocated rabbits to six dietary treatments, where the positive control group received a standard commercial diet and the diets of five experimental groups were supplemented with crayfish (*Cambarus diminutus*) meal, rainbow crab (*Cardisoma armatum*) meal, periwinkle (*Tympanotonus fuscatus*) meal, clam (*Ergeria radiata*) meal, and a combination of these four meals. An analysis of selected biochemical parameters of rabbits revealed that dietary supplementation with seafoods delivers health benefits. Thus, seafoods can be used for dietary modifications, to meet the nutritional needs of humans and animals, and to decrease plasma cholesterol levels.

Insects

Insect-based feed ingredients are mostly meals derived from different insect species and insects in various stages of development (Finke, 2002) as well as insect fat,

described in another section. The efficacy of insect meal in rabbit nutrition was studied by Carregal and Takahashi (1987) who replaced SBM with silkworm (*Bombix mori*) chrysalis meal. It should be stressed that in a study by Liu et al. (1987), insect meal was a standard component of rabbit diets, not an experimental factor, which indicates that insect-based feeds are widely used in China. The Web of Science database contains Chinese patents describing the use of mealworm larvae meal and silkworm pupae in rabbit diets.

The 21st century saw a revival of interest in insects as feed for rabbits. Duwa et al. (2014) determined the effect of maggot meal (housefly pupae meal – *Musca domestica*) as a substitute for fish meal on the performance of growing rabbits, their carcass characteristics, and hematological and serum biochemical parameters. The inclusion rates of maggot meal in experimental diets were 1.25 to 5%. Maggot meal in the amount of 5% (50% fish meal replacement) had no negative influence on the analyzed traits and parameters.

Insect meals as ingredients of rabbit diets have also been studied in Poland (Gugolek et al., 2019, 2021; Kowalska et al., 2020, 2021; Strychalski et al., 2021). Gugolek et al. (2019) investigated the effect of silkworm pupae meal on rabbit performance. The control diet contained 10% SBM, the first experimental diets contained 5% SBM and 5% silkworm pupae meal, and the second experimental diet – 10% silkworm pupae meal. The study demonstrated that partial and complete replacement of SBM with silkworm pupae meal led to a decrease in the final body weights of rabbits, average daily gain and feed intake, but improved the feed conversion ratio. The values of the analyzed carcass quality traits were lower in rabbits administered silkworm pupae meal. The proximate chemical composition of rabbit meat was not affected by experimental diets, although the proportions of fatty acid groups tended to be more nutritionally desirable in experimental groups.

Kowalska et al. (2020) determined the effects of dried silkworm pupae and mealworm larvae (*Tenebrio molitor*) meals on the carcass and meat quality of rabbits. Dietary supplementation with insect meals increased the final body weights of animals and carcass meat content. The experimental diets had no influence on the concentrations of total essential amino acids in rabbit muscles, but affected the levels of amino acids (phenylalanine, lysine, tryptophan, threonine, isoleucine and methionine). The concentrations of saturated fatty acids (SFAs) and mono-unsaturated fatty acids (MUFAs) in rabbit muscles were similar in all groups. The levels of n-3 PUFAs increased and cholesterol concentrations decreased in the tissues of rabbits receiving silkworm meal. The study demonstrated that dried silkworm pupae and mealworm larvae meals can be included in rabbit diets at 4% with no adverse effects on growth performance or the quality and nutritional value of meat. In a follow-up study, Kowalska et al. (2021) evaluated the effect of silkworm pupae and mealworm larvae meals on the growth performance

of rabbits, and found that SBM can be partially replaced with the analyzed insect-based feeds.

Gugolek et al. (2021) investigated the effect of silkworm pupae meal on nutrient digestibility, nitrogen utilization, gastrointestinal physiology and blood biochemical parameters in rabbits. An increase in the inclusion rates of silkworm pupae meal in rabbit diets was accompanied by a decrease in nutrient digestibility and nitrogen retention. Interestingly, the activity of bacterial N-acetyl-beta-D-glucosaminidase (NAGase) was lowest in the group fed SBM, and highest in the group fed 10% silkworm pupae meal. It was concluded that the inclusion level of silkworm pupae meal in rabbit diets should not exceed 5%.

Strychalski et al. (2021) evaluated the effects of silkworm pupae meal and mealworm larvae meal on productive performance and gastrointestinal function in rabbits. The cited authors reported that silkworm pupae meal (4%) and mealworm larvae meal (4%) increased the final body weights and daily weight gains of rabbits, as well as the digestibility coefficients of fat, acid detergent fiber and acid detergent lignin without compromising the digestibility of other nutrients or energy. Both insect-based products enhanced the activity of cecal and colonic bacterial NAGases due to higher chitin utilization. However, they also disrupted the metabolism of large intestinal microbiota, which was reflected in reduced enzyme activity and lower SCFA concentrations.

Czech researchers, Volek et al. (2021), performed an experiment where SBM was replaced with mealworm

larvae meal (3%) in diets for fattening rabbits. They found that neither the growth of animals nor nutrient digestibility or nitrogen output were compromised by a total dietary replacement of SBM with mealworm meal.

Silkworm pupae, the by-products of sericulture, have long been used in Asia as both foodstuffs and feedstuffs. Their efficacy in rabbit nutrition was investigated only in the 1980s. The 21st century has witnessed a growing global interest in farmed insects used as alternative protein and energy sources for livestock. The potential of housefly pupae meal, silkworm pupae meal and mealworm larvae meal as feed materials for rabbits has been evaluated. Research shows that insect meals can be added to rabbit diets at up to 10%, but based on our studies, we would recommend lower dietary inclusion levels, not exceeding 5%. Wider use of insects as feed will depend on the popularization of insect farming and reduced costs of insect meal. Invertebrates other than insects as rabbit diet components have not received research interest, although the results of some experiments were promising.

Mineral feeds of animal origin in rabbit nutrition

Complete rabbit diets are always supplemented with mineral feeds, usually calcium and phosphorus compounds as well as salt (NaCl). Their total inclusion level does not exceed 3% of the ration. The experiments described below were designed to evaluate whether various mineral additives of animal origin can be used as calcium and phosphorus sources in rabbit diets.

Table 3. Studies investigating rabbit diets containing bone meal

Dietary inclusion level of bone meal (%)	Authors
1.0	Akinfala et al. (2003), Bioibaku et al. (2003), Mbanya et al. (2005), Nodu et al. (2015), Oloruntola (2018)
2.0	Njidda and Isidahomen (2010), Mohammed et al. (2011 b), Ojebiyi et al. (2013), Duwa et al. (2014)
2.5	Fotso et al. (2000), Oshibanjo et al. (2018), Ikyume et al. (2019), Wafar et al. (2019 a)
2.8	Oluwafemi and Adeiza (2017)
3.0	Iyeghe-Erakpotobor (2007), Togun et al. (2009), Adeniji (2012), Nnenna and Kanayo (2013), Ojebiyi and Salu (2014), Vermysy and Ahemen (2019), Wafar et al. (2019 b)
3.5	Okpanachi et al. (2010)
4.0	Akuru et al. (2021)

Table 4. Studies investigating rabbit diets containing animal fat

Type of animal fat	Authors
Beef tallow	Raimondi et al. (1976), Reid et al. (1980), Santomá et al. (1987), Abdelhamid (1989), Fekete et al. (1990), Fernandez and Fraga (1992), Fernandez et al. (1994), Xiccato et al. (1995), Falcão-E-Cunha et al. (1996), Pla and Cervera (1997), Kritchevsky et al. (1998), Pascual et al. (2002), Andrade et al. (2018)
Butter	Kang et al. (1997, 2000), Bansal et al. (2002), Mehta et al. (2002), Purohit and Vyas (2005), Faulconnier et al. (2006), Roy et al. (2007), Elrufai et al. (2015)
Fish oil	Lin et al. (1991), Gillis et al. (1992), Aguilera et al. (2005), Kowalska and Bielański (2009), Kowalska et al. (2011), Castellano et al. (2012), El-Moghazy et al. (2014), Rebollar et al. (2014), Ivanowa et al. (2015), Rodríguez et al. (2017, 2019)
Insect oil	Gasco et al. (2017), Dalle Zotte et al. (2018), Martins et al. (2018), Gasco et al. (2019 a, b, c), Cullere et al. (2021)
Krill oil	Ivanowa et al. (2015)
Poultry fat	Hemid et al. (1995), Hernández et al. (2000), Pascual et al. (2002), Andrade et al. (2018)
Pork lard	Fraga et al. (1989), Gillis et al. (1992), Kritchevsky et al. (1998), Aguilera et al. (2002, 2005), Casado et al. (2010, 2013), García-Quirós et al. (2014), Rebollar et al. (2014), Liang et al. (2015), Rodriguez et al. (2019)

Invertebrate-based mineral feeds

Oyster shells are an example of invertebrate-based mineral feeds. They were added to rabbit diets at 2% (Biobaku et al., 2003; Akinfala et al., 2003) and 3% (Oladunjoye et al., 2014).

Limestone can also be considered a feed ingredient of animal origin. It is a sedimentary rock composed mainly of calcium carbonate (CaCO_3) in different crystal forms such as calcite and aragonite, which also contains the skeletal fragments of marine organisms (corals, foraminifera and mollusks). Limestone is often added to livestock diets (Wheeler and Noller, 1976; Davin et al., 2020; Majeed et al., 2020), and it was also fed to rabbits at 3% (Grobner et al., 1982), 2% (Oluwafemi and Adeiza, 2017), 1% (Tùmowá et al., 2002) and 0.5–1% (Al-Dobaib, 2010).

Vertebrate-based mineral feeds

Bone meal is a slaughterhouse waste product. The bones of various species of farmed mammals, birds and fish are processed into bone meal by different methods. Theoretically, bone meal can be a source of calcium, phosphorus and other minerals in diets for livestock, including rabbits. From a nutritional perspective, bone meal can replace other dietary sources of calcium and phosphorus. The calcium to phosphorus ratio should remain within the recommended range (Orban and Roland, 1992; Lee et al., 2010). However, the use of bone meal as well as meat and bone meal was prohibited in the European Union for a long time (Regulation EC, 2002). Bone meal and meat and bone meal are also valuable mineral fertilizers applied to various crop species (Nogalska et al., 2014). Selected studies that analyzed the optimal inclusion levels of bone meal in rabbit diets are listed in Table 3.

It should be noted that in the cited studies, bone meal was not an experimental factor, but a standard component of rabbit diets, included in the amount of 1% up to even 4%. Bone meal was used as a mineral feed additive primarily in developing countries, and less frequently in Europe and North America, where commercial mineral supplements that do not raise sanitary concerns are widely available. In developed countries, such alternative mineral sources in rabbit diets are often preferred due to their lower costs.

Animal fats in rabbit nutrition

The use of animal fats in rabbit nutrition was described in detail in one of our previous articles (Gugolek and Kowalska, 2020), therefore only major studies addressing this problem are summarized in this review.

Research studies conducted to date have investigated the following animal fat sources in rabbit diets: beef tallow, butter, pork lard, poultry fat, fish oil, krill oil, insect oil as well as mixtures of various animal fats, and vegetable oils and animal fats (Table 4). Their effects

on the growth performance of rabbits, lactation, rearing parameters, meat quality and the health status of animals were evaluated (Table 4). Animal fats, in particular, pork lard and butter, were added to rabbit diets to balance them and to increase their energy value, especially when rabbits were used as model animals in trials examining cardiovascular diseases and obesity (Bertomeu et al., 1990; Aguilera et al., 2002; Bansal et al., 2002; Mehta et al., 2002; Roy et al., 2007; Liang et al., 2015).

The above review indicates that various animal fats can be included in rabbit diets at 2–5% without negative effects on performance, reproduction or meat quality. Moreover, it has been found that meat quality can be modified through the addition of different dietary fat types. It should also be stressed that research into the effects of different animal fats added to rabbit diets contributes to a better understanding of the main causes and mechanisms underlying numerous diseases associated with high-fat diets in humans.

Since each of the main subsections concerning different animal-based feed materials included in rabbit diets contains a fairly detailed description of the cited studies, this review article ends with a short summary focusing on the opportunities and future perspectives regarding the use of this group of feeds in rabbit nutrition.

Conclusion

The efficacy of meals derived from mammals, birds, fish and invertebrates as feed ingredients and additives for rabbits has been evaluated to date. The above feeds can be added to rabbit diets to increase protein content or replace other high-protein components of plant and animal origin. In general, their recommended inclusion rate is 5–10% of the ration. Selected milk products have become standard ingredients of rabbit diets; their optimal inclusion level is 2–2.5% of the ration. Bone meal, treated as a mineral feed additive, is also routinely incorporated into rabbit diets at 1–4%, mostly in developing countries. Animal fats of various origin can be safely added to rabbit diets at 2–5% of the ration.

From a historical perspective, research into the use of animal-based feeds in commercial rabbit diets began in the 1970s and continues to this day. However, their popularity declined when sanitary regulations relating to BSE were introduced. Today, it appears that animal feeds will receive renewed attention as components of diets for different livestock species, including rabbits, because the above restrictions have already been loosened. Another important consideration is the implementation of the announced regulations restricting the use of GM-SBM as the protein source in animal diets. Wider use of animal by-products in rabbit nutrition will also depend on their prices on the feed market. Moreover, consumers should be persuaded to accept animal-derived ingredients in food products.

References

- Abdel-Azeem F., El-Bordeny N.E., Khorshed M.M. (2007). Efficacy of biogen in improving the utilization of dried poultry manure in rabbit diets. *Egypt. J. Rabbit Sci.*, 17: 119–138.
- Abdelhamid A.M. (1989). Possibility of fat addition in the rabbit diets. *Archiv. Anim. Nutr.*, 39: 729–739.
- Adeniji A.A. (2012). Effects of replacing groundnut cake with blood vegetable waste meal in the diets of weaner rabbits. *Int. Schol. Res. Network ISRN Vet. Sci.*, 2012: 1–4.
- Adeniji A.A., Rumak S., Oluwafemi R.A. (2015). Effects of replacing groundnut cake with rumen content supplemented with or without enzyme in the diet of weaner rabbits. *Lipids Health Dis.*, 14: 1–6.
- Aggarwal A.K., Kansal V.K. (1991). Regression of atherosclerosis in rabbit on skim milk diet. *Milchwissenschaft*, 46: 766–769.
- Aggarwal R.A., Kansal V.K. (1992). Effect of skim milk on progression of atherosclerosis in cholesterol-fed rabbits. *Indian J. Med. Res.*, 96: 53–59.
- Aguilera C.M., Ramírez-Tortosa M.C., Mesa M.D., Ramírez-Tortosa C.L., Gil A. (2002). Sunflower, virgin-olive and fish oils differentially affect the progression of aortic lesions in rabbits with experimental atherosclerosis. *Atherosclerosis*, 162: 335–344.
- Aguilera C.M., Ramírez-Tortosa C.L., Quiles J.L., Yago M.D., Martínez-Burgos M.A., Martínez-Victoria E., Gil A., Ramírez-Tortosa M.C. (2005). Monounsaturated and-3 but not-6 polyunsaturated fatty acids improve hepatic fibrosis in hypercholesterolemic rabbits. *Nutrition*, 21: 363–371.
- Ahlawat S.S., Sharma D.P., Panda P.C. (2001). Effect of feeding poultry viscera meal on carcass traits of broiler rabbits. *Indian J. Anim. Res.*, 35: 141–143.
- Ahlawat S.S., Khanna N., Sharma D.P., Panda P.C. (2003). Effect of feeding poultry viscera meal on wool traits of Angora rabbits. *Indian J. Anim. Res.*, 37: 152–156.
- Akinfala E.O., Matanmi O., Aderibigbe A.O. (2003). Preliminary studies on the response of weaned rabbits to whole cassava plant meal basal diets in the humid tropics. *Livest. Res. Rural Develop.*, 15: 10–14.
- Akuru E.A., Ani A.O., Orji J.A., Oyeagu C.E., Osita C.O., Idamokoro M.E., Ogwuegbu M.C., Lewu F.B. (2021). Nutrient digestibility, growth, carcass, and bio-marker traits of weaner rabbits fed diets containing graded levels of cowpea (*Vigna unguiculata*) hull meal. *J. Appl. Anim. Res.*, 49: 39–45.
- Akuzawa M., Matsunuma N., Suzuki Y. (1978). Hand-rearing of rabbits using rabbit milk and commercial milk powder, Teo Milk®. *Exp. Anim.*, 27: 427–429.
- Alagón G., Arce O.N., Martínez-Paredes E., Ródenas L., Cervera C., Pascual J.J. (2014). Effect of inclusion of distillers dried grains and solubles from barley, wheat and corn in isonutritive diets on the performance and caecal environment of growing rabbits. *World Rabbit Sci.*, 22: 195–205.
- Al-Dobaib S.N. (2010). Effect of diets on growth, digestibility, carcass and meat quality characteristics of four rabbit breeds. *Saudi J. Biol. Sci.*, 17: 83–93.
- Alemede I.C., Aremu A., Oriade I., Ijaiya, A.T. (2014). Reproductive performance of rabbits (*Oryctolagus cuniculus*) fed diets containing varying levels of dried bovine rumen digesta. *Adv. Life Sci. Technol.*, 23: 43–50.
- Alemi H., Asghari A., Abedi G., Akbarzadeh A., Mortazavi P. (2019). The effects of nanocomposite containing ostrich eggshell on calvaria bone formation in rabbit: radiographic and hematological survey. *Cresc. J. Med. Biol. Sci.*, 6: 18–23.
- Al-Harthi M.A., El-Deek A.A., Salah El-Din M., Alabdeen A.A. (2010). A nutritional evaluation of hatchery by-product in the diets for laying hens. *Egypt. Poultry Sci.*, 30: 339–351.
- Alhussary B.N., Taqa Gh.A., Taqa A.A. (2020). Histological effects of adding gold to (eggshell and seashell) nanohydroxyapatite on rabbits bone healing. *Al-Rafidain Dent. J.*, 20: 46–54.
- Anashar A.A., Daoud A. (2019). Evaluation of the activity of hen eggshell graft in experimentally induced mandibular defects in rabbits: pilot study. *Int. J. Res. Med. Sci.*, 7: 1133–1135.
- Andrade T.H.L.D., Pascoal L.A.F., Martins T.D.D., Silva J.H.V., Silva J.F.D., Watanabe P.H., Ferreira V.C.D.S. (2018). Performance, fatty acids profile and oxidative stability of meat of rabbits fed different lipid sources. *Food Sci. Technol.*, 38: 351–356.
- Aribi M., Smahi I., Taïbi A. (2010). Effects of casein and adapted milk formula on the proliferation of lymphocytes, mid-cells and granulocytes and on circulating lipids. *Pediatr. Res.*, 68: 355.
- Auerbach B.J., Krause B.R., Bisgaier C.L., Newton R.S. (1995). Comparative effects of HMG-CoA reductase inhibitors on apo B production in the casein-fed rabbit: atorvastatin versus lovastatin. *Atherosclerosis*, 115: 173–180.
- Auxilla M.T., Moseoro G., Bergolio G., Terramocchia S. (1982). Use of poultry litter for feeding rabbits. I. Growth trial. *Nutr. Abstracts rev. Series B.*, 52: 234.
- Ayanwale B.A. (2006). An evaluation of hydrolysed feather meal as a protein source in rabbit diets. *Res. J. Biol. Sci.*, 1: 32–35.
- Bansal G., Singh U., Bansal M.P. (2002). Changes in heat shock protein 70 localization and its content in rabbit aorta at various stages of experimental atherosclerosis. *Cardiovasc. Pathol.*, 11: 97–103.
- Batterham E.S., Lowe R.F., Darnell R.E. (1986). Availability of lysine in meat meal, meat and bone meal and blood meal as determined by the slope-ratio assay with growing pigs, rats and chicks and by chemical techniques. *Br. J. Nutr.*, 55: 427–440.
- Bergeron N., Jacques H. (1990). Influence of dietary carbohydrates on cholesterol metabolism in casein-fed rabbits. *Nutr. Res.*, 10: 1455–1462.
- Bertomeu M.C., Crozier G.L., Haas T.A., Fleith M., Buchanan M.R. (1990). Selective effects of dietary fats on vascular 13-hode synthesis and platelet/vessel wall interactions. *Thromb. Res.*, 59: 819–830.
- Beynen A.C., West C.E. (1981). The distribution of cholesterol between lipoprotein fractions of serum from rabbits fed semipurified diets containing casein and either coconut oil or corn oil. *J. Anim. Physiol. Anim. Nutr.*, 46: 233–239.
- Beynen A.C., den Engelsman G., Scholz K.E., West C.E. (1983 a). Casein-induced hypercholesterolemia in rabbits: distribution of cholesterol, triglycerides and phospholipids between serum and liver. *Ann. Nutr. Metab.*, 27: 117–124.
- Beynen A.C., Winnubst E.N.W., West C.E. (1983 b). The effect of replacement of dietary soybean protein by casein on the fecal excretion of neutral steroids in rabbits. *J. Anim. Physiol. Anim. Nutr.*, 49: 43–49.
- Biobaku W.O., Bamgbose A.M., Achike C.U. (2003). Utilisation of different protein sources for growing rabbits. *Pertanika J. Trop. Agric. Sci.*, 26: 73–77.
- Blas E., Moya A., Cervera C., Fernandez Carmona J. (1990). Use of a feed with milk for suckling rabbits. *Avances Aliment. Mej. Anim.*, 30: 155–157.
- Bumann G., Stauffer D. (2002). Scavenging of ruffed grouse in the appalachians: influences and implications. *Wildl. Soc. Bull.*, 30: 853–860.
- Canzi E., Zanchi R., Camaschella P., Cresci A., Greppi G.F., Orpianesi C., Serrantoni M., Ferrari A. (2000). Modulation by lactic-acid bacteria of the intestinal ecosystem and plasma cholesterol in rabbits fed a casein diet. *Nutr. Res.*, 20: 1329–1340.
- Caroppo S., Toppino P.M., Masoero G., Auxilia M.T. (1980). Production of a spray-dried lactic acid bacteria feed additive, its use in a whey-supplemented diet for rabbits, and the effects of its entry into the intestinal tract. *Ann. Microb. Enzimol.*, 30: 171–181.
- Carregal R.D., Takahashi R. (1987). Use of silkworm (*Bombyx mori* L.) chrysalis meal as a replacement for soyabean meal in the feeding of growing rabbits. *Rev. Brasil. Zootec.*, 16: 158–162.
- Casado C., Moya V.J., Fernández C., Pascual J.J., Blas E., Cervera C. (2010). Diet digestibility in growing rabbits: effect of origin and oxidation level of dietary fat and vitamin E supplementation. *World Rabbit Sci.*, 18: 57–63.
- Casado C., Moya V.J., Pascual J.J., Blas E., Cervera C. (2013). Dietary fatty acid profile: effects on caecal fermentation and performance of young and fattening rabbits. *World Rabbit Sci.*, 21: 235–242.
- Castellano C.A., Audet I., Laforest J.P., Matte J.J. (2012). Fish oils, omega-3 fatty acids and male fertility. In: *Fish Oil: Production,*

- consumption and health benefits, Chapter XII. Nova Science Publishers, pp. 283–300.
- Castillo-Rodríguez S.P., Aguilar-Reyes J.M., Lucero-Magaña F.A., Martínez-González J.C. (2007). Sustitución de alimento comercial por excretas en la dieta de conejos en crecimiento. Substitution of commercial feed for manure in the diet of rabbits in growth. *Avan. Invest. Agropec.*, 11: 41–48.
- Chao Y.S., Yamin T.T., Alberts A.W. (1982). Effects of cholestyramine on low density lipoprotein binding sites on liver membranes from rabbits with endogenous hypercholesterolemia induced by a wheat starch-casein diet. *J. Biol. Chem.*, 257: 3623–3627.
- Chao Y.S., Kroon P.A., Yamin T.T., Thompson G.M., Alberts A.W. (1983). Regulation of hepatic receptor-dependent degradation of LDL by mevinolin in rabbits with hypercholesterolemia induced by a wheat starch-casein diet. *Biochim. Biophys. Acta.*, 754: 134–141.
- Chao Y.S., Yamin T.T., Seidenberg J., Kroon P.A. (1986). Secretion of cholesteryl-ester-rich lipoproteins by the perfused livers of rabbits fed a wheat-starch-casein diet. *Biochim. Biophys. Acta.*, 876: 392–398.
- Chelmińska A., Kowalska D. (2013). The effectiveness of maize DDGS in rabbit diets. *Ann. Anim. Sci.*, 13: 571–585.
- Cho J.H., Kim I.H. (2010). Fish meal – nutritive value. *J. Anim. Phys. Anim. Nutr.*, 95: 685–692.
- Christiansen A.T., Andersen M.M., Kappel K. (2019). Are current EU policies on GMOs justified? *Transgenic Res.*, 28: 267–286.
- Clauss M., Lischke A., Botha H., Hatt J.M. (2016). Carcass consumption by domestic rabbits (*Oryctolagus cuniculus*). *Eur. J. Wildl. Res.*, 62: 143–145.
- Coach J.R. (1974). Evaluation of poultry manure as a feed ingredient. *World Poul. Sci.*, 30: 279–289.
- Colina R., Coppings R. (1989). Feeding fresh liquid sweet whey to weaned New Zealand White rabbits. *J. Appl. Rabbit Res.*, 12: 31–32.
- Commission Regulation (EU) 2021/1372 of 17 August 2021 amending Annex IV to Regulation (EC) No. 999/2001 of the European Parliament and of the Council as regards the prohibition to feed non-ruminant farmed animals, other than fur animals, with protein derived from animals (Text with EEA relevance).
- Coppings R.J., Ekhtor N.N. (1990). Incorporation of dehydrated whey in diets for growing rabbits. *J. Appl. Rabbit Res.*, 13: 62–65.
- Cullere M., Singh Y., Gerencsér Z., Matics Z., Cappelozza S., Zotte A.D. (2021). Silkworm (*Bombyx mori* L.) oil in growing rabbit nutrition: effects on meat physicochemical traits, sensory profile and shelf-life. *J. Insects Food Feed.*, 8: 733–741.
- Dairo F.A.S., Aina O.O., Asafa A.R. (2005). Performance evaluation of growing rabbits fed varying levels of rumen content and blood rumen content mixture. *Niger. J. Anim. Prod.*, 32: 67–72.
- Dalle Zotte A., Cullerea M., Martins C., Alves S.P., Freire J.P.B., Falcão-e-Cunha L., Bessa R.J.B. (2018). Incorporation of Black Soldier Fly (*Hermetia illucens* L.) larvae fat or extruded linseed in diets of growing rabbits and their effects on meat quality traits including detailed fatty acid composition. *Meat Sci.*, 146: 50–58.
- Daszkiewicz T., Gugolek A., Janiszewski P., Kubiak D., Czoik M. (2012). The effect of intensive and extensive production systems on carcass quality in New Zealand White rabbits. *World Rabbit Sci.*, 20: 25–33.
- Davin R., Kwakernaak C., Dersjant-Li Y. (2020). Effect of two commercial limestone sources with different solubility on the efficacy of two phytases in 0–21 d old broilers. *J. Appl. Anim. Nutr.*, 8: 61–73.
- Donadelli R.A., Jones C.K., Beyer R.S. (2019). The amino acid composition and protein quality of various egg, poultry meal by-products, and vegetable proteins used in the production of dog and cat diets. *Poultry Sci.*, 98: 1371–1378.
- Dong F.M., Hardy R.W., Haard N.F., Barrows F.T., Rasco B.A., Fairgrieve W.T., Forster I.P. (1993). Chemical composition and protein digestibility of poultry by-product meals for salmonid diets. *Aquaculture*, 116: 149–158.
- Durmus E., Celik I., Ozturk A., Ozkan Y., Aydin M.F. (2003). Evaluation of the potential beneficial effects of ostrich eggshell combined with eggshell membranes in healing of cranial defects in rabbits. *J. Int. Med. Res.*, 31: 223–230.
- Durmus E., Celik I., Aydin M.F., Yildirim G., Sur E. (2008). Evaluation of the biocompatibility and osteoprotective activity of ostrich eggshell powder in experimentally induced calvarial defects in rabbits. *J. Biomed. Mater. Res. B Appl. Biomater.*, 86: 82–89.
- Duwa H., Saleh B., Igwebuike J.U. (2014). The replacement of fish meal with maggot meal on the performance, carcass characteristic, hematological and serum biochemical indices of growing rabbits. *Glob. J. Bio-Sci. Biotech.*, 3: 215–220.
- Ekpenyong T.E., Biobaku W.O. (1986). Growth response of rabbit fed activated sewage sludge and dried poultry waste. *J. Appl. Rabbit Res.*, 9: 14–16.
- El-Adawy M.M. (1997). Utilization of dry sediment of rumen liquor in rabbit nutrition. *Egypt. J. Rabbit Sci.*, 7: 107–122.
- El-Moghazy M., Zedan N.S., El-Atrsh A.M., El-Gogary M., Tousson E. (2014). The possible effect of diets containing fish oil (omega-3) on hematological, biochemical and histopathological alterations of rabbit liver and kidney. *Biomed. Prevent. Nutr.*, 4: 371–377.
- Elrufai S., Mohamed H.E., Barriand M.E.S., Elsammani F. (2015). The effects of fat sources on lipid profile in New Zealand rabbits. *Inter. J. Agric. Sci. Res.*, 4: 035–038.
- Falcão-E-Cunha L., Bengla Freire J.P., Gonçalves A. (1996). Effect of fat level and fiber nature on performances, digestibility, nitrogen balance and digestive organs in growing rabbits. *Proc. VI World Rabbit Congress, Toulouse, France, 9–12.07.1996*, 1: 157–162.
- Fanimo A.O., Oduguwa O.O., Adesehinwa A.O.K., Akinsola A.O., Ojo T.A. (2002). Comparative utilization of five animal protein concentrates by domestic rabbits. *ASSET - Series A: Agric. Environ.*, 2: 81–89.
- Fatufe A.A., Matanmi I.O., Alalade A.O. (2010). Performance and carcass characteristics of growing rabbits fed bacterial protein meal. *African J. Food, Agric., Nutr. Develop.*, 10: 2413–2426.
- Faulconnier Y., Roy A., Ferlay A., Chardigny J.-M., Durand D., Lorenz S., Gruffat D., Chilliard Y. (2006). Effect of dietary supply of butters rich either in trans-10-18 : 1 or in trans-11-18 : 1 plus cis-9, trans-11-18 : 2 on rabbit adipose tissue and liver lipogenic activities. *Brit. J. Nutr.*, 96: 461–468.
- Fekete S. (1985). A potential source of feed [for rabbits]. *Krolikovodstvo Zverovodstvo*, 9.
- Fekete S., Hegedus M. (1986). On the utilization of enzymatically digested feathers in rabbit feeding. *J. Appl. Rabbit Res.*, 9: 175–177.
- Fekete S., Hullár I., Fébel H. (1990). Rabbit digestion and blood composition after fat or oil addition to the feed. *J. Appl. Rabbit Res.*, 12: 233–238.
- Fernandez C.J., Fraga M.J. (1992). Effect of sources and inclusion level of fat on growth performance. *J. Appl. Rabbit Res.*, 15: 1071–1078.
- Fernandez C., Cobos A., Fraga M.J. (1994). The effect of fat inclusion on diet digestibility in growing rabbits. *J. Anim. Sci.*, 72: 1508–1515.
- Finke M.D. (2002). Complete nutrient composition of commercially raised invertebrates used as food for insectivores. *Zoo Biol.*, 21: 269–285.
- Fotso J.M., Fomunyan R.T., Ndoping B.N. (2000). Protein and energy sources for rabbit diets in Cameroon. 1 – protein sources. *World Rabbit Sci.*, 8: 57–60.
- Fraga M.J., Lorente M., Carabaño R.M., de Blas J.C. (1989). Effect of diet and of remating interval on milk production and milk composition of the doe rabbit. *Anim. Sci.*, 48: 459–466.
- Furlan A.C., Fraiha M., Scapinello C., Murakami A.E., Moreira I. (1997). Soybean meal replacement by protein hydrolyzed cattle hide scrap meal in growing rabbit diets. *Rev. UNIMAR*, 19: 905–912.
- Galan G.L., De Souza Franco M.L.R., De Souza E.D., Scapinello C., Gasparino E., Visentainer J.V., Del Vesco A.P. (2013). Meal of Nile Tilapia carcass in diets for rabbits: chemical composition and bone resistance. *Ciênc. Agrár.*, Londrina, 34: 2473–2484.
- García-Quirós A., Arnau-Bonachera A., Penadés M., Cervera C., Martínez-Paredes E., Ródenas L., Selva L., Vianaa D., M.Corpa J., Pascual J.J. (2014). A robust rabbit line increases leucocyte counts

- at weaning and reduces mortality by digestive disorder during fattening. *Vet. Immunol. Immunopath.*, 161: 123–131.
- Gasco L., Dabbou S., Meneguz M., Renna M., Brugiapaglia A., Dama A., Bressan E., Schiavone A., Trocino A., Gratta F., Birolo M., Xiccato G., Zoccarato I., Gai F. (2017). Partial or total substitution of soybean oil by *Tenebrio molitor* oil or *Hermetia illucens* fat in rabbit diets. Preliminary results: effects on growth and slaughtering performances. Proc. III Insecta Conference, Berlin, Germany, 7–8.09.2017, pp. 60–62.
- Gasco L., Biasato I., Dabbou S., Schiavone A., Gai F. (2019 a). Animals fed insect-based diets: state-of-the-art on digestibility, performance and product quality. *Animals*, 9: 170.
- Gasco L., Dabbou S., Trocino A., Xiccato G., Capucchio M.T., Biasato I., Dezzutto D., Birolo M., Meneguz M., Schiavone A., Gai F. (2019 b). Effect of dietary supplementation with insect fats on growth performance, digestive efficiency and health of rabbits. *J. Anim. Sci. Biotechnol.*, 10: 1–9.
- Gasco L., Dabbou S., Gai F., Brugiapaglia A., Schiavone A., Birolo M., Xiccato G., Trocino A. (2019 c). Quality and consumer acceptance of meat from rabbits fed diets in which soybean oil is replaced with black soldier fly and yellow mealworm fats. *Animals*, 9: 629.
- Gasmi-Boubaker A., Abdouli H., El Hichi M., Faiza K., Tayachi L. (2007). Feeding rapeseed meal to rabbits: digestibility, performance and carcass characteristics. *Asian J. Anim. Vet. Adv.*, 2: 38–41.
- Gillis A.M., Keashly R., Watson P.A., Mathison H.J., Parsons H.G. (1992). Influence of dietary fat on the pharmacodynamics of propafenone in isolated, perfused rabbit hearts. *Circulation*, 85: 1501–1509.
- González-Redondo P., Zamora-Lozano M. (2008). Neonatal cannibalism in cage-bred wild rabbits (*Oryctolagus cuniculus*). *Archiv. Med. Vet.*, 40: 281–287.
- Grobner M.A., Harris D.J., Cheeke P.R., Patton N.M. (1982). Effect of dietary buffers and zeolite on growth and mortality of weanling rabbits. Proc. Annual Meeting. American Society for Animal Science Western Section, USA, 33: 340–343.
- Gugolek A., Kowalska D. (2020). Animal fats in rabbit feeding – a review. *Ann. Anim. Sci.*, 20: 1185–1215.
- Gugolek A., Lorek M.O., Kowalska D., Janiszewski P., Daszkiewicz T. (2008). Wpływ systemu utrzymania i żywienia na wyniki produkcyjne i stopień zarażenia kokcydiami królików białych nowozelandzkich (in Polish). *Rocz. Nauk. Pol. Tow. Zoot.*, 4: 39–44.
- Gugolek 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.
- Gugolek A., Juśkiewicz J., Strychalski J., Zwoliński C., Żary-Sikor ska 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.
- Gugolek 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.
- Gugolek 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.
- Halga M. (1974). Nutritive value of feeds for domestic rabbits. *Lucrari Stiintifice, Institutul Agronomic, Iasi*, II: 25–26.
- Handa M.C., Sapra K.L., Shingari B.K. (1996). Effect of feeding extruded hatchery waste on the performance of Soviet Chinchilla rabbits. *World Rabbit Sci.*, 4: 89–92.
- Hassan A., Gibril S., Sabahelkhiar M. (2014). Effect of different concentration of acid whey in drinking water on rabbit performance. *Int. J. Adv. Res.*, 2: 996–999.
- Hemid A.A., El-Zeiny M.A., Abdel-Azeem F. (1995). Effects of dietary fat and/or oil on rabbit productive performance under intensive meat production. *Egypt. J. Rabbit Sci.*, 5: 77–88.
- Hendriks W.H., Butts C.A., Thomas D.V., James K.A.C., Morel P.C.A., Verstegen M.W.A. (2002). Nutritional quality and variation of meat and bone meal. *Asian-Austral. J. Anim. Sci.*, 15: 1507–1516.
- Hernández P., Pla M., Oliver M.A., Blasco A. (2000). Relationships between meat quality measurements in rabbits fed with three diets of different fat type and content. *Meat Sci.*, 55: 379–384.
- Ikyume T.T., Ogu I.E., Okwori I.A., Shaahu D.T. (2019). Growth performance and apparent nutrient digestibility of grower rabbits fed combinations of concentrate with grass and/or legume forage. *J. Multidisc. Res. Rev.*, 1: 41–45.
- Isaac L.J., Okonkwo A.C., Eyoh G.D., Ekpenyong A.E., Akata O.R. (2007). Performance of weaner rabbits fed growers mash supplemented with graded levels of hatchery waste meal. *J. Anim. Vet. Adv.*, 6: 1262–1264.
- Ivanova Z., Bjørndal B., Grigorova N., Roussenov A., Vachkova E., Berge K., Burri L., Berge R., Stanilova S., Milanova A., Penchev G., Vik R., Petrov V., Mircheva Georgieva T., Bivolraski B., Penchev Georgiev I. (2015). Effect of fish and krill oil supplementation on glucose tolerance in rabbits with experimentally induced obesity. *Eur. J. Nutr.*, 54: 1055–1067.
- Iyeghe-Erakpotobor G.T. (2007). Effect of concentrate and forage type on performance and digestibility of growing rabbits under sub-humid tropical conditions. *Asian J. Anim. Vet. Adv.*, 2: 125–132.
- 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.
- Jeziński T., Konecka A.M. (1994). Effect of feeding egg yolk on total plasma cholesterol and atherosclerosis in young rabbits. *J. Anim. Feed Sci.*, 3: 317–324.
- Kang B.P.S., Mehta U., Bansal M.P. (1997). Effect of diet induced hypercholesterolemia and selenium supplementation on nitric oxide synthase activity. *Archiv. Phys. Bioch.*, 105: 603–607.
- Kang B.P.S., Bansal M.P., Mehta U. (2000). Hyperlipidemia and Type I 5'-monodeiodinase activity: Regulation by selenium supplementation in rabbits. *Biol. Trace Element Res.*, 77: 231–239.
- Karikari P., Darkoh G., Deku G. (2011). Evaluation of millet residue meal based diets as feed for the domestic rabbit (*Oryctolagus cuniculus*). *Res. Opin. Anim. Vet. Sci.*, 1: 144–149.
- Khosla P., Samman S., Carroll K.K., Huff M.W. (1989). Turnover of 125I-VLDL and 131I-LDL apolipoprotein B in rabbits fed diets containing casein or soy protein. *Biochim. Biophys. Acta (BBA)-Lipids and Lipid Metab.*, 1002: 157–163.
- Khosla P., Samman S., Carroll K.K. (1991). Decreased receptor-mediated LDL catabolism in casein-fed rabbits precedes the increase in plasma cholesterol levels. *J. Nutr. Biochem.*, 2: 203.
- Kishawy A.T.Y., Amer S.A., Osman A., Elsayed S.A.M., Abd El-Hack M.E., Swelum A.A., Ba-Awadh H., Saadeldin I.M. (2018). Impacts of supplementing growing rabbit diets with whey powder and citric acid on growth performance, nutrient digestibility, meat and bone analysis, and gut health. *AMB Express*, 8: 86.
- Konecka A.M., Jeziński T., Wnuk A. (1996). Effect of feeding cholesterol-enriched diet on plasma and tissue cholesterol and atherosclerosis in rabbits. *J. Anim. Feed Sci.*, 5: 163–173.
- Korver D.R., Klasing K.C. (1997). Dietary fish oil alters specific and inflammatory responses in chicks. *J. Nutr.*, 127: 2039–2046.
- Kowalska D., Bielański P. (2009). Meat quality of rabbits fed a diet supplemented with fish oil and antioxidant. *Anim. Sci. Pap. Rep.*, 27: 139–148.
- Kowalska D., Bielański P., Chelmińska A. (2011). Effect of linseed and fish oil supplements in feed on fatty acid profile and intramuscular fat oxidation in rabbits (in Polish). *Żywn. Nauka. Technol. Jakość*, 2: 148–159.
- Kowalska D., Gugolek A., Strychalski J. (2020). 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. Pecu.*, 12: 151–162.
- Kritchevsky D., Tepper S.A., Weber M.M., Klurfeld D.M. (1988). Influence of soy protein or casein on pre-established atherosclerosis in rabbits. *Artery*, 15: 163–169.

- Kritchovsky D., Tepper S.A., Kuksis A., Eghtedary K., Klurfeld D.M. (1998). Cholesterol vehicle in experimental atherosclerosis. 21. Native and randomized lard and tallow. *J. Nutr. Biochem.*, 9: 582–585.
- Kuuyvenhoven M., Roszkowski W., West C., Hoogenboom, R., Vos R., Beynen A., Van Der Meer R. (1989). Digestibility of casein, formaldehyde-treated casein and soya-bean protein in relation to their effects on serum cholesterol in rabbits. *Brit. J. Nutr.*, 62: 331–342.
- Landete-Castillejos T., Currey J.D., Estevez J.A., Gaspar-López E., García A., Gallego L. (2007). Influence of physiological effort of growth and chemical composition on antler bone mechanical properties. *Bone*, 41: 794–803.
- Lebas F. (2004). Reflections on rabbit nutrition with a special emphasis on feed ingredients utilization. Proc. VIII World Rabbit Congress, Puebla, Mexico, 7–10.09.2004, pp. 686–736.
- Lee K.-J., Powell M.S., Barrows F.T., Smiley S., Bechtel P., Hardy R.W. (2010). Evaluation of supplemental fish bone meal made from Alaska seafood processing byproducts and dicalcium phosphate in plant protein based diets for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, 302: 248–255. <https://doi.org/10.1016/j.aquaculture.2010.02.034>
- Liang S.N., Xu K., Zhong H.S. (2015). Establishment of rabbit abdominal aortic atherosclerosis model by pancreatic elastase infiltration associated with high fat diet. *Acta Cardiol. Sin.*, 31: 406–413.
- Lin D.S., Anderson G.J., Connor W.E. (1991). High levels of the (n-6) fatty acid 4,7,10,13,16-docosapentaenoate in the retinas of rabbits are reduced by feeding dietary fish oil from birth to adult life. *J. Nutr.*, 121: 1924–1931.
- Liu M.L., Tang L.M., Yan J.P., Liu Y.G. (1987). Effects of concentrated rapeseed protein on growing rabbits. *Chinese J. Anim. Sci.*, 2: 20–22.
- Lounaoui-Ouyed G., Berchiche M.G., Gidenne T. (2014). Effects of substitution of soybean meal-alfalfa-maize by a combination of field bean or pea with hard wheat bran on digestion and growth performance in rabbits in Algeria. *World Rabbit Sci.*, 22: 137–146.
- Lovati M.R., West C.E., Sirtori C.R., Beynen A.C. (1990). Dietary animal proteins and cholesterol metabolism in rabbits. *Brit. J. Nutr.*, 64: 473–485.
- Lyu J.M., Cai Z.W., Cai Y.Q., Xu J.Q., Zhu K.Y. (2013). Effects of whey powder on growth performance, antioxidant and immune functions of weanling laboratory rabbits. *Chinese J. Anim. Nutr.*, 25: 2951–2957.
- Majeed S., Qudsieh R., Edens F.W., Brake J. (2020). Limestone particle size, calcium and phosphorus levels, and phytase effects on live performance and nutrients digestibility of broilers. *Poultry Sci.*, 99: 1502–1514.
- Martin G.R., Twigg L.E., Zampichelli L. (2007). Seasonal changes in the diet of the European rabbit (*Oryctolagus cuniculus*) from three different Mediterranean habitats in south-western Australia. *Wildl. Res.*, 34: 25–42.
- Martina C., Poleacu T., Vintila M. (1987). Use of poultry dropping in fattening rabbits. *Nut. Abst. Rev.*, 57: 4200.
- Martins H., Milne J.A., Rego F. (2002). Seasonal and spatial variation in the diet of the wild rabbit (*Oryctolagus cuniculus*) in Portugal. *J. Zool.*, 258: 395–404.
- Martins C., Cullere M., Dalle Zotte A., Cardoso C., Alves S.P., Branquinho de Bessa R.J., Freire J.P.B., Falcão-e-Cunha L. (2018). Incorporation of two levels of Black Soldier Fly (*Hermetia illucens* L.) larvae fat or extruded linseed in diets of growing rabbits: Effects on growth performance and diet digestibility. *Czech J. Anim. Sci.*, 63: 356–362.
- Masoero G., Auxilia M.T., Toppino P.M. (1980 a). The use of lactic acid bacteria in rabbit diets containing dried whey. *Annali dell'Istituto Sperimentale per la Zootecnia* 13: 37–51.
- Masoero G., Auxilia M.T., Caroppo S., Toppino P. (1980 b). Lactic bacteria in feeding growing rabbits with supplementation of dried whey *Streptococcus faecium*. *Annali dell'Istituto Sperimentale per la Zootecnia*, 3: 37–51.
- Masoero G., Auxilia M.T., Bergoglio G., Toppino P.M., Bossi M.G., Lizzoli G., Contarini G. (1982). Dried whey, hydrolysed whey and *Streptococcus faecium* in diets for growing rabbits. *Annali dell'Istituto Sperimentale per la Zootecnia*, 2: 85–99.
- Mbahi T.F., Adi A., Yakubu B., Wafar R.J. (2018). Effect of yeast treated bovine blood-rumen content mixture on performance and blood profile of weaner rabbits. *Nigerian J. Anim. Prod.*, 45: 106–113.
- Mbanya J.N., Ndoping B.N., Mafeni J.M., Fomunyan D.W. (2005). The effect of different protein sources and their combination on the performance of growing rabbits in tropical conditions. *Livest. Res. Rural Dev.*, 17: 32.
- Mehta U., Kang B.P.S., Kukreja R.S., Bansal M.P. (2002). Ultrastructural examination of rabbit aortic wall following high-fat diet feeding and selenium supplementation: A transmission electron microscopy study. *J. Appl. Toxicol.*, 22: 405–413.
- Mohammed G., Igwebuike J.U., Kwari I.D. (2005). Performance of growing rabbits fed graded levels of goat rumen content. *Glob. J. Pure Appl. Sci.*, 11: 39–43.
- Mohammed G., Igwebuike J.U., Ubosi C.O., Alade N.K. (2008). Comparative study of the nutrient composition, amino acid profile and microbial assay of fresh and dried cattle, camel, sheep and goat rumen content. Proc. XIII Annual Conference of Animal Science Association of Nigeria (ASAN) ABU Zaria, 15–19.09.2008, pp. 518–520.
- Mohammed G., Igwebuike J.U., Alade N.K. (2011 a). Performance of growing rabbits fed graded levels of goat blood-rumen content meal. *Int. J. Sci. Nat.*, 2: 38–41.
- Mohammed G., Igwebuike J.U., Alade N.K. (2011 b). Performance of growing rabbits fed graded levels of bovine blood-rumen content mixture. *Agric. Biol. J. N. Am.*, 2: 720–723.
- Mohammed G., Igwebuike J.U., Alade N.K. (2012). Haematological and serum biochemical indices of growing rabbits fed bovine blood rumen-content mixture (BBRCM). *Agric. Biol. J. N. Am.*, 2: 724–728.
- Mokhtar S., Radwan M., Essmat M., Omar M., Aly M. (2002). The use of dried pigeon dropping in rabbit nutrition. *CIHEAM, Option Mediterraneenes*, 169–175.
- Moritz J.S., Latshaw J.D. (2001). Indicators of nutritional value of hydrolyzed feather meal. *J. Poultry Sci.*, 80: 79–86.
- Nengas I., Alexis M.N., Davies S.J. (1999). High inclusion levels of poultry meals and related byproducts in diets for gilthead seabream *Sparus aurata* L. *Aquaculture*, 179: 13–23.
- Newburgh L.H., Squier T.L. (1920). High protein diets and arteriosclerosis in rabbits – A preliminary report. *Arch. Int. Med.*, 26: 38–40.
- Newburgh L.H., Clarkson S. (1922). Production of arteriosclerosis in rabbits by diets rich in animal protein. *J. Am. Med. Assoc.*, 79: 1006–1108.
- Newburgh L.H., Clarkson S. (1923). The production of arteriosclerosis in rabbits by feeding diets rich in meat. *Arch. Int. Med.*, 31: 653–676.
- Niedźwiadek S., Kawińska J. (1981). Suitability of krill meal for fattening rabbits. *Rocz. Nauk. Zoot.*, 8: 245–253.
- Nijdam D., Rood T., Westhoek H. (2012). The price of protein: review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy*, 37: 760–770.
- Njidda A.A., Isidahomen C.E. (2010). Haematology, blood chemistry and carcass characteristics of growing rabbits fed grasshopper meal as a substitute for fish meal. *Pak. Vet. J.*, 30: 7–12.
- Nnenna O.P., Kanayo O. (2013). Impact of feeding spice-treated bovine blood rumen content mixtures on productive performance and economics of production of weaned rabbits. *Int. J. Agric. Innovat. Res.*, 1: 195–199.
- Nodu M.B., Okpeku M., Nengi D.V., Suofe P. (2015). Effects of feeding graded levels of *Costus afer* on growth, organ weight and haematological indices of growing rabbits. *J. Agric. Vet. Sci.*, 8: 23–27.
- Nogalska A., Chen L., Sienkiewicz S., Nogalski Z. (2014). Meat and bone meal as nitrogen and phosphorus supplier to cereals and oil-seed rape. *Agric. Food Sci.*, 23: 19–27.
- Ogunsipe M.H. (2011). Effects of feeding layer's litter on performance and microbial diversity of the faeces of growing rabbits. *J. Anim. Prod. Adv.*, 7: 206–213.
- Ogunsipe M.H. (2014). Effect of poultry litter with or without enzyme supplementation on the growth performance, nutrient digestibility and economy of rabbit production. *Int. J. Livest. Prod.*, 5: 23–29.

- Ojebiyi O.O., Saliu A.S. (2014). Effects of feeding bovine rumen content-blood meal (50:50) mixtures on performance and slaughter characteristics of growing rabbits. *J. Anim. Plant Sci.*, 24: 430–434.
- Ojebiyi O.O., Farinu G.O., Babatunde G.M., Morohunfolu O.O. (2006). Effect of varying levels of sun-dried cassava peel-blood meal mixtures (3:2) on growth performance and organ characteristics of weaner rabbits. *J. Anim. Vet. Adv.*, 5: 886–890.
- Ojebiyi O.O., Shittu M.D., Oladunjoye I.O., Omotola O.B., Olaniyi S.A. (2013). Haematology, carcass and relative organ weights of growing rabbits on skip-a-day concentrate feeding regime. *Int. J. Appl. Agric. Apic. Res.*, 9: 167–174.
- Ojebiyi O.O., Oladunjoye I.O., Rafiu T.A., Shittu M.D., Ajayi O. (2014). Synergistic effects of hatchery by-products and cassava peel meal mixtures on the performance of crossbred growing rabbits. *J. Anim. Feed Res.*, 4: 91–96.
- Ojiako O.A., Ujowundu C.O., Alisi C.S., Igwe C.U., Ogbuji C.A. (2018). South Eastern Nigerian seafood diets have desirable effects on biochemical indices of experimental rabbits. *Pak. J. Nutr.*, 17: 421–426.
- Okpanachi U., Aribido S.O., Daikwo I.S. (2010). Growth and haematological response of growing rabbits to diets containing graded levels of sun dried bovine rumen content. *Afric. J. Food Agric. Nutr. Dev.*, 10: 4444–4457.
- Oladunjoye I.O., Ojebiyi O.O., Adeleke J., Famakinwa B. (2013). Nutritional evaluation of cattle rumen epithelial tissue scrapings meal for growing rabbits. *Malaysian J. Anim. Sci.*, 16: 87–95.
- Oladunjoye I.O., Ojo A.J., Jamiu B.A. (2014). Evaluation of baobab seed meal as feed for growing rabbits. *Int. J. Current Microbiol. Appl. Sci.*, 3: 971–977.
- Oloruntola O.D. (2018). Influence of enzyme supplementation on rabbits fed rumen liquor with poultry waste fermented cassava peels based diets. *Anim. Res. Int.*, 15: 2950–2964.
- Oloruntola O.D., Agbede J.O., Onibi G.E., Igbanan F.A. (2016). Replacement value of rumen liquor fermented cassava peels for maize in growing rabbit diet. *Archiv. Zootec.*, 65: 89–97.
- Oluwafemi R.A., Iliyasu A. (2016). Effects of graded levels of rumen digesta based diets with or without enzyme supplementation on the blood chemistry of weaner rabbits. *Int. J. Vet. Sci. Anim. Husb.*, 1: 43–46.
- Oluwafemi R.A., Adeiza I.A. (2017). Performance characteristics of grower rabbits fed enzyme supplemented dried bovine rumen digesta as replacement for maize. *Int. J. Agric. Sci. Nat. Res.*, 4: 26–31.
- Omole T.A., Sonaiya E.B. (1981). The effect of protein source and methionine supplementation on cassava peel meal utilization by growing rabbits. *Nutr. Rep. Int.*, 23: 729–737.
- Onimisi P.A., Omega J.J. (2006). Evaluation of poultry litter as feed-stuff for growing rabbits. *Livest. Res. Rural Dev.*, 18: 1–5.
- Oonincx D.G.A.B., Van IJterbeek J., Heetkamp M.J.W., Van Den Brand H., Van Loon J.J.A., Van Huis A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *Plos One*, 5: 12.
- Orban J.I., Roland D.A.Sr. (1992). The effect of varying bone meal sources on phosphorus utilization by 3-week old broilers. *J. Appl. Poultry Res.*, 1: 75–83.
- Orozco A.M., Ortega C.M., Pérez-Gil R.F. (1988). Use of earthworms as a protein supplement in diets for rabbits (in Spanish). *Archivos Latinoamericanos de Nutricion*, 38: 946–955.
- Oshibanjo Olusegun D., Gholshak P.M., Akinfolarin O., Akwashik M.A., Adediran O., Adeose I., Abegunde L. (2018). Evaluation of reproductive performance of rabbits fed graded levels of *Moringa oleifera* leaves and twigs meals. *Int. J. Res. Inn. Appl. Sci.*, III: 1–4.
- Pascual J.J., Motta W., Cervera C., Quevedo F., Blas E., Fernández-Carmona J. (2002). Effect of dietary energy source on the performance and perirenal fat thickness evolution of primiparous rabbit does. *Anim. Sci.*, 75: 267–279.
- Peers M.J., Majchrzak Y.N., Konkolics S.M., Boonstra R., Boutin S. (2018). Scavenging by snowshoe hares (*Lepus americanus*) in Yukon, Canada. *Northwestern Naturalist*, 99: 232–235.
- Pla M., Cervera C. (1997). Carcass and meat quality of rabbits fed with diets having a high level of vegetable or animal fat. *Anim. Sci.*, 65: 299–303.
- 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.
- Prasad R., Karim S.A., Patnayak B.C. (1996 a). Growth performance of broiler rabbits maintained on diets with varying levels of energy and protein. *World Rabbit Sci.*, 4: 75–78.
- Prasad R., Singh G., Patnayak B.C. (1996 b). Growth performance of broiler rabbits maintained on different diets. *World Rabbit Sci.*, 4: 11–14.
- Purohit A., Vyas K.B. (2005). Hypolipidaemic efficacy of Capparis decidua fruit and shoot extracts in cholesterol fed rabbits. *Indian J. Exp. Biol.*, 43: 863–866.
- Raimondi R., Auxilia M.T., Maria C.D., Masoero G. (1976). The effect of adding fat to the feed on meat production by rabbits. *Conigli-cultura*, 13: 37–45.
- Rebollar P.G., García-Rebollar P., García-García R.M., Millán P., Rodríguez M., Formoso-Rafferty N., De la Riva S., Masdeu M., Lorenzo P.L., Arias-Álvarez M., Rey A.I. (2014). Reproductive long-term effects, endocrine response and fatty acid profile of rabbit does fed diets supplemented with n-3 fatty acids. *Anim. Reprod. Sci.*, 146: 202–209.
- Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption.
- Reid B.L., Maiorino P.M., Parker D.J., Schurg W.A. (1980). Estimates of energy needs for protein and fat deposition in growing rabbits. *Nutr. Rep. Int.*, 21: 157–162.
- Ribeiro A.S., Silva M.N., Tagliapietra B.L., Brum B.S.Jr., Ugalde M.L., Richards N.S.P.S. (2019). Development of symbiotic yoghurt and biological evaluation (New Zealand White Rabbits) of its functional properties. *Food Sci. Technol.*, 39: 418–425.
- Rodehutsord M., Abel H.J., Friedt W., Wenk C., Flachowsky G., Ahlgrimm H.J., Johnke B., Kuhl R., Breves G. (2002). Consequences of the ban of by-products from terrestrial animals in livestock feeding in Germany and the European Union: alternatives, nutrient and energy cycles, plant production, and economic aspects. *Arch. Anim. Nutr.*, 56: 67–91.
- Rodríguez M., Carro M.D., Valiente V., Formoso-Rafferty N., Rebollar P.G. (2017). Effects of dietary fish oil supplementation on performance, meat quality, and cecal fermentation of growing rabbits. *J. Anim. Sci.*, 95: 3620–3630.
- Rodríguez M., Carro M.D., Valiente V., Formoso-Rafferty N., Rebollar P.G. (2019). Supplementation with fish oil improves meat fatty acid profile although impairs growth performance of early weaned rabbits. *Animals*, 9: 437.
- Roy A., Chardigny J.-M., Bauchart D., Ferlay A., Lorenz S., Durand D., Gruffat D., Faulconnier Y., Sébédio J.-L., Chilliard Y. (2007). Butters rich either in trans-10-C18:1 or in trans-11-C18:1 plus cis-9, trans-11 CLA differentially affect plasma lipids and aortic fatty streak in experimental atherosclerosis in rabbits. *Animal*, 1: 467–476.
- Sahu B.B., Prasad V.S.S. (1990). Growth performance of Soviet Chinchilla fryers on rations with animal-meals. *Indian J. Anim. Sci.*, 60: 211–218.
- Samman S., Khosla P., Carroll K.K. (1989). Effects of dietary casein and soy protein on metabolism of radiolabelled low density apolipoprotein B in rabbits. *Lipids*, 24: 169.
- Samman S., Khosla P., Carroll K.K. (1990). Intermediate density lipoprotein-apolipoprotein B turnover in rabbits fed semipurified diets containing casein or soy protein. *Ann. Nutr. Metab.*, 34: 98.
- Santomá G., De Blas J.C., Carabaño R., Fraga M.J. (1987). The effect of different fats and their inclusion level in diets for growing rabbits. *Anim. Prod.*, 45: 291–300.
- Sarode A., Sawale P., Khedkar C., Kalyankar S., Pawshe R. (2016). Casein and caseinate: methods of manufacture. Elsevier, Amsterdam, The Netherlands, pp. 676–683.
- Sayed A-B.N. (2019). Evaluation of dried poultry dropping as a feed ingredient in the diets of rabbits. *EAS J. Vet. Med. Sci.*, 1: 18–22.
- Scheitrum D., Schaefer K.A., Nes K. (2020). Realized and potential

- global production effects from genetic engineering. *Food Policy*, 93: 101882.
- Schingoethe D.J. (1976). Whey utilization in animal feeding: A summary and evaluation. *J. Dairy Sci.*, 59: 556–570.
- Shiratsuchi H., Shimoda M., Imayoshi K., Noda K., Osajima Y. (1994). Volatile flavor compounds in spray-dried skim milk powder. *J. Agric. Food Chem.*, 42: 984–988.
- Smith R.J. (1974). Cannibalism by confined cottontail rabbits. *J. Wildl. Manag.*, 38: 576–578.
- Spreadbury D. (1978). A study of the protein and amino acid requirements of the growing New Zealand White rabbit with emphasis on lysine and the sulphur-containing amino acids. *Brit. J. Nutr.*, 39: 601–613.
- Srilatha B., Adaikan P.G., Ng S.C., Aulkumaran S. (1997). Effects of feeding egg yolk on the serum lipid levels in rabbits. *Methods Find. Exp. Clin. Pharmacol.*, 19: 489–492.
- Strychalski J., Juśkiewicz J., Gugolek 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., Gugolek 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.
- Swick R.A., Cheeke P.R., Patton N.M. (1978). Evaluation of dried rabbit manure as a feed for rabbits. *Can. J. Anim. Sci.*, 58: 753–757.
- Terpstra A.H., Sanchez-Muniz F.J. (1981). Time course of the development of hypercholesterolemia in rabbits fed semipurified diets containing casein or soybean protein. *Atherosclerosis*, 39: 217–227.
- Togun V., Farinu A.G.O., Ojebiyi O.O., Awotunde A.I. (2009). Effect of replacing maize with a mixture of rumen content and blood meal on the performances of growing rabbits: Initial study with mash feed. *World Rabbit Sci.*, 17: 21–26.
- Trigo M., Borrás M., Muro M., Lamanna L., Antonini A., Cossu M. (2012). Evaluation of feather meal in the diet of growing rabbits. *Proc. X World Rabbit Congress*, Sharm El-Sheikh, Egypt, 3–6.09.2012, pp.777–780.
- Trung T.T., Dong N.T.K., Thu N.V. (2017). Effect of different protein sources in the diets on feed intake, nutrient digestibility, growth and carcass value of Californian rabbits (*Oryctolagus cuniculus*) in the Mekong delta of Vietnam. *Can. Tho. Univ. J. Sci.*, 5: 158–165.
- Tůmová E., Skřivan M., Skřivanová V., Kacerovska L. (2002). Effect of early feed restriction on growth in broiler chickens, turkeys and rabbits. *Czech J. Anim. Sci.*, 47: 418–428.
- Van der Meer R., De Vries H., West C.E., De Waard H. (1985). Casein-induced hypercholesterolaemia in rabbits is calcium-dependent. *Atherosclerosis*, 56: 139–147.
- Verita P., Orlandi M. (1977). Hydrolysates of leather in the feeding of rabbits. *Coniglicoltura*, 14: 47–51.
- Vermys S., Ahemen T. (2019). Effect of *Mucuna pruriens* (Velvet Bean) seed meal diet at varying levels on blood profile and reproductive performance of rabbit bucks. *Asian J. Res. Anim. Vet. Sci.*, 4: 1–16.
- 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., 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 fattening rabbits. *Anim. Feed Sci. Technol.*, 280: 115048.
- Wafar R.J., Ndubuisi D.I., Tarimbuka L.I., Sini T., Odah E. (2019 a). Growth performance and blood profile of weaner rabbits fed different legume haulms supplemented with concentrate. *Nig. J. Anim. Sci.*, 21: 377–384.
- Wafar R.J., Lalabe B.C., Adi Z.A., Obun C.O., Shinggu P.A., Yusuf H.B., Caleb M., Doofan U., Obogo G. (2019 b). Impact of toasted African locust bean (*Parkia biglobosa*) meal (Tabm) on the growth performance, nutrient digestibility, blood profile and carcass characteristics of grower rabbits. *Nig. J. Anim. Sci. Technol.*, 2: 85–96.
- Wafar R.J., Tarimbuka L.I., Adi Z.A., Lalabe B.C. (2019 c). Response of grower rabbits fed enzyme supplemented 50:50 bovine rumen digesta and blood meal mixture as replacement for ground nut cake. *Nig. J. Agric. Food Environ.*, 15: 142–148.
- West C.E., Beynen A.C., Scholz K.E., Terpstra A.H.M., Schutte J.B., Deuring K., Van Gils L.G.M. (1984). Treatment of dietary casein with formaldehyde reduces its hypercholesterolemic effect in rabbits. *J. Nutr.*, 114: 17–25.
- West C.E., Spaaij C.J.K., Clous W.M., Twisk H.P., Goertz M.P.H., Hubbard R.W., Kuyvenhoven M.W., van der Meer R., Roszkowski W.F., Sanchez A., Beynen A.C. (1989). Comparison of the hypocholesterolemic effects of dietary soybean protein with those of formaldehyde-treated casein in rabbits. *J. Nutr.*, 119: 843–856.
- Wheeler W.E., Noller C.H. (1976). Limestone buffers in complete mixed rations for dairy cattle. *J. Dairy Sci.*, 59: 1788–1793.
- Xiccato G., Parigi-Bini R., Dalle Zotte A., Carazzolo A., Cossu M.E. (1995). Effect of dietary energy level, addition of fat and physiological state on performance and energy balance of lactating and pregnant rabbit does. *Anim. Sci.*, 61: 387–398.
- Xing W.W., Wu J.Z., Jia M., Du J., Zhang H., Qin L.P. (2009). Effects of polydatin from *Polygonum cuspidatum* on lipid profile in hyperlipidemic rabbits. *Biomed. Pharmacother.*, 63: 457–462.
- Zwoliński C., Gugolek A., Strychalski J., Kowalska D., Chwastowska-Siwińska 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.

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