

## ARTICLE IN PRESS

# Dietary supplements used in rabbit nutrition and their effect on the fatty acid profile of rabbit meat - a review

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**ABSTRACT.** Meat and its processing products, despite the presence of many valuable nutrients, are rarely considered as particularly healthy or dietetic. However, consumers tend to view so-called 'white meats', including rabbit meat, as a somewhat healthier option. Rabbit meat is lean, easily digestible and rich in biologically valuable proteins and contains high levels of essential amino acids and long-chain unsaturated fatty acids, with linoleic acid being the predominant component. While the fatty acid profile of rabbit meat depends on several factors, such as breed, sex or age, the most critical factor affecting its fat structure is the composition of the feed given to the animals. It is through appropriate feeding that the fatty acid profile of meat can be improved relatively quickly and effectively. The aim of the study was to collect the results of the research conducted thus far and determine the effect of nutritional additives (oregano, thyme, commercial herbal blend Digestarom® 1315, moringa, grape pomace, olive leaves, avocado waste, palm seed cake, white lupin, linseed, chia seeds, perilla seeds, alfalfa, soybean oil, rapeseed oil, fish oil, linseed oil, sunflower oil, rocket seed oil, wheat germ oil, maize oil, curcuma, black soldier fly larvae fat, mulberry silkworm oil, *Albizia lebbek* seed oil and synthetic conjugated linoleic acid) used in rabbit feed mixtures on the fatty acid profile of the resulting meat. The literature review indicates that adding even low doses of certain substances, such as oils or synthetic acids, can have a positive effect on meat. However, the use of nutritional additives modifying the fat composition of meat should be prudent and well-considered so as not to adversely affect its technological suitability and shelf-life.

## Introduction

Cardiovascular disease, reduced immunity, cancer and obesity are the main causes of mortality worldwide among people living in developed countries. However, increasing public awareness has highlighted the potential for prevention and even elimination of these diseases through the adoption of healthy lifestyles and appropriate dietary choices (Marangoni et al., 2020). One group of bioactive compounds that plays a significant role in promot-

ing human health is n-3 polyunsaturated fatty acids (PUFAs). These compounds offer a range of benefits, including regulating plasma lipid levels, affecting cardiovascular and immune functions, glucose metabolism or supporting neural cell development (Rodríguez et al., 2019a). When n-3 PUFAs are consumed as part of the diet, they accumulate in the body's tissues and become involved in various metabolic processes. They influence the composition and function of biological membranes, play a role in the synthesis of eicosanoids, i.e. precursors of

prostaglandins and leukotrienes, and help regulate the expression of certain genes (Rodríguez et al., 2019a). Products such as fish, linseed, rapeseed and borage oils are excellent sources of n-3 fatty acids, which include eicosapentaenoic acid (C20:5 n-3; EPA), docosahexaenoic acid (C22:6 n-3; DHA) or  $\alpha$ -linolenic acid (C18:3 n-3; ALA), the latter being a precursor in the synthesis of the first two acids. On the other hand, products such as cereals, cottonseed, sesame seed, soybean and evening primrose are sources of n-6 fatty acids, among others, linoleic acid (LA) (C18:2 n-6), eicosadienoic acid (C20:2 n-6) or arachidonic acid (AA) (C20:4 n-6). PUFA n-6 play an important role in metabolic processes, but their consumption in large amounts can be potentially harmful to the body (Ponnampalam et al., 2021, Marangoni et al., 2020).

Although meat and products resulting from its processing contain many valuable nutrients, they are rarely regarded as healthy nutrition. There is a general perception that meat is a calorific product, high in saturated fatty acids (SFAs), cholesterol and sodium (Dalle Zotte and Szendrő, 2011). Consumers consider 'white meats', which include poultry meat (also duck and goose meat), fish, seafood and rabbit meat, as relatively healthier alternatives. Rabbit meat, in particular, is known for its favourable nutritional attributes. It is lean, easily digestible and rich in biologically valuable proteins with high levels of essential amino acids (Para et al., 2015). It has a high content of lysine (2.12 g/100 g), sulphur-containing amino acids (1.10 g/100 g), threonine (2.01 g/100 g), valine (1.19 g/100 g), isoleucine (1.15 g/100 g), leucine (1.73 g/100 g) and phenylalanine (1.04 g/100 g) (Hernandez and Dalle Zotte, 2010). In addition, it is low in fat (~6.8%), cholesterol (59 mg/100 g meat) and sodium (37 mg/100 g loin meat), while containing a relatively high proportion of potassium, phosphorus and magnesium (Para et al., 2015).

Rabbit meat also serves as a valuable source of long-chain fatty acids, which are essential for the proper functioning of the body. Of particular note is the high content of unsaturated fatty acids. Oleic acid (C18:1) and LA are the dominant fatty acids present, comprising approximately 60% (Para et al., 2015).

LA is an essential nutrient that cannot be synthesised by the human body and therefore must be supplied with food. As an essential component of ceramides, LA is involved in maintaining the transdermal water barrier of the epidermis, and its deficiency in the diet of infants can result in skin lesions

such as psoriasis, growth retardation and thrombocytopenia (Whelan and Fritsche, 2013). LA content of rabbit meat is approximately ten times higher than in beef and mutton, and about twice as high as in pork (Hernandez and Gondret, 2006). LA in rabbit meat is also found in the form of conjugated linoleic acid (CLA), which has antioxidant, antiatherosclerotic and antidiabetogenic properties. It plays a role in protecting the immune system and is involved in bone formation (Zhang et al., 2010). Rabbits, as monogastric animals, are unable to synthesise CLA, but thanks to the phenomenon of cecotrophy, they can deposit this acid in their muscles (Corino et al., 2007). On the other hand, monounsaturated fatty acids (MUFAs), with oleic acid as a prominent representative, have demonstrated antiatherosclerotic effects, as well as hypocholesterolemic properties by lowering blood cholesterol and low-density lipoprotein (LDL) (Zymon and Strzetelski, 2010). Scientific studies indicate that the consumption of rabbit meat, given its specific properties, can contribute to the prevention of many diseases and pathologies (Meineri et al., 2010).

Research carried out over the last few years has focused on improving the quality of rabbit meat, including modifying the fatty acid profile. The primary objective is to elevate the levels of n-3 polyunsaturated fatty acids, with particular emphasis on EPA and DHA, which are present in rabbit meat only in trace amounts (Siudak and Pałka, 2022). Furthermore, current research efforts are also aimed at reducing the ratio of n-6/n-3 acids to 5:1 (Lunn and Theobald, 2006), from the current proportion of 7:1 in loin meat and 11:1 in hind leg meat (Meineri et al., 2010).

The fatty acid profile of rabbit meat depends on several factors, such as breed, sex, age, type of tissue examined, animal body weight at slaughter and the degree of carcass fatness. However, the factor that has the greatest impact on the fat profile of meat is the composition of the feed administered to animals. Proper feeding practices play a pivotal role in achieving a relatively rapid and effective improvement in the fatty acid profile of meat (Cobos et al., 1995). The objective of the present study was to compile research findings and assess the impact of nutritional additives utilised in feed mixtures for rabbits on the fatty acid profile of their meat.

The authors conducted a comprehensive review of the scientific literature, as part of the manuscript preparation, using search engines for scientific texts such as Science Direct, PubMed, Google Scholar, EBSCO and CABI. Keywords such as rabbit,

fatty acid profile, PUFA, nutritional supplements, complete feed rations, compound feeds, oils, protein crops, herbs, and others were applied to find relevant literature. Most of the cited works consists of scientific articles and books in English published after 2015, thereby providing the latest perspective on the issues discussed in this review.

## Herbs and herbal extracts

Herbs and spices are gaining popularity as nutritional additives in livestock feeds. Scientific literature confirms their beneficial effects on the functioning of the immune system, regulation of the digestive system, increased feed intake and conversion by animals, and ultimately meat quality. They owe their action to the presence of many biologically active substances such as alkaloids, glycosides, phenols, saponins, tannins, coumarins and essential oils. Currently, the most popular form of incorporating herbs into animal diets is the preparation of pelleted mixtures containing these additives and feeding them in the form of aqueous extracts (Pałka et al., 2021).

Oregano (*Origanum vulgare*) extract was used as a feed additive in a study by Matioli et al. (2017) on rabbit meat quality. In that study, the rabbits were divided into six dietary groups, which received the following: a control feed, a feed enriched with 150 ppm vitamin E, a feed supplemented with 2% oregano extract, a ration with 1.5 g/kg feed of the prebiotic THEPAX, a feed with 150 ppm vitamin E and 1.5 g/kg feed of the prebiotic THEPAX, and a group given 2% oregano supplement and 1.5 g/kg feed of the prebiotic THEPAX. The researchers showed that the addition of oregano significantly reduced the saturated fatty acid content of the meat, which was coupled with an increase in polyunsaturated fatty acids. Particularly noteworthy in the results presented in the discussed study was an increase in the content of linoleic acid (C18:2 n-6) from 22.8% to 24.5%, and ALA from 7.3% to 9.0% in loin meat. Interestingly, it was found that oregano extract reduced the levels of these acids in hind leg meat. Different levels of oregano extract addition were not investigated in this study, only its 2% supplementation to the feed. Considering only the values presented for the loin, this additive improved the quality of rabbit meat.

Thyme (*Thymus vulgaris*) was investigated as a nutritional supplement in a study by Dal Bosco et al. (2014). Rabbits in the experimental groups were administered a 5% spirulina supplement, a 3%

thyme supplement or a combination of both. One of the important findings of the study was that the inclusion of thyme in the feed ration significantly increased the level of n-3 polyunsaturated fatty acids in the loin. Furthermore, a positive effect of thyme on the oxidative properties of PUFAs was observed. Meat from rabbits fed a thyme-supplemented feed stored in cold storage or subjected to freezing was characterised by reduced lipid oxidation, and lower losses of n-3 fatty acids. Importantly, the group of rabbits that received thyme as a dietary supplement throughout the entire fattening period showed a significant increase in the content of both n-3 (20.3 mg/100 g raw meat) and n-6 acids (228 mg/100 g raw meat). This indicates that thyme is a better nutritional additive than spirulina and can be effectively incorporated into commercial rabbit feed mixtures to improve the quality of the raw material.

Digestarom® 1315 is a commercial herbal blend of ten herbs and spices for meat breed rabbits. It contains onion (*Allium cepa* L.), garlic (*Allium sativum* L.), caraway (*Carum carvi* L.), fennel (*Foeniculum vulgare* L.), yellow gentian (*Gentiana lutea* L.), lemon balm (*Melissa officinalis* L.), mint (*Mentha arvensis* L.), anise (*Pimpinella anisum* L.), oak bark (*Quercus cortex*) and cloves (*Syzygium aromaticum* L.), which are all plants rich in phytochemicals such as flavonoids and carotenoids (Celia et al., 2016). Mattioli et al. (2016) used this herbal mixture as a feed additive for rabbits at a dosage of 300 mg/kg feed. The herbs significantly reduced myristic acid (C14:0) levels in the meat. The ALA content was higher in rabbits receiving the herbal supplement during the fattening period. It was also observed that Digestarom® 1315 had a positive effect on the content of EPA and DHA acids in the meat. The proportion of EPA increased from 0.54% in the meat of control animals to 1.92% in rabbits supplemented throughout their entire life, up to the weaning period. Similarly, the content DHA increased from 0.26% to 1.01%. The significantly higher level of n-3 acids and reduced n-6/n-3 ratio in the group that received Digestarom® 1315 during their entire life have indicated that the most effective way to utilise this herbal blend is to provide it to lactating females and unweaned rabbits. This approach yields better results and improves meat quality compared to meat of animals that received the additive only during the fattening period.

Moringa (*Moringa oleifera*) is a plant widely cultivated in Africa, Asia and the USA. Moringa leaves are rich in sulphur-containing amino acids,

n-3 polyunsaturated fatty acids, minerals, vitamins, and bioactive compounds such as carotenoids, saponins, phenols, alkaloids and flavonoids (Mahfuz and Piao, 2019). Selim et al. (2021) used moringa leaves as a dietary supplement for rabbits and determined the effect of its addition on the fatty acid profile of the resulting meat. In this study, rabbits were given a dietary ration with moringa supplemented at 0, 5, 10 and 15 g/kg feed. The researchers showed that the feed additive significantly affected the polyunsaturated acid content in meat. A linear relationship was observed, as with raising content of moringa in the feed ration, the level of n-3 acids in the meat also increased. The content of n-3 PUFAs in rabbit meat was increased by approximately 33.71%, 29.46% and 24.36% for the 1.5%, 1% and 0.5% groups, respectively, compared to the control group. These findings strongly suggest that the most advantageous approach for improving meat quality is to include a 1.5% concentration of moringa leaves in the rabbit feed.

## Agricultural by-products

Approximately 1.3 billion t of food are wasted annually, and fruits and vegetables account for a significant share of these losses. The use of fruit and vegetable processing residues as animal feed could help to address feed shortages found in most developing countries. In addition, the use of waste in animal nutrition would effectively reintegrate it into the human food chain. At the same time, it would help alleviate environmental problems that arise from the decomposition of huge amounts of plant by-products (Manju Wadhwa et al., 2015).

Bouzaida et al. (2021) studied a by-product of the wine industry – grape pomace – that contained mainly grape skins, pulp, seeds, and unremoved stems. The rabbits used in the experiment were assigned to an experimental group that received a diet supplemented with 20% grape pomace and an unsupplemented control group. The study demonstrated that the addition of pomace significantly increased the intramuscular fat content. In the group fed the tested additive, lower levels of saturated fatty acids were found, mainly due to a lower proportion of palmitic (C16:0) and myristic (C14:0) acids. PUFA content increased primarily due to an increase in the proportion of LA content. However, grape pomace also reduced the proportion of ALA, leading to higher PUFA/SFA and n-6/n-3 ratios in the test group compared to the control group. The increased proportion of

polyunsaturated acids can be viewed positively from a health perspective. However, it should be noted that current research efforts aim to reduce the n-6/n-3 PUFA ratio in meat to promote a more balanced and healthy fatty acid profile. In this context, the use of wine industry by-product may not be the optimal solution for improving meat quality.

Olive trees (*Olea europaea* L., *Oleaceae*) are among the most extensively cultivated crops in the world, with 98% of the world's olive production originating from Mediterranean countries. Pruning olive trees can yield significant quantities of olive leaves (up to 25 kg), which are considered a by-product in this sector (Molina-Alcaide and Yáñez-Ruiz, 2008). A study conducted by Mattioli et al. (2018) explored the use of olive leaves as a dietary component in rabbit nutrition. The researchers organised the animals into two experimental groups and a control group. The first treatment group received a 10% olive leaf supplement and the second received the same supplement additionally enriched with selenium (209 mg/ 100 g dry matter). The overall content of PUFAs, MUFAs and SFAs did not differ significantly between the feeding groups. However, there was a significant decrease in n-6 fatty acid content in the groups administered olive leaves, accompanied by a decrease in the  $\gamma$ -linolenic acid (GLA, C18:3 n-6) content. However, these changes did not significantly affect the n-3/n-6 ratio. ALA levels were highest in the group of rabbits receiving selenium supplementation. In conclusion, the inclusion of olive leaves in the rabbit diet did not significantly affect, and consequently, did not compromise the quality of rabbit meat. Therefore, olive leaves can be considered a suitable and viable feed option for these animals.

Avocado is a fruit that is a valuable source of vegetable fats, consisting mainly of monounsaturated fatty acids. It contains large amounts of biologically important sterols due to the presence of phenolic compounds and pigments with antioxidant activity (Wang et al., 2012). Export companies packing avocados reject some batches of the product due to undersize or physical damage. These imperfections, however, do not affect the nutritional and chemical composition of the fruit, making it suitable for alternative uses, such as animal nutrition (Graeola et al., 2010). Galeano-Díaz et al. (2023) introduced avocado waste into rabbit nutrition. Animals were divided into groups and administered diets with 0, 4.32, 8.39 and 12.25% avocado addition. As a result, a significant increase in palmitoleic (C16:1) and LA acid contents was observed in the avocado-

supplemented groups. The total content of SFA was higher in the meat of rabbits receiving the control ration and the ration with 4.32% avocado supplementation, while it was lower in the group fed the diet with 12.25% avocado. Differences in the latter study were also found in the total PUFA n-3 content, with higher levels recorded in the meat of rabbits fed with 8.39% and 12.25% avocado supplementation. The n-6/n-3 PUFA ratio had a lower value in the meat of rabbits administered the test rations compared to the control ration. The highest proportion of n-3 fatty acids, as well as the lowest n-6/n-3 PUFA ratio, was observed in the group with the highest percentage of avocado in the feed ration. However, the discussed study has also demonstrated that this by-product increases the pH value of meat. This in turn may reduce its technological suitability, hence the dose of 4.32% and 8.39% of the studied product appear to be the most optimal.

In a study conducted by Teye et al. (2020), waste from palm oil production was utilised in a feeding experiment conducted on local breed rabbits. Referring to scientific literature, the researchers aimed to investigate how the substitution of wheat bran at three different levels (25, 50, and 100%) with oil cake derived from oil processing would affect the fatty acid profile of rabbit meat. The addition of oil cake reduced the level of palmitic acid in the meat. The fat of animals fed with experimental feed contained C6:0, C8:0 and C10:0 acids, which were not found in rabbits from the control group. An increased proportion of myristic acid was also determined in animals from the experimental groups. The meat from animals in the experimental groups showed higher levels of n-3 PUFAs compared to the control group, and an increase in the n-6 PUFA content was also observed. The significant rise in the percentage of n-6 acids resulted in an elevated PUFA n-6/n-3 ratios from 0.82 to 2.29, 2.43 and 2.53, depending on the proportion of pomace in the ration (25, 50, and 100%, respectively). It should be noted that both the higher amounts of saturated acids in meat and the resulting n-6/n-3 ratio do not represent favourable outcomes from a nutritional perspective.

## Protein crop and oil seeds

Protein concentrates, which contain extracted soybean meal, soybean meal, or soybean cake, are the most common sources of protein used in feeding farm animals, including rabbits (Volek et al., 2014). There are ongoing discussions in European Union countries about the possibility of eliminat-

ing genetically modified (GM) feedstuffs, especially soybean, from livestock feeds. The ban on GMO feed was introduced in the Feed Act of 2006, but has not been implemented to date. An analysis of the fodder production in Poland indicates that there is no viable alternative crop source in the temperate climate zone that could replace genetically modified soybean imported mainly from the USA, Brazil and Argentina (Grela and Czech, 2019). Consequently, researchers are actively exploring alternative protein sources that can be integrated into animal diets without compromising key productivity parameters and the quality of the resulting raw materials. Currently, there is ongoing research focused on incorporating insect protein into animal feeds (Schiavone et al., 2017; Kierończyk et al., 2018; Onsongo et al., 2018; Kowalska et al., 2020; Maurer et al., 2016), as well as utilising high-protein seeds of plants native to our geographical region. These plants, thanks to their abundance in biologically active substances, have the potential to serve as valuable dietary components that significantly improves the quality of the animal products (Sławińska and Olas, 2022).

Seeds of white lupin (*Lupinus albus*), a high-protein legume, were applied in the diet of rabbits in a study conducted by Volek and Marounek (2011). The control group consisted of rabbits fed sunflower seed meal at a dose of 150 g/kg in their mixture, while the experimental group of animals received whole white lupin seeds at a dose of 120 g/kg feed. Feeding the diet with lupin resulted in lower levels of saturated fatty acids in rabbit meat. Notably, the hind leg meat of rabbits in the experimental group showed a significantly lower content of PUFA compared to those in the control group. Meat from the treated animals contained less AA and eicosatrienoic acid (C20:3 n-6), and more ALA and EPA. The PUFA n-6/n-3 ratio, as well as satiety, atherogenicity and thrombogenicity indices were significantly reduced in rabbits fed the lupin-based diet compared to those fed the control feed. Lupine not only serves as a source of protein in the diet, but also has a positive effect on the quality of rabbit meat. Therefore, further research into its utilisation in animal nutrition should be continued.

Bianchi et al. (2006) used linseed as a nutritional additive in the feed administered to rabbits. Both linseed and linseed oil are recognised for their high content of n-3 PUFAs. This supplement is mainly used to increase the content of ALA in meat. The inclusion of 8% linseed in the diet strongly influenced the composition of fatty acids in the meat, increasing the content of PUFA from 27.79 to 33.68%.

The level of ALA increased three-fold in the meat of rabbits receiving the experimental feed. However, it was found that the higher content of PUFA was associated with reduced meat shelf life and higher susceptibility to lipid oxidation. In the study conducted by Kouba et al. (2008), rabbits were provided with a diet containing 60 g/kg of Croquelin®, which included approximately 30 g of extruded linseed. Similar to the study by Bianchi et al. (2006), a significant increase in ALA, as well as EPA and DHA acids was observed in the meat of rabbits fed the supplemented feed. Furthermore, the PUFA n-6/n-3 ratio decreased from 7.88% in the control group to 4.09% in the group receiving linseed. On the basis of the presented studies, it could be concluded that the addition of 8% linseed had a negative effect on shelf life and technological suitability of the meat, while a 3% addition to the ration significantly reduced the n-6/n-3 PUFA ratio and enhanced the dietary value of rabbit meat.

Chia (*Salvia hispanica* L.) is an oil plant native to areas of Mexico and northern Guatemala. The oil extracted from chia seeds is rich in polyunsaturated fatty acids, particularly LA and ALA. In addition, the seeds contain approximately 24% crude protein. Peiretti and Meineri (2008) incorporated chia seeds into a rabbit feed mixture and investigated the effect of a feed ration containing 10% and 15% chia seeds on the composition of fat in rabbit meat. Their study revealed a decrease in the levels of C14:0, C15:0, C16:0 and C18:1 acids. The high content of ALA in the rations with 10% and 15% chia seeds resulted in a higher percentage of this acid in the loin muscles (*m. longissimus dorsi*) of rabbits from these groups compared to the control group. Specifically, the content of ALA in the *longissimus dorsi* muscle was 5.0% in rabbits fed the control feed and 20.9% and 25.2% in rabbits fed rations with 10% and 15% chia seed supplementation, respectively. A similar relationship was observed for LA and AA. This finding clearly demonstrated that in order to obtain meat with the highest content of n-3 and n-6 PUFAs, it was most optimal to use a blend with 15% chia seeds.

Peiretti et al. (2011) used the seeds of perilla (*Perilla frutescens* L.) in rabbit nutrition and examined their effect on the quality of the resulting meat. The tested dietary mixtures contained 5% and 10% perilla. The researchers selected perilla for their experiment due to its well-documented high content of ALA seeds. The experiment revealed that the addition of perilla in the rabbit feed exerted a significant effect on the concentration of polyunsaturated fatty acids in the meat. An increase in

the PUFA content was recorded in the *longissimus dorsi* muscle and perirenal fat. However, the content of saturated fatty acids and monounsaturated fatty acids decreased. The PUFA n-6/n-3 ratio in rabbit meat decreased from 6.53 in the control group to 1.35 in the group with 5% perilla addition, and 1.00 in the group with 10% supplementation of this plant. Other measurements made in the experiment, such as carcass weight, dressing-out percentage or meat colour and acidity, indicated that the most optimal results were obtained in the group fed 5% perilla. The n-3 acid content in this group was 5 times higher compared to the control group, making this outcome highly satisfactory for both rabbit meat producers and consumers.

Alfalfa (*Medicago sativa* L.) is an example of a plant classified as roughage, which serves as a source of protein in livestock feed. Dal Bosco et al. (2015) added 20 g/day alfalfa sprouts and 20 g/day flax sprouts in the feed administered to rabbits. These sprout diets significantly reduced fat levels in meat. Alfalfa improved the total PUFA content, positively affected the PUFA/SFA ratio, increased the proportion of n-3 acids, and decreased the n-6/n-3 PUFA ratio. However, alfalfa supplementation negatively affected SFA levels in rabbit meat, significantly increasing their percentage. The group that received a feed ration with flax sprouts was characterised by the best meat parameters, and thus the highest healthiness. Both the use of alfalfa and flax sprouts could provide benefits and improve the biological value of meat. However, the effect resulting from the application of flax sprout was more pronounced.

## Oils of vegetable and animal origin

Statistics indicate that people in Western European countries mostly consume products with a high proportion of saturated fatty acids. Foods of animal origin primarily contain polyunsaturated acids with n-6 bonds. Due to the low proportion of n-3 fatty acids in the Western European diet, efforts are being made to enrich food products, primarily meat products, with n-6 fatty acids. One way to increase the share of nutritionally valuable fatty acids in meat products is to incorporate components in animal feeds that are excellent sources of these compounds, such as fish and vegetable oils. Oils can be used as an additional component in the feed mixture, a partial substitute for fat of animal origin or another commercially available feed ingredient that provides energy in the diet (Makala, 2018).

An experiment conducted by Papadomichelakis et al. (2010) concerning the effect of a 2% dietary soybean oil addition on the fatty acid profile in rabbit meat, demonstrated that the oil significantly reduced the amount of saturated fatty acids in the meat. The addition of the oil influenced the level of ALA, increasing its proportion from 1.68% to 2.13%, and significantly reduced the content of trans-palmitoleic acids (*trans*-7 C16:1, *trans*-9 C16:1), which are associated with an increased risk of ischemic heart disease. Soybean oil has also been shown to exert a positive effect on the ratio of saturated to unsaturated acids. Similar conclusions were reached by Alves dos Santos et al. (2022), who also found improved saturated/unsaturated acid ratios and increased LA deposition in rabbit meat after supplementing 1.5% and 3% soybean oil. Andrade et al. (2018) demonstrated that a 2.5% addition of soybean oil promoted the absorption of polyunsaturated fatty acids and their deposition in meat. In addition, they noted that soybean oil increased lipid stability in stored meat. Summarising the results obtained in the aforementioned studies, the addition of soybean oil in the amount of 2–2.5% appeared to be the most optimal.

Kowalska (2008) attempted to determine the effect of a mixture of rapeseed oil and fish oil on the fatty acid profile in rabbit meat. The first experimental group received feed enriched with 2% rapeseed oil and 1% fish oil, while the second experimental group was given the same additive, along with an increased vitamin E content in the feed from 50 to 100 mg/kg of the mixture. The use of these oils had a positive effect on the fatty acid composition of the meat. There was a decrease in the content of total saturated fatty acids and an increase in polyunsaturated fatty acids, especially EPA and DHA. Furthermore, Rodríguez et al. (2019b) discussed in their review article the effect of fish oil addition on the fatty acid profile in rabbit meat. According to the latter study, the supplementation of fish oil leads to a significant reduction in the ratio of n-6/n-3 fatty acids both in the meat and perirenal fat. The addition of fish oil seems worth considering, but its proportion in the ration should not exceed 1%, as this oil may affect the sensory properties of the meat, including its taste and smell.

Zsédely et al. (2008) attempted to investigate the effect of supplementing rabbit feed with a mixture of linseed oil and sunflower oil at a rate of 2% each on the fatty acid composition of thigh and loin muscles. The former is a rich source of ALA belonging to the n-3 family, while the latter contains mainly n-6 acids. The results of the chemical analysis showed that dietary supplementation with vegetable

oils increased statistically significantly the amount of LAs and ALAs, while simultaneously reducing the proportion of SFAs and MUFAs in both tested muscles. Additionally, a significantly lower PUFA n-6/n-3 ratio and significantly higher PUFA/SFA ratio was recorded compared to the control group. These changes are considered beneficial for consumers of rabbit meat, as they enhance its nutritional value.

Morshedy et al. (2021) conducted a study to examine the effects of rocket seed (*Eruca sativa* Mill.) oil and wheat germ (*Triticum aestivum* L.) oil on the fat composition of rabbit meat. The study groups received the tested oils (0.3 ml/kg feed) or their mixture (0.15 ml of rocket seed oil and 0.15 ml of wheat germ oil per 1 kg of feed mixture). A reduced fat content in meat was observed in rabbits that received the experimental feeds. In addition, rabbits administered rocket seed oil and wheat germ oil showed a higher content of ALA in their meat. Palmitic acid and oleic acid levels were found to be reduced in the meat of animals receiving wheat germ oil and its mixture with rocket seed oil. Total SFA levels were reduced in the meat of rabbits fed a combination of the test oils. Considering the results presented in the discussed work, the most positive effects on meat composition were obtained in the group of animals fed a mixture of both oils.

Peiretti et al. (2010) studied the effect of replacing palm oil with maize oil by adding 4% of the tested oils to the rabbit diet. The animals participating in the experiment were assigned to four dietary groups, two of which also received an additional 0.03% supplement of *Curcuma longa*. The experiment demonstrated that replacing palm oil with maize oil exerted a positive effect on the n-3 and n-6 PUFA acid content in the meat, but the best results were observed in dietary groups administered the *Curcuma longa* supplement. With respect to ALA, its highest level was recorded in the group receiving palm oil and curcuma (29.8 g/kg FA); this group also had the highest total n-3 PUFA content (29.8 g/kg FA) and the most optimal n-6/n-3 acid ratio (7.43). However, the maize oil-treated groups showed a significant increase in n-6 PUFA levels, a decrease in SFA concentration and the ratio of saturated to unsaturated acids. Analysing the objective of reducing the n-6/n-3 PUFA ratio and increasing the level of n-3 acids in meat, it appeared, that the ration with palm oil and *Curcuma longa* was the most beneficial. Nonetheless, the values obtained for total PUFAs, SFAs, linoleic acid and the ratio of saturated to unsaturated fatty acids indicated an advantage of maize oil without the addition of curcuma.

Considering the European Union Commission Regulation 2021/1925, which authorised the inclusion of processed animal protein (PAP) of insect origin into feed for fish, poultry and pigs, there is an ongoing research aimed to understand the effects of insect protein and its processing products on animal performance and the quality of products obtained from them. In a study by Dalle Zotte et al. (2022), mulberry silkworm (*Bombyx mori* L.) oil was added to the rabbit diet and its effect on the meat fatty acid profile was analysed. This oil is a rich source of PUFA n-3 acids, particularly ALA. The favourable ratio of PUFA n6/n3 acids found in mulberry silkworm oil is closely related to the chemical composition of mulberry leaves. The researchers demonstrated that a diet with mulberry silkworm oil at 13 g/kg feed, provided to rabbits from 7 to 10 weeks of age, significantly increased the n-3 fatty acid content in hind leg muscles, liver, and perirenal fat. The n-6/n-3 ratio in the muscles decreased by half, from 18.9% in the ration containing 13 g/kg feed of sunflower oil to 7.69% in the ration with the addition of mulberry silkworm oil. Therefore, the addition of 1.3% of this oil is recommended in feed mixtures fed to rabbits.

Black soldier fly (*Hermetia illucens* L.) is another insect whose larval fat has been used in complete feed mixtures fed to rabbits. Dalle Zotte et al. (2018) compared in their study the fatty acid profile of rabbit meat obtained from rabbits fed extruded linseed (100 or 200 g/kg dry matter) or fat extracted from black soldier fly larvae (30 or 60 g/kg dry matter). The highest PUFA content (200 g/kg dry matter) was recorded in the group with a high proportion of linseed in the ration (860 mg/100 g meat). This experimental group also had the highest content of n-3 PUFA (400 mg/100 g meat), n-6 PUFA (458 mg/100 g meat) and the lowest n-6/n-3 fatty acid ratio (1.3). However, the highest content of long-chain n-6 fatty acids was determined in the group with 6% fat addition of black soldier fly larvae. The results obtained in the latter experiment proved that a 20% addition of extruded linseed, which positively affected the fatty acid profile of rabbit meat, was a significantly better feed component compared to insect fat.

Sunflower, soybean or linseed oils are widely known and applied in animal nutrition in European countries. However, in other parts of the world, scientists are attempting to use different oil seeds native to their regions. In a study conducted by Alagbe and Akintayo-Balogun (2020), oil extracted from the seeds of the siris plant (*Albizia lebbbeck*), native to ar-

eas of New Guinea and northern Australia, was used as a nutritional supplement in animal feed. Animals were fed diets with the addition of 0, 0.1, 0.2, 0.3 and 0.4% *Albizia lebbbeck* seed oil. The research revealed that the meat of animals administered the diet with the greatest proportion of oil showed the highest polyunsaturated fatty acid content reaching 54.17%. Conversely, with declining percentage of *Albizia lebbbeck* oil in the diet, the polyunsaturated fatty acid content also decreased.

## Synthetic conjugated linoleic acid

Conjugated linoleic acid (CLA), especially its isomer t10,c12-CLA, is known for its positive effects on human health (Bauman et al., 1999). The exact mechanism of action in the body is not yet fully understood, but CLA-rich products are considered functional foods, especially due to the role of CLA in regulating gene expression through nutrient-gene interaction. Peroxisome proliferator-activated receptors (PPARs) play a particularly important role in the response to CLA (Abdelatty et al., 2019). These nuclear receptors can strongly influence lipid and glucose metabolism and are highly expressed in muscle, liver and adipose tissues. In addition, CLA has also been shown to inhibit the accumulation of triglycerides in adipose cells and exert a positive effect on the immune system by alleviating inflammation (Lehnen et al., 2015). Conjugated linoleic acid has been detected in cecotrophs of rabbits, which is associated with microbial lipid activity in the cecum. The presence of this acid in meat is low, hence supplementing animal rations with synthetic CLA offers the possibility to improve the quality of the meat obtained by modifying its FA profile (Abdelatty et al., 2019).

Marounek et al. (2007) introduced a commercial CLA preparation into rabbit diets directly after weaning (day 35). Rabbits received 5 g CLA/kg feed for either 21 or 42 days and 10 g CLA/kg feed for 21 days before slaughter. In all groups tested, CLA significantly increased the proportions of SFAs at the expense of MUFAs in the lipids of both muscle and liver tissues. However, there was also a significant increase in PUFAs in all experimental groups, which was considered beneficial. Tissue CLA levels increased significantly with raising doses of dietary CLA, and this increase was not dependent on the time of administration. The authors therefore concluded that supplementing CLA at a higher dose three weeks before slaughter was sufficient to achieve the desired effects. In contrast



to previous studies, Abdelatty et al. (2019) reported that dietary supplementation of rabbits with 0.5 or 1% CLA for a period of 63 days from the weaning to slaughter period significantly reduced SFA levels. Additionally, the concentration of MUFA acids was also reduced, without significant differences in the SFA/MUFA ratio between the groups. In the experimental groups, on the other hand, there was a significant increase in the total PUFA and lower muscle fat content. The authors concluded that dietary supplementation with CLA in order to increase its meat content was sufficient at the level of 0.5%.

## Conclusions

Despite its excellent nutritional and dietary properties, the consumption of rabbit meat accounts for less than 3% of all meat consumed in the European Union countries. As mentioned in this article, rabbit meat is characterised by a high content of polyunsaturated fatty acids, protein, essential amino acids and serves as an important source of B vitamins. In addition, it has a relatively low energy value, as well as low levels of fat, cholesterol and sodium. Moreover, the composition of rabbit meat can be modified according to consumer preferences through appropriate nutrition.

The present literature review shows that nutrition plays a pivotal role in the modification of the fatty acid profile of rabbit meat. Even a small, 1% addition of certain substances, such as oils or synthetic acids, can exert a positive effect on the quality of the resulting meat. On the other hand, other nutritional supplements, whose proportion may be higher in a rabbit diet, such as protein crops, plant by-products or health-enhancing herbs and spices, can also contribute positively to the meat fatty acid profile. The scientific studies presented here have emphasised that proper nutrition enhances the nutritional value of rabbit meat, potentially rendering it more appealing to consumers because of its beneficial effects on the human body due to the presence of n-3 and n-6 polyunsaturated fatty acids. However, the use of nutritional additives modifying the fat composition of meat should be approached with care and thoughtful consideration to avoid any adverse effects on its technological suitability and shelf-life.

## Conflict of interest

The Authors declare that there is no conflict of interest.

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