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Original Scientific Paper

Determination of the efficiency of energy sources in feed mixtures for broilers

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ABSTRACT

Adding fat to poultry feed mixtures increases the energy value of feed, absorption of liposoluble vitamins, reduces feed spilling, enhances feed palatability, slows down the passage of feed through the digestive tract of animals, and thus, improves the absorption of nutrients and utilization of metabolic energy. In areas where corn is used as the main source of energy, high-energy mixtures are usually used, which also provide the best economic effects. However, good results (especially if the goal is a meaty carcass) can also be achieved by using a feed mixture with a lower energy level that includes nutrients of lower energy value compared to corn. Today, the physiological mechanisms by which poultry react to different energy levels have not yet been fully clarified. In addition to an overview of the most important sources of energy in poultry feed mixtures, this paper presents research organized by the Department of Nutrition and Botany, University of Belgrade, with the aim of examining the influence of different fat sources in broiler feed on production results, health status, fatty acid composition and quality of broiler meat. The selection of energy nutrients that optimizes broiler production results and the meat quality is presented and discussed.

1. Introduction

Poultry meal is mainly composed of concentrated granular nutrients, soybean meal or cake, fats or vegetable oils, macrominerals, and vitamin-mineral supplements with the addition of some synthetic amino acids. In addition to the usual nutrients, various additives are included in poultry feed in order to improve production results and product quality. In poultry feeds, nutrients that serve as a source of energy are the most prevailing components (75%), followed by proteins (20%), minerals (about 5%), and vitamins and other supplements at a low percentage (*Jokić et al*., 2004).

The addition of fat to poultry feed mixtures increases the energy value of feed, the absorption of liposoluble vitamins, reduces feed spilling, enhances feed palatability, slows down the passage of feed through the digestive tract of animals, and thus, improves the absorption of nutrients and the utilization of metabolic energy (*Ševković et al*., 1980). The values of metabolic energy (ME) and net energy (NE) both vary, and they are conditioned by other factors, such as the type of poultry, breed, hybrid, physiological state and age of the poultry, in addition to the composition of the feed mixture. In areas where corn is used as the main source of energy,

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high-energy feed mixtures are usually used, which also provide the best economic effects. However, good results (especially if the goal is a meaty carcass) can also be achieved by using a feed mixture with a lower energy level that includes nutrients of lower energy value than corn (*Marković and Baltić*, 2018). Today, the physiological mechanisms by which poultry react to different energy levels have not yet been fully clarified, despite the fact that several of them have been proposed. Namely, the energy needs of poultry depend on several factors at the same time: their body weight, ambient temperature, daily gain, egg production, etc. Based on the equation given by the United States National Research Council (*NRC*, 1984; 1994), the required amount of feed consumed for layers and broilers can be accurately predicted (*Jokić et al*., 2004).

Fats are, in addition to proteins, an important nutrient that poultry efficiently digest and utilize. These are esters of trihydroxyl alcohol of glycerol and higher fatty acids. The presence of a high amount of saturated fatty acids in a fat molecule refers to solid fats, while oils are predominantly unsaturated fatty acids (with one, two or more double bonds). In the feed mixtures for poultry and other types of domestic animals, fats are the richest source of energy, given that their energy value is 2.25 times higher than that of carbohydrates. In fact, fats have a constructive role and are necessary in intermediate metabolism. Fats are a good source of essential fatty acids, fat-soluble vitamins dissolve in them (*Šefer and Sinovec*, 2008), and they can be deposited in large quantities in the animal body. Depending on the category of poultry and other factors (genetics, structure and composition of the feed mixture, ratio between nutrients), the amount of deposited fat ranges from a few percent (in chickens) to 30% (in ducks). A higher percentage of fat in mixtures (more than 10%) effects more efficient use of feed, but also leads to serious technological and nutritional problems. Such mixtures are difficult to manipulate, because the high proportion of fat requires high levels of protein, some amino acids and other nutrients important in fat metabolism (choline, folic acid, vitamin E and B12). The inclusion of a comparably larger amount of fat in complete poultry mixtures today can be solved technologically successfully by using a special spray technique—applying fat to hot pellets as they exit the pellet mill or extruder.

When using fats in feed mixtures, care must be taken regarding their source and the age of the poultry. Feeds for poultry contain 2-5% fat, except for oilseeds where the fat ranges from 17-30% (soybeans) and 40% (sunflower and rapeseed). Of all cereals, the highest percentage of crude fat is found in corn and oats (4-5%). Sorghum, wheat and barley contain 2-3% crude fat. Somewhat higher levels of 5-10% crude fat are found in protein of animal origin (*Šefer and Sinovec*, 2008).

Corn is used as a basic energy feed in poultry mixtures. In poultry meal, it is found at concentrations of 40-70%, depending on the category of poultry. Corn grain is characterized by a high content of easily digestible starch (about 80%), and low contents of protein of poor biological value and mineral substances. Of all cereals, it has the least cellulose (2-2.5%) and the most fat (about 4%), so it has the highest concentration of energy (14.1 MJ/kg).

Wheat is similar in nutritional value to corn, but with a lower energy/protein ratio. It has a higher protein content and 10% lower energy value because it contains less fat (about 2%) and more non-starchy polysaccharides than does corn. The protein content in wheat is 10-14%, depending on the variety. Wheat proteins are poor in the amino acids lysine and methionine. The ME value of wheat used in poultry nutrition, depending on the variety, is 10.6-12.9 MJ/kg. In poultry meal, wheat serves only as a partial substitute for corn, where the percentage share should not exceed 20% for poultry aged 1-4 weeks, or 25% if the animals are older than 4 weeks. The nature of the protein in wheat and the fineness of the grinding leads to its sticking around the beak, and when used in a higher percentage, to wet and sticky excrement.

Barley contains more proteins (barley grain contains 10-11%) and amino acids (lysine, tryptophan, methionine, cystine) than corn. Due to its lower fat content (1.7%), it has a lower energy value than corn (11.34 MJ/kg). It contains more crude fibre (about 5%) and can only be used as a partial substitute for corn and wheat in poultry feed mixtures. However, barley grain has a low level of essential amino acids, especially lysine. Barley is not widely used in poultry nutrition because it has sharp seeds, so poultry do not like to consume it. That is why it is necessary to free the grain of barley from the axils and cover it before use. Due to its lower energy content, barley is used for the energy dilution of poultry feed mixtures, especially in the last phase of feeding young poultry. This lower energy content has a favourable effect on the quality and deposition of fat, which has a firmer consistency and lighter color compared with the fat laid down in birds consuming higher energy feed.

Oats are characterized by a high content of coarse cellulose fibre in the grain envelope (7-11%), and oats have a low energy value (1.46MJ/kg), so they are of little importance in poultry nutrition. The protein content in this feed is 10-11%, and it is of poor biological value. An oat grain contains about 5% fat, 0.08% calcium and 0.34% phosphorus. In the feed mixtures for young poultry categories, oats should not constitute more than 10-15%, and in feed mixture for laying hens, no more than 20-25%. Oats in broiler feed mixture affects feathering, while if in the form of whole grains, oats prevent feather pecking and cannibalism.

Rye has a similar chemical composition to wheat. It contains about 12% protein, 1.5% fat, 2.2% crude fibre and has an energy value of 12 MJ/kg. Rye proteins have relatively low biological value, because they contain low amounts of lysine, methionine, threonine, leucine and isoleucine. The large amount of pentosan in rye reduces its energy value and utilization of other nutrients. Rye also contains higher amounts of alkyl resorcinol compared to wheat and triticale, and this gives it a bitter taste and limits its use in poultry nutrition.

Triticale is a cereal produced by crossing rye and wheat. It has a higher content of protein (15.8%) and lysine (0.39%) compared to the species from which it was produced and a lower energy value. The content of fat in this feed is 1.5% and raw cellulose is 4%. In the case of young poultry, the share of triticale in the feed mixture should not be higher than 2%, and in the case of breeding stock and layers, 2-15%.

Sorghum is also used in poultry nutrition as an energy feed. Its chemical composition is similar to corn, but it has 10% less nutritional value. It contains more crude protein (10-11%) and ash (1.7-2%), and less fat than corn. Sorghum proteins are of poor biological value with a marked lack of lysine. The energy value of sorghum is 13.6MJ/kg in poultry nutrition. The nutritional value of sorghum really depends on its tannin content. The amount of sorghum in poultry feed mixture, regardless of the category, should not exceed 40-50% (*Ševković et al.*, 1980).

Fats and oils can be used to meet the energy requirements of poultry. Soy and sunflower oil can be used from the group of vegetable oils, and tallow, pork and poultry fats and fish oil from the animal fats. These suitable fats and oils are an excellent source of energy (32.2-36.8MJ/kg), which is the reason for their mandatory inclusion in poultry feed mixture if the mixture of other components is not satisfactory in terms of energy. The effect of added fat depends on the source and age of the poultry. Young poultry categories cannot digest saturated fatty acids, so the optimal solution is to include a mixture of fats and oils in the feed mixture (*Attia et al.*, 2020). Fats are a good source of essential linoleic acid, the amount of which in poultry rations should be at least 1%. All fats and oils should be treated with approved antioxidants to prevent their oxidation. At least 1% and at most 5% of poultry fat, fish or vegetable oil or a mixture of vegetable oil and animal fat can be included in feed mixture for young poultry (1-4 weeks). The same amount can be used in the diet of breeding young (4-18 weeks), with the possibility of including 1-5% tallow or pork fat and more poultry fat (up to 7%). Vegetable oil should constitute up to 8% of the ration produced for laying and breeding hens, while a mixture of vegetable oil and animal fat can make up to 7% of the ration. Using the new technology of applying fat (spray method) to the pellets when they come out of the pellet mill enables the inclusion of larger amounts of fat in poultry feed. In doing so, one must take into account the level of protein and certain vitamins, which are important for the efficient utilization of fat. Using this spray technology, production results can be improved, especially feed conversion rates (*Ševković et al.*, 1980).

A diet high in fat is thought to lead to better digestion and absorption of other nutrients in the feed mixtures. This can be explained by the prolonged retention time of fat in the intestines of poultry (*Baião and Lara*, 2005). Adding lipids affects the composition of lipids laid down in the bird's bodies, that is, the content of fatty acids in muscle tissue and eggs. The fatty acid composition of broiler feed fat has a direct influence on the fatty acid composition of fat reserves in broilers. The main goal of this research was to examine the influence of different fat sources in broiler feed on production results, health status, fatty acid composition and quality of broiler meat.

2. Materials and methods

In the study, 240 broilers of Cobb 500 provenance and both sexes were used, divided into four experimental groups. Broilers in all four experimental groups (K, O-I, O-II and O-III; see below) received feed of standard raw material and chemical composition (NRC, 1994) for the given provenance and production stage (complete broiler fattening mixture I from days 1 to 10; complete broiler fattening mixture II from days 11 to 21 and; complete broiler fattening mixture III from days 22 to 42). Linseed oil and lard were added to the feed for the diet of the experimental groups in different amounts. Feed mixtures for group O-I contained 1%, 2.5% and 5% lard in starter, grower and finisher feed, respectively. Feed mixtures for group O-II contained 1%, 2.5% and 5% linseed oil in starter, grower and finisher feed, respectively. Feed mixtures for group O-III contained 0.5%, 1.25% and 2.5% lard and 0.5%, 1.25% and 2.5% linseed oil in starter, grower and finisher feed, respectively (so this latter group's feed contained a combination of two fat sources).

At the end of each fattening phase, each animal's body weight and feed consumption were measured, and then feed conversion rate and body weight gain were calculated. During the study, the health condition of the animals was monitored. At the end of the feeding trial, birds were slaughtered and the carcasses were cut into the main parts: breast, drumstick with thigh, wings, neck and back. After that, the parts of the carcass were measured, and six drumsticks were taken from each experimental group for chemical analysis.

Fatty acid composition was determined in the broiler drumstick meat. The determination of fatty acids was done using an internal standard (heneicosanoic acid, C23:0). Fatty acid content is presented as a percentage share (%) of the total identified fatty acids. After that, lipid indexes were calculated according to the formula (Ulbricht and Southgate, 1991), which includes in the calculation only those fatty acids that are proven to influence that parameter. For the determination of malondialdehyde (MDA), the test was based on the spectrophotometric determination of the pink complex formed after the reaction of MDA with two molecules of 2-thiobarbituric acid. The test determines the so-called thiobarbituric acid reactive substances (TBARS), and the test result is collectively expressed as the TBARS-number (*Tarladgis et al.,* 1960). The meat samples were stored at -20 °C for 6 months, after which the MDA was determined again.

3. Results and discussion

Statistically significantly higher ($p<0.05$) body weight gain at the end of the study were recorded in the O-II group (Figure 1), while the feed conversion rate was significantly better ($p<0.05$) in groups O-I and O-II (Figure 3). Accordingly, feed consumption was the lowest in group O-II (Figure 2). According to the Cobb 500 broiler performance and nutrition guide, the average weight of broilers at the end of fattening (day 42) should be higher (Cobb 500 Broiler Guide, 2018) than obtained in this study. The resulting difference between the expected body weight gain according to the guide and the lower average body weight gain obtained in the control and experimental groups could have arisen for several reasons. These include differences in feed quality, differences in diet with palletized or mealy feed, length of starvation before slaughter, transport to the slaughterhouse, stress, housing conditions, differences in genetic material, etc. The most likely cause

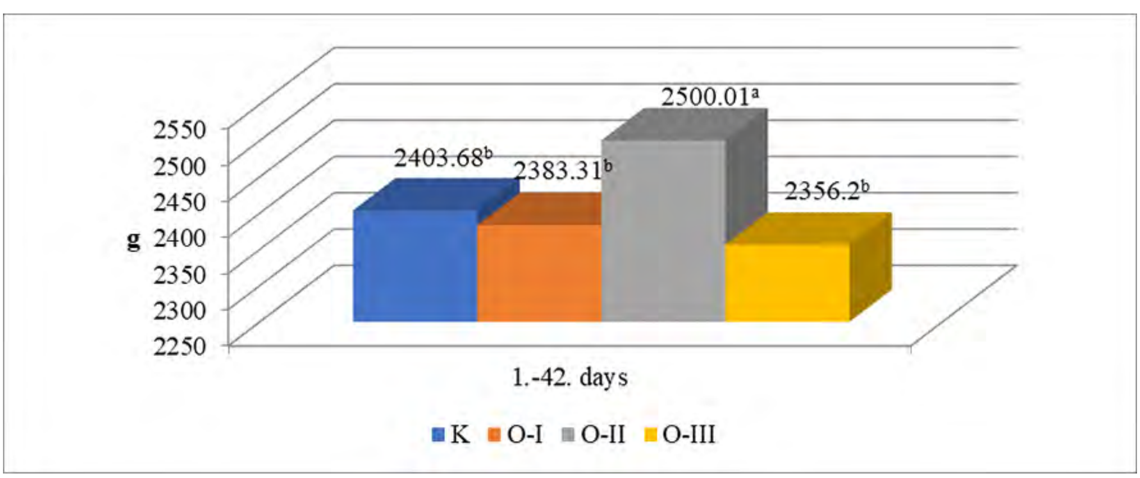

Figure 1. Average body weight gain (g) of broilers during fattening (n=60). O-I; 1%, 2.5% and 5% lard in starter, grower and finisher feed, respectively. O-II; 1%, 2.5% and 5% linseed oil in starter, grower and finisher feed, respectively. O-III; 0.5%, 1.25% and 2.5% lard and 0.5%, 1.25% and 2.5% linseed oil in starter, grower and finisher feed, respectively. Different letters, [a,b], indicate significant difference at $p<0.05$.

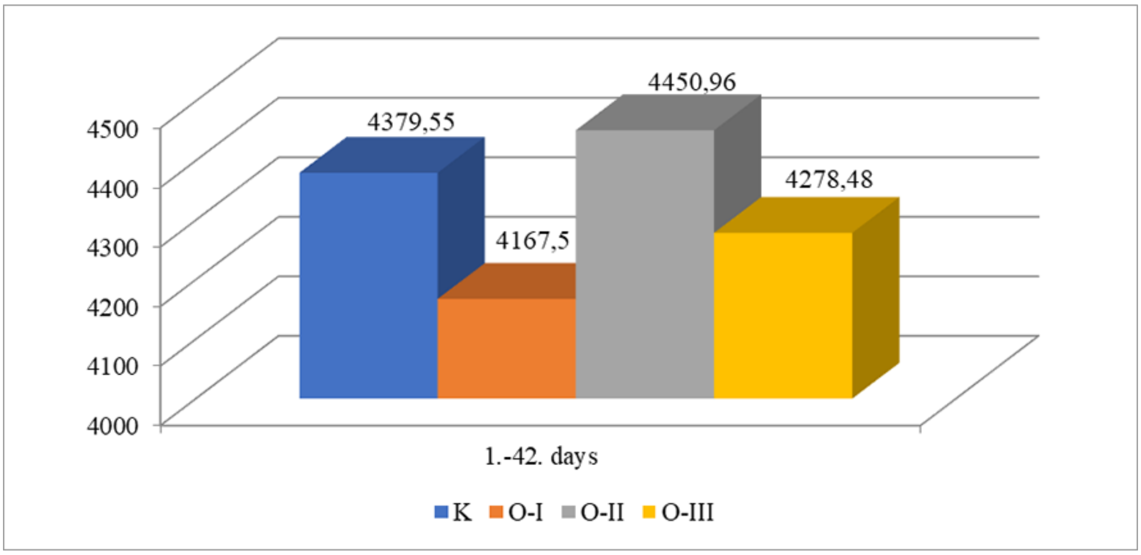

Figure 2. Mean total feed consumption (g) during fattening (n=60). O-I; 1%, 2.5% and 5% lard in starter, grower and finisher feed, respectively. O-II; 1%, 2.5% and 5% linseed oil in starter, grower and finisher feed, respectively. O-III; 0.5%, 1.25% and 2.5% lard and 0.5%, 1.25% and 2.5% linseed oil in starter, grower and finisher feed, respectively.

in this case could be the quality of the feed and the form of the feed. In our study, mealy feed was used, and it is known that when using such feed, generally worse production results are obtained due to the way broilers take the feed and the greater spilling of feed. Other possible reasons for the low body weight gains achieved were the length of starvation before slaughter and the transport of broilers to the place of slaughter.

According to the Cobb 500 standard (*Cobb 500 Broiler Guide*, 2018), the feed conversion rate on the 42nd day of fattening should be 1.61, which is better than the feed conversion rate achieved in the control group and group O-III by 0.21% and 13.04%, respectively. The feed conversion rate according to the Cobb 500 standard is better than the conversions achieved in group O-I by 0.14 or 8.69%, and by group O-II by 0.17 or 10.56%.

The average content of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) in the drumstick meat of group O-I was higher ($p<0.05$), and the content of polyunsaturated fatty

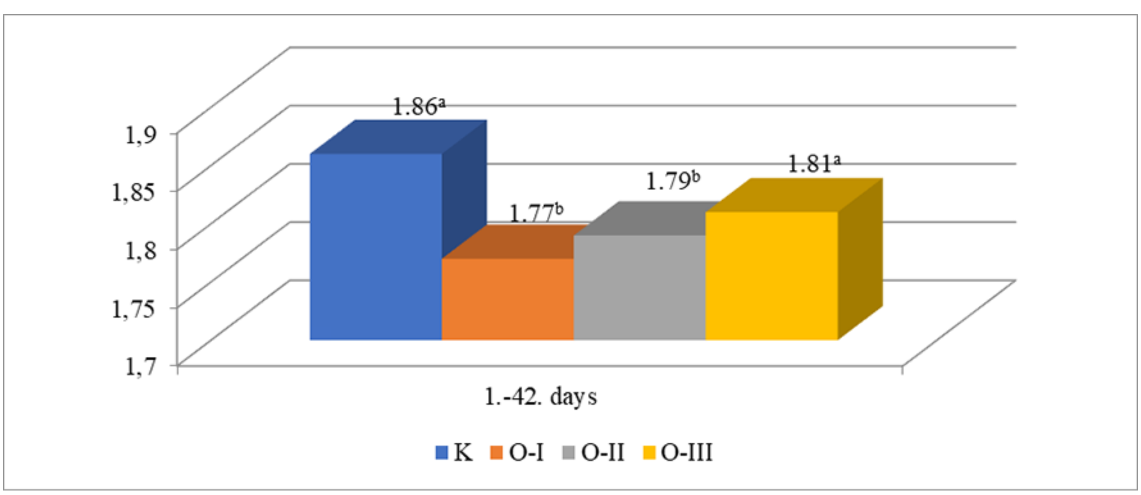

Figure 3. Mean total feed conversion rate (g) during fattening (n=60). O-I; 1%, 2.5% and 5% lard in starter, grower and finisher feed, respectively. O-II; 1%, 2.5% and 5% linseed oil in starter, grower and finisher feed, respectively. O-III; 0.5%, 1.25% and 2.5% lard and 0.5%, 1.25% and 2.5% linseed oil in starter, grower and finisher feed, respectively. Different letters, [a,b], indicate a significant difference at $p<0.05$.

acids (PUFA) was lower ($p<0.05$) compared to the content of these acids in the drumstick meat of the other tested groups (Figure 4). The fatty acid composition of meat is one of the most important characteristics of meat considered in the development of functional foods. The most nutritionally valuable fatty acids, in this sense, are n-3 fatty acids, and especially long-chain n-3 fatty acids: eicosapentaenoic acid 20:5n-3, docosopentaenoic acid 22:5n-3 and docosahexaenoic acid 22:6n-3. These fatty acids have an important influence on the general development of the body and the nervous system and have a cardioprotective effect. One of the first indications of their cardioprotective action was observed in Inuit, who, although they had a high cholesterol content in their blood, had very few cardiovascular diseases (*Desnoyers et al*., 2018). A later analysis of their diet found that they consumed significantly more long-chain n-3 fatty acids than other peoples. Many studies after that showed the cardioprotective effect of n-3 fatty acids (*Keys et al*., 1967; *de Lorgeril et al*., 1998). Also, it was shown that it is possible to influence the fatty acid composition of meat by changes in the composition of complete feed mixtures for broilers, i.e., to obtain a fatty acid composition of the meat very similar to the fatty acid composition of the mixture (*Starčević et al*., 2014). *Desnoyers et al*. (2018) tried to explain why in some studies on humans, the cardioprotective effect of n-3 fatty acids is absent, and they came to the conclusion that this could be due to a large intake of n-6 fatty acids through the usual diet of modern times. Moreover, in order to achieve favourable results, it is not enough to add n-3 fatty acid supplements to the animal diet, but it is also necessary to reduce the animal intake of n-6 fatty acids. For this reason, it is very important to monitor the ratio of n-6/n-3 fatty acids in the obtained meat in every nutritional study on this topic.

The most favourable n-6/n-3 ratio ($p<0.05$) was in groups O-II and O-III (Figure 5). Zelenka et al. (2008) calculated from their experiments with linseed oil that the maximum favourable n-6/n-3 ratio in favour of n-3 fatty acids could be achieved using the inclusion of 5.8-5.9% of linseed oil in the mixture and would be 0.93/1 for drumstick meat. Any inclusion of linseed oil higher than this would exceed the enzyme capacity of the broiler. *Starčević et al*. (2014) achieved a ratio of 1.47/1 with the inclusion of 5% linseed oil, from the 25th to the 52nd days of fattening, which coincides with the results for white meat (*Chen et al*., 2014). In our study (Figure 5), as expected, the lowest ratio was in the group with the addition of 5% linseed oil (2.67/1), and it is interesting that the ratio was higher in the control group (12.18/1) than in the group with the addition of 5% lard (11.24/1), which clearly shows how negative an impact grains can have on the n-6/n-3 ratio.

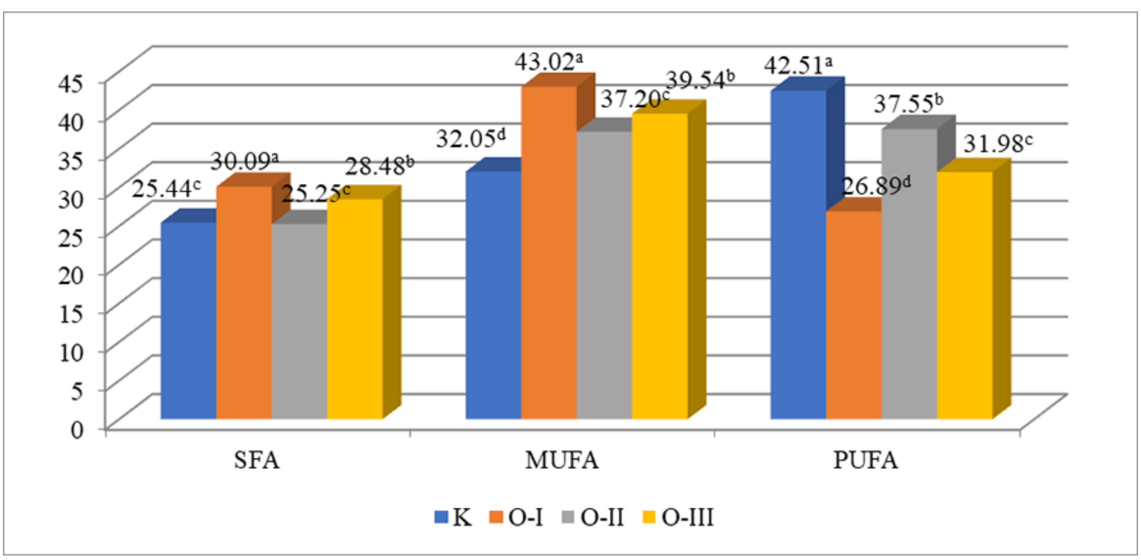

Figure 4. Mean content (%) of SFA, MUFA and PUFA in drumstick+thigh meat from the examined broiler groups (n=6). O-I; 1%, 2.5% and 5% lard in starter, grower and finisher feed, respectively. O-II; 1%, 2.5% and 5% linseed oil in starter, grower and finisher feed, respectively. O-III; 0.5%, 1.25% and 2.5% lard and 0.5%, 1.25% and 2.5% linseed oil in starter, grower and finisher feed, respectively. Different letters, [a,b,c,d], in a fatty acid category indicate significant differences at $p<0.05$.

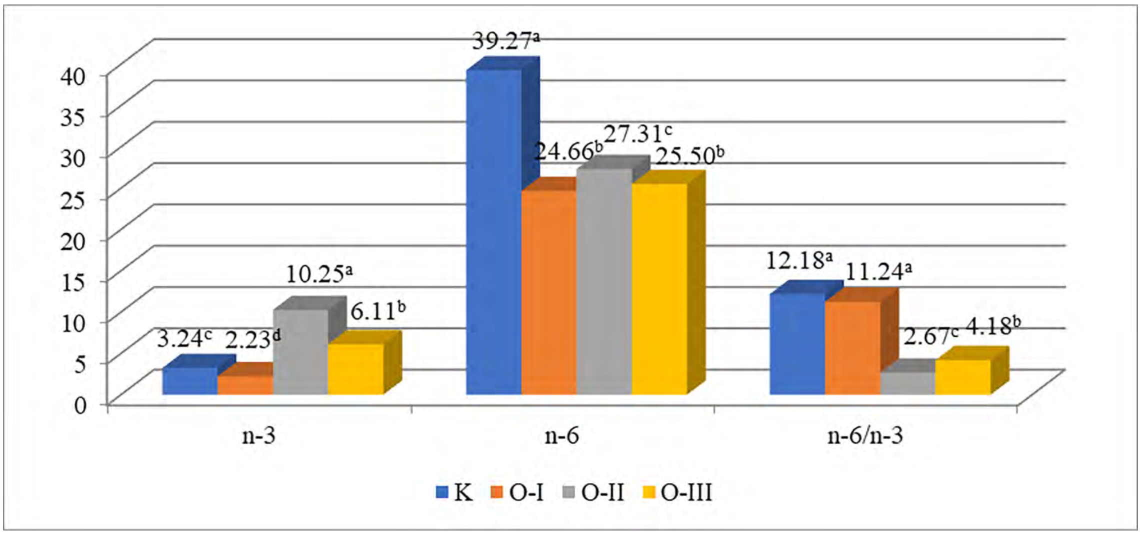

Figure 5. Mean content (%) of n-3 and n-6 fatty acids and n-6/n-3 ratio in drumsticks of the examined broiler groups (n=6). O-I; 1%, 2.5% and 5% lard in starter, grower and finisher feed, respectively. O-II; 1%, 2.5% and 5% linseed oil in starter, grower and finisher feed, respectively. O-III; 0.5%, 1.25% and 2.5% lard and 0.5%, 1.25% and 2.5% linseed oil in starter, grower and finisher feed, respectively. Different letters, [a,b,c,d], in a category of lipid indicate significant differences at $p<0.05$.

Lipid indexes include the atherogenic index (AI), thrombogenic index (TI) and hypo/hypercholesterolemic index (h/H). The concentrations of C14:0 and C16:0 are important for calculating the AI and h/H indexes, while the concentration of C18:0 from saturated fatty acids is also important for the calculation of the TI index. The concentration of n-3 fatty acids is very important for obtaining the most favourable value of lipid indexes, and especially for obtaining a favourable TI. Among our four groups, lower AIs ($p<0.05$) in drumstick meat were found in the control and O-II groups (Figure 6). TI was lower ($p<0.05$) in the O-II group the TIs in the drumsticks meat of the other experimental

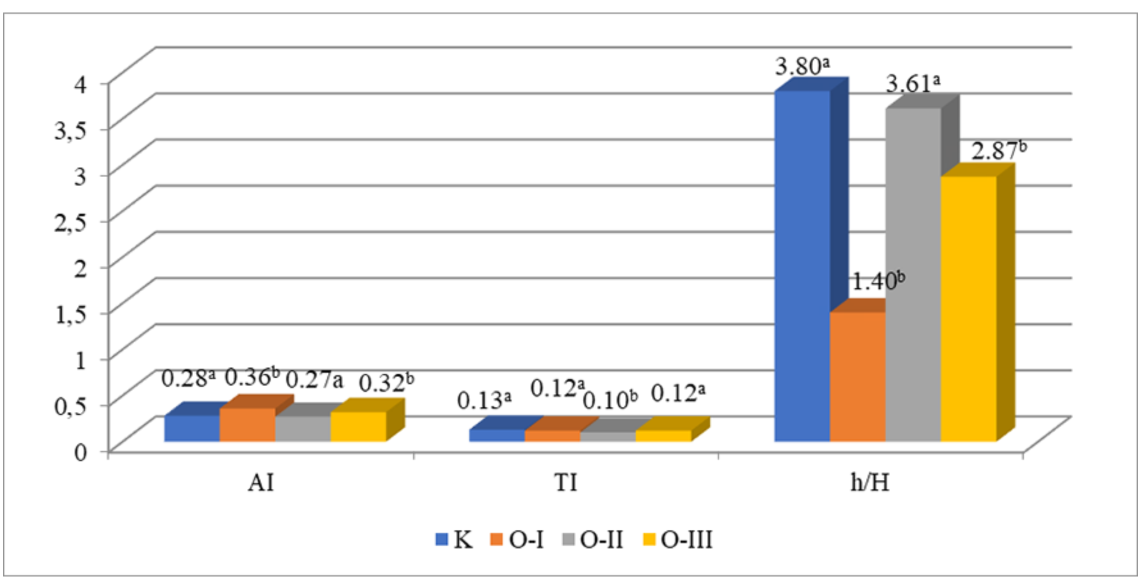

Figure 6. Mean lipid indexes in . AI—atherogenic index; TI—thrombogenic index and h/H—hypo/hypercholesterolemic index. O-I; 1%, 2.5% and 5% lard in starter, grower and finisher feed, respectively. O-II; 1%, 2.5% and 5% linseed oil in starter, grower and finisher feed, respectively. O-III; 0.5%, 1.25% and 2.5% lard and 0.5%, 1.25% and 2.5% linseed oil in starter, grower and finisher feed, respectively. Different letters, [a,b,c,d], in a lipid index indicate significant differences at $p<0.05$.

groups. The h/H of the control and the O-II group were higher ($p<0.05$) compared to those of the other two groups of broilers.

It has been shown that an increased intake of saturated fatty acids, cholesterol and food with an increased AI and TI has negative consequences on human health (*Vitina et al*., 2012; *Attia et al*., 2020). By replacing red meat with chicken meat, the risk of developing cardiovascular diseases is reduced by 19% (*Hu*, 2005). However, *Attia et al*. (2017) determined that the h/H index of broiler meat is influenced by whether the meat is fresh or frozen. Fresh meat, compared with frozen, had a larger, i.e. more favourable h/H index, as well as higher MUFA, PUFA, and n-6 MK contents, MUFA/SFA ratio, and lower content of malondialdehyde (MDA) and SFA (Attia et al., 2017). In this study, the mixture with added pork fat (1%, 2.5% and 5%) had the highest content of ZMK. The h/H index of this O-I mixture was significantly lower than those of the other groups.

The mean content of MDA on day 0, i.e., before frozen storage, in the drumstick with thigh meat of the control group was higher ($p<0.05$) compared to the mean content of MDA of the experimental groups of broilers. After six months of storage, the mean content of MDA in the meat of the O-I group was lower ($p<0.05$) compared to the other groups (Table 1).

Different unsaturated fatty acids are differently sensitive to the process of lipid peroxidation. PUFA undergo this process easier and faster than MUFA, so linoleic acid (C18:2) oxidizes 10 times faster than oleic acid (C18:1), while linoleic acid (C18:3) oxidizes 20 to 30 times faster. Ions of iron and copper, as well as myoglobin, can further increase the degree of lipid peroxidation. The process of lipid peroxidation of the cell membrane occurs at the moment when the level of free radicals exceeds the antioxidant capacity of the cell, which results in the formation of primary peroxides (Glišić, 2020).

Table 1. Mean content of malondialdehyde (MDA; mg/kg) in drumstick+thigh meat (n=6) from control and experimental broiler groups after six months of frozen storage

	MDA ($\overline{X}$)	**Measures of variation**				
		Sd	Se	X_{min}	X_{max}	**C_v (%)**
K	0.40[a]	0.02	0.01	0.37	0.44	**6.11**
O-I	0.30[b]	0.03	0.01	0.26	0.34	**9.00**
O-II	0.39[a]	0.03	0.01	0.35	0.43	**6.80**
O-III	**0.38**[a]	**0.03**	**0.01**	**0.34**	**0.41**	**7.11**

O-I; 1%, 2.5% and 5% lard in starter, grower and finisher feed, respectively. O-II; 1%, 2.5% and 5% linseed oil in starter, grower and finisher feed, respectively. O-III; 0.5%, 1.25% and 2.5% lard and 0.5%, 1.25% and 2.5% linseed oil in starter, grower and finisher feed, respectively. Different letters, [a,b], ascribed to means indicate significant differences at $p<0.05$.

4. Conclusion

The best weight gain in the study was achieved by broilers consuming mealy feed with the addition of linseed oil, while the best feed conversion parameters were achieved with the addition of linseed oil and lard to the feed. Also, the best meat yield and the most favourable fatty acid profile in the meat was achieved through broilers consuming mealy feed with added linseed oil as an energy source, which means that the quality of the meat can be influenced by the correct choice of energy source.

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