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# Quality of Chicken Meat

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Gordana Kralik, Zlata Kralik, Manuela Grčević and  
Danica Hanžek

Additional information is available at the end of the chapter

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## Abstract

Chicken meat is considered as an easily available source of high-quality protein and other nutrients that are necessary for proper body functioning. In order to meet the consumers' growing demands for high-quality protein, the poultry industry focused on selection of fast-growing broilers, which reach a body mass of about 2.5 kg within 6-week-intensive fattening. Relatively low sales prices of chicken meat, in comparison to other types of meat, speak in favor of the increased chicken meat consumption. In addition, chicken meat is known by its nutritional quality, as it contains significant amount of high-quality and easily digestible protein and a low portion of saturated fat. Therefore, chicken meat is recommended for consumption by all age groups. The technological parameters of chicken meat quality are related to various factors (keeping conditions, feeding treatment, feed composition, transport, stress before slaughter, etc.). Composition of chicken meat can be influenced through modification of chicken feed composition (addition of different types of oils, vitamins, microelements and amino acids), to produce meat enriched with functional ingredients (n-3 PUFA, carnosine, selenium and vitamin E). By this way, chicken meat becomes a foodstuff with added value, which, in addition to high-quality nutritional composition, also contains ingredients that are beneficial to human health.

**Keywords:** chicken meat, nutritive value, meat quality, n-3 PUFA, carnosine, selenium, health benefit

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## 1. Introduction

Throughout the world, poultry meat consumption continues to grow, both in developed and in the developing countries. In 1999, global production of chickens reached 40 billion, and by 2020 this trend is expected to continue to grow, so that poultry meat will become the consumers' first choice [1]. Fresh chicken meat and chicken products are universally popular. This

occurrence can be explained by the fact that this meat is not a subject of culturally or religiously set limitations, and it is perceived as nutritionally valuable foodstuff with low content of fat, in which there are more desirable unsaturated fatty acids than in other types of meat [2, 3]. More importantly, quality poultry products are available at affordable prices, although their production costs may vary [4]. If referring to overall consumption of all types of meat, poultry meat consumption takes one of the leading places in all countries throughout the world [3]. Such good rating of poultry meat is influenced by many factors, such as short fattening duration, excellent space utilization, high reproductive ability of poultry, excellent feed conversion, satisfactory nutritional value of poultry meat and relatively low sales prices. The quality of broiler meat is affected by a number of factors, as follows: fattening system, duration of fattening, hybrid and sex, feeding treatment, handling before slaughter, freezing of carcasses, storage time, etc. [5–11]. It should be emphasized that nowadays poultry is fattened in an intensive way, so the stress is an inevitable factor, and the feed, with increased content of microalgae and vegetable and fish oils used to enrich poultry products with desirable fatty acids, is susceptible to oxidation [11–14]. The same as designed poultry feed mixtures with increased microalgae or oil content, poultry products (meat and eggs) enriched with omega-3 fatty acids are also subjected to oxidation. In order to reduce oxidation in poultry feed, it is necessary to supplement it with some antioxidants, such as selenium or vitamin E. Such chicken meat is considered as “functional food”, as it has the increased content of bioactive substances, which positively influences consumers’ health. The most common bioactive substances used to enrich chicken meat are conjugated linoleic acid (CLA), vitamins, microelements, amino acids, microalgae and oils rich in omega-3 PUFA (polyunsaturated fatty acids) [14–19].

The aim of this research was to present the nutritive value of chicken meat, as well as to assess the influence of different fattening system factors that determine the meat quality. Furthermore, the aim was to elaborate the possibility of enriching the meat with omega-3 fatty acids, carnosine and selenium, and to point out the benefits that consumption of enriched chicken meat has on human health.

## 2. Nutritional value of chicken meat

Chicken meat is appropriate for quick and simple preparation, yet it offers a variety of combinations with different foodstuffs, thus making itself as a usual choice of consumers faced with modern lifestyle. When compared to other types of meat (**Table 1**), it is proved that chicken meat (breasts) contains more protein and less fat than red meat, thus making it a dietetic product.

It is important to mention that chicken with skin contains 2–3 times more fat than chicken without skin, so it should be eaten without skin to ensure the intake of high-quality protein without extra calories and fat. When compared to red meat, the main advantage of white chicken meat is in its low caloric value and a low portion of saturated fat, so consumption of white chicken meat is recommended to people who want to reduce the fat intake, as well as

Nutrient	Chicken <sup>1</sup>	Pork <sup>2</sup>	Beef <sup>3</sup>	Lamb <sup>4</sup>
Energy/kcal	165	165	185	180
Water/g	65.26	65.75	64.83	64.92
Protein/g	31.02	28.86	27.23	28.17
Total fat/g	3.57	4.62	7.63	6.67
Saturated fatty acids	1.010	1.451	2.661	2.380
Monounsaturated fatty acids	1.240	1.878	3.214	2.920
Polyunsaturated fatty acids	0.770	1.066	0.285	0.440
Cholesterol (mg)	85	86	78	87

Source: [20].<sup>1</sup>Chicken, broilers or fryers, breast, meat only, cooked, roasted.

<sup>2</sup>Pork, fresh, leg (ham), rump half, separable lean only, cooked, roasted.

<sup>3</sup>Beef, round, bottom round, roast, separable lean only, trimmed to 0" fat, choice, cooked, roasted.

<sup>4</sup>Lamb, domestic, leg, shank half, separable lean only, trimmed to 1/4" fat, choice, cooked, roasted.

**Table 1.** Nutritive content of different types of meat (per 100 g).

to people suffering from heart and coronary diseases. When compared to cholesterol content, white chicken meat does not differ much from other types of meat, however, if considering other benefits (more protein, less total fat, less saturated fat and less calories), it has better nutritional quality and therefore, it is recommended for consumption to anyone who takes care of diet and health. High protein content makes chicken meat an ideal foodstuff for all consumers who need high-quality, easily degradable protein (athletes, children, the elderly). Average daily requirement (AR—average requirements) of adults for protein is 0.66 g/kg body weight (BW), while young children and athletes' needs are twice as high (1.12 g/kg body weight). Pregnant women's needs for protein are considerably higher and they depend on the pregnancy trimester, by increasing to an additional 23 g/day for the third pregnancy trimester [21]. Because of all stated above, chicken meat is recommended as a rich source of high-quality protein in human nutrition. Chicken meat contains low collagen levels, which is another positive characteristic. Collagen is a structural protein that reduces meat digestibility, so chicken meat is easier to digest than other types of meat [22].

Chicken meat is also a good source of some minerals and vitamins (**Table 2**). When compared to red meat (except for pork meat), it contains more calcium, magnesium, phosphorus and sodium. Content of iron is almost the same as in pork. Iron is necessary for creation of hemoglobin, for prevention of anemia, as well as for normal muscle activity. Calcium and phosphorus are important for healthy bones and teeth. Sodium is an electrolyte, and magnesium is important for normal synthesis of protein and proper muscle activity. Out of the total content of vitamin in chicken meat, niacin (vitamin B3) is contained in highest portion, and content of vitamins A and B6 is also higher than in other types of meat. Niacin is very important for proper metabolism of carbohydrates and for energy creation. It is also important for healthy skin, hair and eyes, as well as for nervous system. It plays a role in the synthesis

	Chicken <sup>1</sup>	Pork <sup>2</sup>	Beef <sup>3</sup>	Lamb <sup>4</sup>
<b>Minerals</b>				
Calcium (mg)	15	16	6	8
Iron (mg)	1.04	0.97	2.40	2.06
Magnesium (mg)	29	27	18	26
Phosphorus (mg)	228	273	172	208
Potassium (mg)	256	425	222	342
Sodium (mg)	74	80	36	66
Zinc (mg)	1.00	2.48	4.74	5.02
<b>Vitamins</b>				
Vitamin C (mg)	0.0	0.0	0.0	0,0
Thiamin (mg)	0.070	0.523	0.057	0.110
Riboflavin (mg)	0.114	0,408	0.170	0,280
Niacin (mg)	13.712	7.940	5.232	6.390
Vitamin B6 (mg)	0.600	0.538	0.380	0.170
Folate (µg)	4	0	9	24
Vitamin B12 (µg)	0.34	0.67	1.61	2.71
Vitamin A (µg)	6	1	0	0
Vitamin E (mg)	0.27	0.26	0.37	0.18
Vitamin D (D2 + D3) (µg)	0.1	0.3	—	—
Vitamin K (µg)	0.3	0.0	1.3	—

Source: [20].<sup>1</sup>Chicken, broilers or fryers, breast, meat only, cooked, roasted.  
<sup>2</sup>Pork, fresh, leg (ham), rump half, separable lean only, cooked, roasted.  
<sup>3</sup>Beef, round, bottom round, roast, separable lean only, trimmed to 0" fat, choice, cooked, roasted.  
<sup>4</sup>Lamb, domestic, leg, shank half, separable lean only, trimmed to 1/4" fat, choice, cooked, roasted.

**Table 2.** Content of minerals and vitamins in different types of meat (per 100 g).

of sex hormones and in improving circulation and reducing cholesterol level. Niacin is often used as an additional therapy in patients that take drugs for lowering of blood lipids. In this case, it is scientifically proven that niacin affects the increase of high density lipoprotein (HDL) cholesterol level, but it does not affect the improvement of cardiovascular disease state [23, 24]. When niacin is taken as an independent therapy, it reduces the development of cardiovascular diseases, and lowers the mortality associated with cardiac or cardiovascular diseases [25, 26]. The chronic lack of niacin in the organism causes pelagic disease, which is characterized by uneven skin pigmentation (skin redness), gastrointestinal disorders (diarrhea) and brain function disorder (dementia), [27]. In light of the abovementioned, chicken meat is considered as convenient, affordable and acceptable source of basic nutrients, vitamins and minerals necessary for proper body functioning.

By applying different feeding treatments, the nutritional profile of chicken meat, such as fat and cholesterol content and fatty acid profile, can be modified in order to produce a foodstuff of improved nutritional value. Furthermore, supplementation of various antioxidants (selenium and vitamin E) to chicken feed influences their deposition in chicken tissue, thus enabling production of enriched foodstuff. The possibilities of enriching chicken meat with favorable omega-3 fatty acids and antioxidants are explored in the following text.

## 2.1. Health benefit of chicken meat

In present times, emphasis is put on importance of chicken meat consumption for maintaining and reducing body weight. It is known that the intake of dietary protein is effective in reducing body weight, so the chicken meat is often a part of the diet aimed to reduce body weight, because of its high protein and low fat content. The studies have shown that weight loss was higher in people who consumed low calorie meals rich in protein in comparison with low calorie meals with low protein content. This is due to the fact that protein provides a greater sense of satiety, so that people consume less calories during the day, thus reducing the intake of carbohydrates [28, 29].

Chicken meat is considered as desirable foodstuff in prevention of cardiovascular diseases. Saturated fat, cholesterol and heme iron, which is more contained in red than in white meat, are very important factors in development of atherosclerosis, cardiovascular diseases, hypertension and in increase of blood cholesterol [30]. According to the data of Bernstein et al., by replacing meals with red meat with white chicken meat, the risk of cardiovascular disease occurrence can be lowered by 19% [31]. The authors assumed that this was a consequence of less intake of heme iron and sodium, and of more polyunsaturated fatty acids in meals. Therefore, chicken meat, as a source of protein, could be a significant factor in reducing risks of cardiovascular disease development.

There has been recently a lot of evidence on how the lifestyle has been influencing the increase or the decrease of disease risk occurrence, such as diabetes. Changes in our lifestyle and nutrition can significantly affect the decrease of that disease occurrence. The increased risk of developing diabetes is related to various factors, of which the intake of saturated animal fat is among the most significant ones [32]. The authors stated a positive correlation between the intake of saturated fat intake and the resistance to insulin. The research results of Pan et al. pointed out that consumption of red meat, especially of red meat products, was associated with increased risk of developing the type 2 diabetes [33]. Although the increased intake of protein of animal origin represents a risk of developing diabetes, consumption of chicken meat, as a part of balanced diet, is recommended for prevention of disease development and its control [34]. Healthy lifestyle, which includes consumption of chicken meat, fruit, legumes, nuts, whole grains and vegetable oils, is associated with reduced risk of death in patients suffering from diabetes [35]. The results of these studies encourage the change of lifestyle and dietary habits, within which white chicken meat with low content of saturated fat serves as a healthier alternative to animal protein intake in daily meals, so it is recommended as a part of a healthy diet.

As stated above, excessive intake of proteins of animal origin is associated with the risk of developing diabetes. Still, some studies have also confirmed that excessive intake of meat, especially



of red meat, is a potential risk factor for development of certain types of cancer. Red meat contains more potentially harmful ingredients than white meat. These potentially harmful ingredients are saturated fat, heme iron, sodium, N-nitroso compounds and aromatic amines produced by high temperature cooking, so the consumption of red meat represents a risk of developing cancers. Therefore, red meat is associated with a higher risk of cancers, while white meat shows neutral or moderately protective correlation to cancer occurrence [36, 37]. Cancers in digestive system are usually associated with consumption of animal products. This conclusion was confirmed by researches carried out among populations with significantly higher consumption of meat than recommended. It is assumed that myoglobin from red meat activates pre-cancerous damage by accelerating the heme iron influence on the formation of carcinogenic N-nitroso compounds and by developing cytotoxic and genotoxic aldehydes through the lipid peroxidation process [38]. These facts are in favor of supporting consumption of white chicken meat. Zhu et al. carried out a comprehensive review of literature on the occurrence of esophageal cancer, and concluded that there was a reverse correlation between the number of chicken meat meals a week and the risk of developing esophageal cancer [39]. The authors stated researches showed the decreasing risk of developing esophageal cancer by about 53% in Europe in cases of increased consumption of chicken meat. Of course, such research conclusions should be interpreted cautiously, because it cannot be stated with full certainty that red meat causes cancers and white meat does not, yet there is a lot of evidence that consumption of white meat is more favorable than consumption of red meat.

### 3. Parameters of chicken meat quality

When considering nutritional aspects, poultry meat is good for consumers because it is rich in protein and minerals, and contains a small amount of fat with high portion of unsaturated fatty acids and a low cholesterol level [2]. Changes in consumers' lifestyle in developed countries have influenced the meat market by changing the demand and supply of certain types of meat, which the food industry used as an advantage to market so called "fast food" and more recently also "functional food". In both food groups, chicken meat is highly represented [3]. This growing demand for poultry meat influenced the scientists to create chickens of fast-growing genotypes, which have good feed conversion, better carcass formation (higher portion of breast meat and less abdominal fat), lower mortality, etc. However, all of these positive changes in new chicken genotypes cause greater stress, and many researchers point out that this fast growth of chickens resulted in histological and biochemical modifications of muscle tissue [40, 41, 42]. The researches proved that selection of fast-growing chickens had negative effects on some meat quality parameters: reduced water holding capacity of meat, poor cohesiveness in cooked meat, appearance of pale, soft, exudative (PSE) meat, that is, of dark, firm, dry (DFD) meat [43, 44]. In addition to the mentioned factors, the available literature states that parameters of chicken meat quality are affected by the keeping system and duration of chicken fattening, feeding treatment and sex of chickens, pre-slaughter handling, transport to slaughterhouse, etc.

An important factor for consumers when deciding on the purchase of meat is its appearance, therefore, in this chapter are described some technological features such as color, pH value, drip loss, cooking loss and water holding capacity (WHC), that have a direct impact on meat

appearance. Consumers connect the color of meat with its freshness. The color of meat can be determined visually or using instruments (colorimeters). For the visual evaluation of the meat color, it is necessary to have trained panelists, who evaluate the appearance of meat by using the hedonic scale. The instrumental determination of meat color is more efficient and the methods of reflection or extraction are used to quantify the amount of pigment. The color of foods can be defined as the interaction of a light, an object, an observer and the surroundings of the food. Recently, the International Commission on Illumination described how background can influence the appreciation of color. Instruments used for evaluation of meat color by reflection method are colorimeters, for example, CR Minolta 300 or 400 that work on the principle of meat color comparison in regard to standard color values. The International Commission on Illumination lists three values: CIE  $L^*$ ,  $a^*$  and  $b^*$ . CIE  $L^*$  indicates lightness, where values range from 0 (black) to 100 (white). The value of CIE  $a^*$  shows redness while CIE  $b^*$  indicates yellowness. Negative  $a^*$  and  $b^*$  values indicate the appearance of green and blue color of the meat.

### 3.1. Influence of genotype, sex and feeding on the chicken meat quality

Kralik et al. reported that the chicken genotype did not influence the CIE  $L^*$  (lightness) and CIE  $b^*$  (yellowness) values referring to meat color [45]. As of the results, the CIE  $L^*$  49.93 and CIE  $b^*$  10.17 was reported for chicken meat of Cobb 500 genotype, and for the Hubbard Classic, the values were CIE  $L^*$  51.11 and CIE  $b^*$  10.50 ( $P > 0.05$ ). Furthermore, the authors stated that there was a negative correlation between pH and CIE  $L^*$  value  $r = -0.285$  for Cobb 500 and  $r = -0.438$  for Hubbard Classic genotypes. In the research into the influence of chicken sex on the quality of fresh and cooked meat, Salakova et al. also determined the negative correlation between pH and CIE  $L^*$  value measured in fresh and cooked breast meat of the Ross 308 chicken genotype ( $r = -0.41$ ,  $P < 0.001$  and  $r = -0.31$ ,  $P < 0.05$ ), [46]. The authors stated that male chickens of the Ross 308 genotype had statistically significantly higher pH values than female chickens ( $P < 0.05$ ), which was not depending on the portion of crude protein in the finisher mixture (A = 22.6%, B = 20.1% and C = 18.7%). The highest pH values were measured in breast meat of male and female chickens of the group A (pH = 6.08 and pH = 5.97, respectively), while in feeding treatments with lower portion of crude protein in feeding mixture the value of pH in breast meat of both sexes decreased ( $\sigma$  B = 5.99 and C  $\sigma$  = 5.77 and  $\phi$  B = 5.85 and  $\phi$  C = 5.66). Female chickens had statistically significantly brighter meat color than male chickens in the A treatment (CIE  $L^*$  54.90 and CIE  $L^*$  52.24, respectively;  $P < 0.01$ ). The same trend referring to the meat color was noticed in other feeding treatments, however, the differences were not statistically significant ( $\phi$  B=CIE  $L^*$  59.43 C=CIE  $L^*$  58.11 and  $\sigma$  B=CIE  $L^*$  58.36 C=CIE  $L^*$  55.17). The research of Živković et al. describes the influence of extruded linseed in chicken feed on the physico-chemical and sensory traits of meat [47]. They fattened chicken separated by sex in control and experimental group. The control group (C) consumed the commercial mixture and the experimental group (E) had mixture supplemented with 6% of extruded linseed. The authors concluded that feeding treatment influenced the protein content in meat of thighs of females only (C = 19.27% E = 17.76%;  $P < 0.05$ ). The feeding treatment had effect on the breast meat color ( $P < 0.05$ ). Experimental group of chickens had lighter breast meat color than the control. Male chickens had statistically significantly lighter breast meat than females ( $P < 0.05$ ). The value of CIE  $a^*$  (redness) reduced significantly in *m. pectoralis profundus*, and CIE  $b^*$  increased in *m. pectoralis superficialis* in both chicken sexes ( $P < 0.001$ ). In thigh muscles



(*m. biceps femoris*), the value of CIE  $a^*$  reduced significantly ( $P < 0.05$ ) in meat of male chickens, while in female chickens the values of CIE  $b^*$  increased significantly ( $P < 0.05$ ). The feeding treatment, sex and their interaction did not influence the results of chicken meat sensory analysis. In their research into the effects of genotype on some parameters of chicken meat quality, Kralik et al. reported that breast meat of the Hubbard Classic genotype was of better quality than the breast meat of Cobb 500 and Ross 308 genotypes [48]. Hubbard Classic chickens had better  $pH_{45min}$  and CIE  $L^*$  values than other two genotypes (Cobb 500 and Ross 308). The highest  $pH_{45min}$  was determined in Cobb 500 chickens, while the values for  $pH_{45min}$  in Ross 308 and Hubbard Classic chicken were similar (6.05, 5.99 and 5.98, respectively;  $P > 0.05$ ). Genotype had no effect on  $pH_{24h}$  values ( $P > 0.05$ ). Hubbard Classic chickens had the lowest CIE  $L^*$  value in breast muscle tissue (53.86), while Ross 308 and Cobb 500 chickens had slightly higher CIE  $L^*$  values (55.12 and 54.36, respectively;  $P > 0.05$ ). Kralik et al. reported statistically significant influence of genotype on  $pH_1$  ( $P = 0.004$ ) and  $pH_2$  ( $P < 0.001$ ), drip loss ( $P = 0.015$ ) and meat color (CIE  $L^*$   $P = 0.015$  and CIE  $a^*$   $P < 0.001$ ) in their research [49]. The values of pH were measured 45 minutes after slaughtering ( $pH_1$ ) and 24 h after slaughtering and cooling of chickens ( $pH_2$ ). The authors stated that chicken sex had statistically significant influence on meat color ( $P < 0.001$ ). Female chickens had lower CIE  $L^*$  values than male chickens (Cobb ♀ = CIE  $L^*$  49.24 and ♂ = CIE  $L^*$  50.60, i.e. Hubbard ♀ = CIE  $L^*$  49.97 and ♂ = CIE  $L^*$  52.61). Influence of interaction between genotype and sex was observed in breast texture values ( $P < 0.020$ ). In the research into the influence of pH values on the meat quality of different chicken genotypes, Ristić and Damme concluded that the chicken genotype and sex had statistically significant effect on the pH measured 15 minutes after slaughtering of chickens [50]. Male chickens had statistically significantly lower pH values than females. In the research into the influence of chicken genotype (Cobb, Ross and Hubbard) and the age (42 and 50 days) on the quality of meat, Glamoclija et al. stated that the pH values measured at different times after slaughtering ( $pH_{15min}$ ,  $pH_{24h}$  and  $pH_{48h}$ ) were influenced by the chicken age at slaughter ( $P < 0.05$ ), [51]. Older chickens had higher pH values of breast meat than younger ones. Interaction of chicken genotype and age had effect on the  $pH_{15min}$  value, while the genotype did not affect the pH values ( $P > 0.05$ ).

### 3.2. Influence of keeping system and fattening duration on the chicken meat quality

Bogosavljević-Bošković et al. determined that the fattening system (intensive or semi-intensive) had statistically significant influence on the portion of breasts and drumsticks with thighs ( $P < 0.05$ ), [52]. The authors indicated that the portion of muscle tissue in chickens kept in semi-intensive system was by 1.44% higher ( $P < 0.01$ ), but the same chickens had the portion of bone and skin by 0.82 and 0.67% lower than chickens fattened in the intensive system ( $P < 0.05$ ). Li et al. investigated the influence of chicken keeping systems (free range, cage and litter) on production parameters and meat quality and they reported that the keeping system had statistically significant influence on the final weight of chickens and feed consumption, as well as on the texture and portion of intramuscular fat in breast meat ( $P < 0.05$ ), [53]. However, chicken keeping system had no effect on pH and drip loss in breast meat ( $P > 0.05$ ). Castellini et al. [54] studied the influence of keeping systems (K = conventional and O = organic) and duration of fattening of chickens (56 and 81 days) on the quality of chicken meat, and they confirmed that breast and thigh meat of chickens kept in organic production had lower WHC values and  $pH_{24h}$  than meat of chickens fattened conventionally. The breast meat had the following WHC values:

$K_{56 \text{ days}} = 52.02\%$  and  $K_{81 \text{ days}} = 55.26\%$ , and  $O_{56 \text{ days}} = 51.82\%$  and  $O_{81 \text{ days}} = 53.17\%$  ( $P < 0.05$ ), while the values in thighs were as follows:  $K_{56 \text{ days}} = 59.69\%$  and  $K_{81 \text{ days}} = 60.15\%$ , and  $O_{56 \text{ days}} = 56.21\%$  and  $O_{81 \text{ days}} = 57.45\%$  ( $P < 0.05$ ). The values of pH in breast muscles of the treatments  $K_{56 \text{ days}}$  and  $K_{81 \text{ days}}$  were statistically significantly higher ( $P < 0.05$ ) than in the treatments  $O_{56 \text{ days}}$  and  $O_{81 \text{ days}}$  (pH 5.96 and pH 5.98, and pH 5.75 and pH 5.80, respectively). Referring to all other meat quality parameters of both tested tissue (breasts and thighs), chicken meat from organic production had better values than the meat produced in conventional fattening system (cooking loss %, CIE  $L^*$ , CIE  $a^*$ , CIE  $b^*$  and shear value  $\text{kg/cm}^2$ ).

### 3.3. Influence of transport and pre-slaughter handling on the chicken meat quality

When animals are exposed to long-lasting stress (long-distance transport, lack of feed before transport and slaughter, overcrowded transport cages, high or low temperatures in the production facility or during transport, etc.), they will be exhausted and the glycogen stored in muscles will turn into lactic acid, which will then lead to a sudden lowering of pH value in muscles after slaughter, while the carcass is still warm. High temperature and low pH in chicken meat will stimulate protein denaturation, which will further influence lowering of the water holding capacity in meat. Low pH values stimulate the oxidation of myoglobin (pink color) and oxyhemoglobin (red color) to metamyoglobin (brown meat color). If animals are exposed to longer stress before slaughtering, they will have less stored glycogen in muscles because of exhaustion. Reduced glycogen reserve affects postmortem changes after slaughtering, meaning that the pH value remains high, which causes the occurrence of DFD meat. In this meat, protein denaturation and drip loss are slowed down [41]. In their study about influences of transport-caused stress on the meat quality parameters, Doktor and Połtowicz [55] stated that after 42 days of fattening of Hubbard Flex chickens, their treatment before and during transport to slaughterhouse had statistically significant influence only on  $\text{pH}_1$ , while other meat quality parameters were not influenced ( $\text{pH}_2$ , meat color ( $L^*$ ,  $a^*$ ,  $b^*$ ), drip loss (%), water holding capacity—WHC (%), shear force (N)). Bressan and Beraquet studied the influence of heat stress during fattening on the chicken meat quality and determined that chickens exposed to high daily temperatures (ambient temperature  $30^\circ\text{C}$ ) had higher cooking loss measured in breast meat when compared to chickens kept at lower ambient temperatures ( $17^\circ\text{C}$ ), (28.7 and 27.2%, respectively), [56].

### 3.4. Influence of some technological parameters on the chicken meat quality

Since appearance and odor, as the parameters of meat quality, significantly affect the consumers' preferences at purchase, it is important to achieve "normal" meat color with the odor typical for fresh meat [57]. The stated authors assessed the consumers' opinions toward pale, soft and exudative chicken meat. In their research they used meat of lighter color ( $L^* = 59.26$ ), that is, the meat color that was considered as normal for chicken filets ( $L^* = 49.24$ ). The examinees made differences between PSE and meat of normal quality in stores, while panelists assessed sensory quality of cooked meat and showed preference toward control samples (meat of "normal" quality). Qiao et al. determined the border values for color of chicken breast muscle: lighter than normal ( $L^* > 53$ ), normal ( $48 < L^* < 53$ ) and darker than normal ( $L^* < 48$ ), [58]. Furthermore, the authors defined the values for breast muscle color measured 24 hours post mortem, as of the following: dark  $L^* 45.68$ , normal  $L^* 51.32$  and light  $L^* 55.95$ . Woelfel et al.

determined the border values for “normal” chicken breasts  $L^*$  52.15, drip loss 3.32% and cooking loss 21.02%, while for PSE meat these values were:  $L^*$  59.81, drip loss 4.38% and cooking loss 26.39% [59]. Border values reported by Karunanayaka et al. are slightly higher than those determined by the abovementioned authors [60]. According to Karunanayaka et al., the values for normal meat are  $L^*$  56.82 and WHC 77.95, while the PSE meat has the following values:  $L^*$  61.83 and WHC 77.12 [60]. **Table 3** presents border values for PSE, normal and DFD chicken meat, as reported by various authors.

According to Zhang and Barbut, meat color typical to PSE meat is  $L^* > 53$ , the meat of normal quality has the values ranging between  $46 < L^* < 53$ , and the DFD meat has the value  $L^* < 46$  [63]. The same authors stated the cooking loss of meat classified as of color: 20.96% for PSE meat, 25.77% for normal meat and 21.32% for DFD meat. Referring to the values of meat color ( $L^*$ ,  $a^*$  and  $b^*$ ), Kissel et al. classified the chicken meat as normal, with measured values of  $L^* = 51.42$ ,  $a^* = 7.26$  and  $b^* = 6.74$ , and as PSE meat with measured values  $L^* = 57.63$ ,  $a^* = 2.11$  and  $b^* = 5.46$  [62]. In their research into the PSE chicken meat in further processing (marinating and cooking), Barbut et al. [64] reported that fresh PSE meat was of lighter color ( $L^* = 57.7$ ) and had lower pH (5.72), while DFD meat was of darker color  $L^* = 44.8$  and higher pH (6.27). Carvalho et al. determined that PSE meat had  $L^* = 58.90$ ; drip loss = 6.52%, cooking loss = 27.02% and WHC 79.84% [61]. The authors defined the meat to be of normal quality if exhibiting the following values:  $L^* = 56.86$ ; drip loss = 4.04, cooking loss = 24.41% and WHC = 85.43%.

Condition	pH Value of meat	References
PSE	$pH_{24h}$ 5.75	[61]
	pH 5.83	[60]
	pH 5.61	[57]
	$pH \leq 5.8$	[50]
	$pH_{24h}$ 5.77	[62]
	$pH < 5.7$	[63]
	pH 5.72	[64]
	pH 5.76	[59]
Normal	$pH_{24h}$ 5.94	[61]
	pH 5.97	[60]
	pH 5.96	[57]
	pH 5.9–6.2	[50]
	$pH_{24h}$ 5.93	[62]
	$pH < 6.1$	[63]
	pH 6.07	[59]
DFD	$pH \geq 6.3$	[50]
	$pH > 6.1$	[63]
	pH 6.27	[64]

**Table 3.** Typical limits of pH values for PSE, normal and DFD chicken meat.

## 4. Enrichment of chicken meat with functional ingredients

### 4.1. Polyunsaturated fatty acids (n-3 PUFA)

Science on nutrition has developed over the years, and new analytical methods have enabled the determination of various functional food ingredients that have a beneficial effect on human health and that help to reduce the disease risks. Such ingredients, called nutraceuticals, have an important biological activity in human cells [65]. The concept of functional food has been first mentioned in Japan in the 1980s. The project foods for specified health uses (FOSHU) was focused on food that was expected to have a specific health effect based on the content of some important and useful ingredients [66]. Ingredients in which consumers show interest are n-3 PUFA, Se, vitamin E, lutein and carnosine. Chicken meat can be enriched with n-3 PUFA if the content of FA (Fatty Acids) is changed in their feed [10, 67, 68, 69]. The optimal ratio of n-6 PUFA:n-3 PUFA is from 10:1 to 5:1 [70, 71]. The RDI (Recommended Daily Intake) for n-3 long-chain PUFA is 350–400 mg. Vegetable and fish oils are predominant sources of omega-3 fatty acids. Vegetable oils are the main source of  $\alpha$ -linolenic acid (C18:3n3, ALA), and fish oils are the main source of eicosapentaenoic acid (C20:5n3, EPA) and docosahexaenoic acid (C22:6n-3, DHA), [72]. Vegetable oils contain significant amounts of polyunsaturated omega-6 fatty acids, of which linoleic acid (C18:2n-6, LA) is the most significant. It is also present in sunflower and soybean oils [65]. Metabolic processes are initiated over arachidonic acid (C20:4n6, AA) and EPA in endoplasmic reticulum, and further carried out by the enzymes elongase  $\Delta$ 6 and desaturase  $\Delta$ 5. The mechanism of conversion into DHA is still not fully known, yet is believed that this

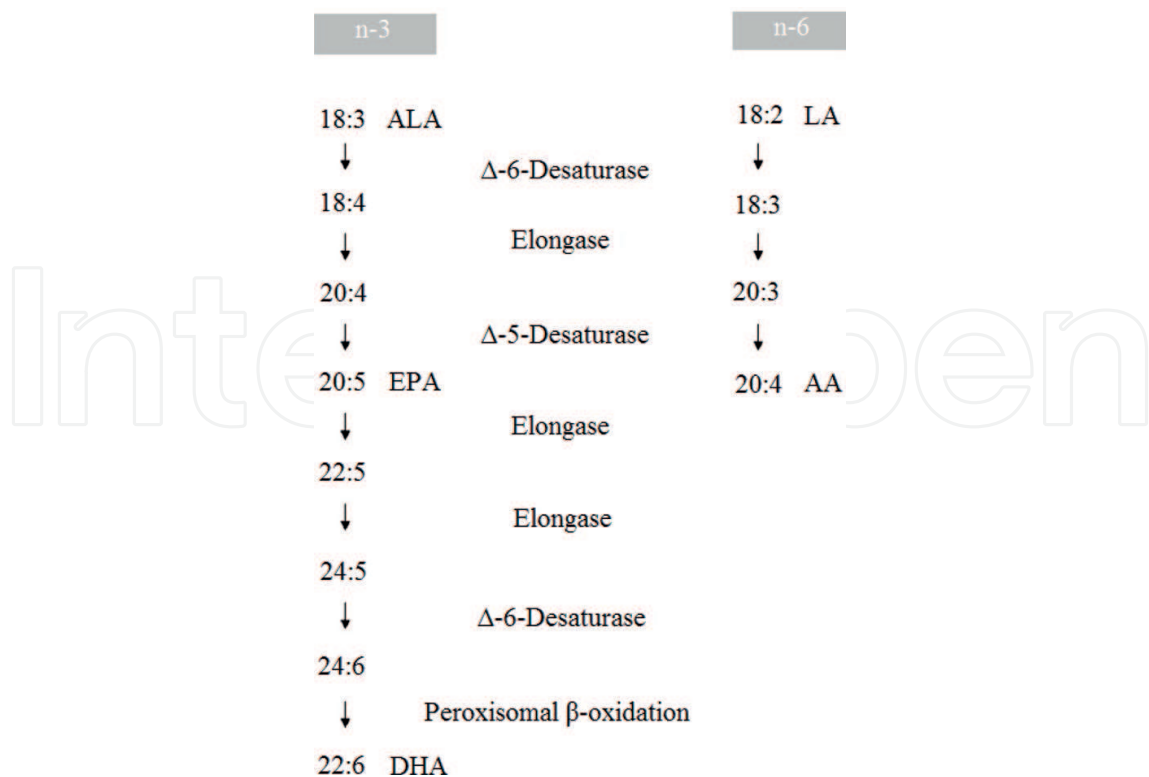


Figure 1. Metabolism of n-3 and n-6 PUFA [76].

process is supported by the enzyme desaturase  $\Delta 4$  [73]. Infante and Huszagh stated that DHA is synthesized in mitochondrial membranes, while EPA and AA are synthesized in the endoplasmic reticulum [74, 75]. **Figure 1** presents the metabolism of n-3 and n-6 PUFA.

There are two reasons for increasing the concentration of n-3 PUFA in chicken meat. The first reason is that nutritionists recommend the reduced consumption of saturated fatty acids (SFA)

Reference	Diet	ALA	EPA	DHA
		% of total FA		
[12]	Sunflower oil 2.5% + fish oil 2.5%	3.16	0.79	5.62
	Soybean oil 2.5% + fish oil 2.5%	2.37	0.93	6.44
	Rapeseed oil 2.5% + fish oil 2.5%	2.36	1.32	8.95
	Linseed 2.5% + fish oil 2.5%	6.25	1.18	5.66
[77]	Control	0.72	0.75	0.87
	Rapeseed oil 2%	0.37	1.18	2.03
	Rapeseed oil 4%	0.61	0.62	0.75
[78]	Poultry fat 3%	1.59	1.04	0.15
	Poultry fat 2% + fish oil 1%	0.70	5.84	0.66
	Poultry fat 1% + fish oil 2%	2.17	8.53	2.39
	Fish oil 3%	2.14	10.54	3.80
[10]	Linseed oil 6%	7.09	0.77	0.90
	Linseed oil 6% + 0.3% Se	8.51	0.73	0.93
	Linseed oil 6% + 0.5% Se	6.78	0.51	0.84
[79]	Sunflower oil 3% + linseed oil 3%	5.14	0.29	0.39
	Sunflower oil 3% + linseed oil 3% + 0.3 mg Se/kg feed	6.29	0.34	0.59
	Sunflower oil 3% + linseed oil 3% + 0.5 mg Se/kg feed	4.39	0.29	0.50
[80]	Corn oil 15%	2.21	–	0.07
	Canola oil 5% + corn oil 10%	2.01	–	0.05
	Canola oil 10% + corn oil 5%	3.41	–	0.13
	Canola oil 15%	3.52	–	0.07
[81]*	Rice bran oil S 1% + F 2%	0.33	0.15	0.43
	Rice bran oil (S 0.7% + F 1.6%) + linseed oil (S 0.3% + F 0.4%)	0.86	0.50	0.88
	Rice bran oil (S 0.3% + F 1.0%) + linseed oil (S 0.7% + F 1.0%)	0.98	0.98	1.77
[11]**	Sunflower oil S 2% + F 3%	0.23	0.17	0.23
	Soybean oil S 2% + F 3%	0.92	0.25	0.63
	Mustard oil S 2% + F 3%	3.23	0.63	1.47
	Linseed oil S 2% + F 3%	5.02	1.74	3.51
	Fish oil S 2% + F 3%	4.60	2.72	5.76

S-starter diet.

F-finisher diet.\*Rice bran oil and linseed oil are supplemented to S and F diets in the amounts as presented.

\*\*Oils of different origin are supplemented in the amount of 2% to S and 3% to F diets.

**Table 4.** Supplementation of oils in chicken feeding mixtures and their effect on enriching of breast muscles with n-3 PUFA.



to lower the risk of cardiovascular diseases development [82]. The second reason is that fats are replaced by polyunsaturated oils [83, 84, 85]. It is known that fish flour and oil are rich in essential n-3 PUFAs (EPA, DHA), however it is also proved that, if supplemented to chicken feed in higher amounts, they have negative effect on organoleptic properties of meat [86]. For that reason, as an alternative to fish oil, scientists use vegetable oils as supplements to chicken feed (soybean, rapeseed, sunflower and linseed oils), as well as combinations of those oils [11, 12, 77, 87]. In addition to oils, chicken feed can be supplemented also by extruded linseed or rapeseed [88], in order to change the FA profile. References about the use of various oils in chicken diets for the purpose of enriching broiler meat with n-3 PUFA are overviewed in **Tables 4 and 5**.

According to some researches, people have changed their dietary habits, so that over the past 150 years, once favorable and very narrow n-6 PUFA/n-3 PUFA ratio turned into unfavorable and wide ratio. There is also increased consumption of saturated fat originating from livestock fed grains, as well as increased consumption of trans-fatty acids originating from hydrogenated vegetable oils, along with significantly increased consumption of n-6 PUFA [91]. In developed countries, there is daily consumption of about 2.92 mg ALA, 48 mg EPA and 72 mg DHA [92], which is considered as insufficient. The studies have shown that human nutrition in Western European countries is lacking n-3 PUFA, and due to the significant amounts of n-6 PUFA in animal products, the n-6 PUFA/n-3 PUFA ratio is unfavorable, as it ranges from 15/1 to 16.7/1 [93, 94]. At present times, our diet is richer in calories than the food that man consumed in the Paleolithic. Nutrition in industrial societies is characterized by a surplus of calories, by increased consumption of SFA, n-6 PUFA and trans-fatty acids, and at

Reference	Diet	ALA	EPA	DHA
		% of total FA		
[89]	Fish oil 6%	1.01	5.66	6.27
	Fish oil 4% + 2% linseed oil	1.80	3.83	4.72
	Fish oil 2% + 2% linseed oil +2% sunflower oil	2.27	1.94	2.84
	Soybean oil 6%	3.37	-	0.72
[80]	Corn oil 15%	1.97	-	0.09
	Canola oil 5% + corn oil 10%	2.13	-	0.08
	Canola oil 10% + corn oil 5%	3.55	-	0.14
	Canola oil 15%	3.67	0.01	0.03
[10]	Linseed oil 6%	6.75	0.17	0.17
	Linseed oil 6% + 0.3% Se	11.90	0.26	0.18
	Linseed oil 6% + 0.5% Se	8.28	0.17	0.19
[90]	Sunflower oil 3% + linseed oil 3%	4.755	0.107	0.107
	Sunflower oil 3% + linseed oil 3% + 0.5 mg Se/kg feed	5.692	0.100	0.127
[81]*	Rice bran oil S 1% + F 2%	0.41	0.82	1.20
	Rice bran oil (S 0.7% + F 1.6%) + linseed oil (S 0.3% + F 0.4%)	0.07	0.35	0.48
	Rice bran oil (S 0.3% + F 1.0%) + linseed oil (S 0.7% + F 1.0%)	0.20	0.71	1.23

\*Rice bran oil and linseed oil supplemented to starter (S) and finisher (F) mixtures in the amounts as presented.

**Table 5.** Supplementation of oils to chicken diets and their effects on enrichment of thigh muscles with n-3 PUFA.

Period – area	n-6/n-3
Paleolithic	0.79
Greece prior to 1960	1.00–2.00
Current Japan	4.00
Current India, rural	5–6.1
Current UK and Northern Europe	15.00
Current US	16.74
Current India, urban	38–50

**Table 6.** Ratio of n-6 PUFA/n-3 PUFA in human nutrition.

the same time, by reduced consumption of n-3 PUFA, as well as of fruits, vegetables, protein, antioxidants and calcium. **Table 6** gives an overview of the n-6 PUFA/n-3 PUFA ratios in human nutrition according to different time periods and geographic locations [95].

#### 4.2. The increase of PUFA in chicken meat

Within conventional chicken feeding treatment, fat contained in chicken meat is dominated by palmitic and stearic fatty acids from the SFA group. Among the unsaturated fatty acids, the most present are oleic and linoleic acids,  $\alpha$ -linolenic and arachidonic acids are represented in small amounts. Eicosapentaenoic and docosahexaenoic fatty acids are present only in traces or not present at all. In order to ensure the deposition of desirable fatty acids into poultry muscle tissue, chickens should be fed diet rich in polyunsaturated fatty acids. Vegetable oils, such as rapeseed and linseed oils, are rich in  $\alpha$ -LNA, but they do not contain EPA and DHA. When supplementing fish oil to poultry feed, meat can obtain a “fishy” smell and taste that is undesirable for consumers [86]. Intensive researches into the effects of different diets on the content and profile of fatty acids in chicken meat are carried out, with the aim to produce meat with increased portion of n-3 PUFA and to retain organoleptic properties that are acceptable to consumers. Zelenka et al. concluded that broilers have limited capacity of desaturation and elongation of ALA into long-chain FA [96]. This conclusion was confirmed also by Lopez-Ferrer et al. [97]. Within the research into efficiency of enriching meat with EPA and DHA by using individual vegetable oils, such as sunflower, soybean, rapeseed and linseed oil in the amount of 5% as dietary supplements, it was proven that the most efficient was linseed oil as chicken feed supplement, as it achieved in muscle lipids the following results: 0.89% EPA and 1.85% DHA, which was, respectively, 7.41 and 1.92 times higher than the results achieved by the control fed sunflower oil [98].

Rahimi et al. fattened broilers with linseed and rapeseed as dietary supplements (7.5 and 15%, respectively), as well as with combination of both seeds (10 + 10%), and they determined that the combination of seeds influenced the increase of n-3 PUFA concentration in breast muscle when compared to the control group (0.004–0.25 mg/g meat), and the decrease of AA (0.08–0.03 mg/g), as well as the decrease of n-6/n-3 PUFA ratio (from 47.78 to 8.14), [13]. The authors pointed out that the most favorable ratio of n-3/n-6 fatty acids in chicken thighs was determined in the group of chickens which consumed diets supplemented with 15% linseed ( $P < 0.05$ ). Furthermore, the same group had the highest content of n-3 PUFA (1.15 mg/g), while the least content of those fatty acids was determined in the control group (0.26 mg/g). Better tendency of

Fatty Acid	Control <sup>1</sup>		Lofish		Hifish		P	
	Ross <sup>2</sup>	Cobb	Ross	Cobb	Ross	Cobb	Breed	Diet
EPA	7.5	6.9	17.4	20.0	27.2	30.8	NS <sup>*</sup>	<0.001
DHA	39.6	38.6	54.9	64.3	118	126	NS	<0.001

<sup>1</sup>Diets contained fish oil at Control 0, Lofish 20 and Hifish 40 g/kg diet.

<sup>2</sup>Breed of birds used, Ross 308 and Cobb 500.

<sup>\*</sup>NS: Not Significant.

**Table 7.** Effects of fish oil in the diet and breed of chicken on the mean EPA and DHA concentration (mg/100 g meat) in white chicken meat.

ALA deposition was noticed in thighs than in breasts, and it was not depending on the feeding treatment. These results can be explained by the fact that thigh meat has higher content of fat than breast meat in all investigated groups. The content of fat in thighs was ranging from 8.97% (7.5% linseed) to 9.85% (combination 10% rapeseed + 10% linseed), and in breasts it was 6.79% (7.5% linseed). Combination of linseed and rapeseed as dietary supplement proved to be the most efficient in enriching of chicken meat (breasts and thighs) with the n-3 PUFA, however, the same group had statistically significantly higher concentration of MDA  $\mu\text{g/kg}$  thigh meat than meat of other investigated groups ( $P < 0.01$ ). The authors explained the statistically significantly higher oxidation of fat in meat of the mentioned group by the weak stability of n-3 PUFA.

Rymer and Givens [99], citation Givens [16], stated that there was a possibility of enriching white chicken meat by using fish oil (Table 7).

The authors concluded that the chicken genotype did not influence the incorporation of EPA and DHA in muscle tissue, however, the dosage of fish oil to feed is very significant (20 g/kg feed, i.e. 40 g/kg feed). The stated amounts enriched white chicken meat with n-3 PUFA for 171 and 573%, respectively. The authors recommended the supplementation of 200 mg/kg vitamin E to chicken feed in order to preserve oxidative stability and organoleptic traits. Yan and Kim reported the efficient usage of microalgae in enrichment of poultry products (meat and eggs) with DHA [14].

#### 4.3. The increase of carnosine in chicken meat

Carnosine is a dipeptide composed of  $\beta$ -alanine and L-histidine, which is considered as a bioactive food component because of its physiological role in an organism. As a dipeptide precursor, L-histidine is important in the synthesis of carnosine ( $\beta$ -alanine – L-histidine), homocarnosine ( $\gamma$ -glutamine – L-histidine) and anserine ( $\beta$ -alanine – 3-methyl-L-histidine). Haug et al. supplemented histidine in the amount of 1 g/kg of feed and achieved the increase in carnosine concentration in chicken breast muscle for 64%, as well as the increase of anserine for 10% [100]. The authors concluded that higher amounts of histidine can cause the growth depression and the increase in feed conversion. Hu et al. did not determine the influence of carnosine supplementation (0.5% from 1st–21st day and from 22nd–42nd day of fattening) on the growth performances [101]. Experimental groups had higher weight of breast muscle and reduced thiobarbituric acid reactive substances (TBARS) values, while the meat color and pH values did not depend on the supplemented amount of carnosine to diets. Kopec et al.

determined that supplementation of histidine to turkey diet resulted in the increased diphenyl-2-picrylhydrazyl (DPPH) radical scavenging capacity in breast muscles and blood, but did not result in the increased histidine dipeptide concentration [102]. The enzymatic antioxidant system of turkey blood was affected by the diet-containing spray dried blood cells (SDBC). In the plasma, the SDBC addition increased both superoxide dismutase (SOD) and glutathione peroxidase (GPx) activity and decreased GPx activity in the erythrocytes. Turkeys fed with diet-containing SDBC had increased BW (body weight) and the content of isoleucine and valine in breast muscles. Kralik et al. investigated the effects of dietary supplementation with 0, 0.1, 0.2 and 0.3% histidine on the quality of meat and the content of carnosine in breast and thigh muscles in Cobb 500 and Hubbard Classic chickens [103]. Dietary supplementation with L-histidine significantly affected live weight, carcass weight, weight of drumsticks and thighs, backs and wings, share of back and the  $a^*$  value ( $P < 0.05$ ), as well as the content of carnosine in breast muscle ( $P = 0.003$ ). The Cobb 500 broiler chickens deposited more carnosine in meat than Hubbard Classic chickens. Chicken breast muscle had higher content of carnosine than thighs and drumsticks [18, 104, 105, 106]. Results of studies into the enrichment of chicken meat with carnosine through implementation of different dietary treatments indicated the need for further investigations in order to determine the most efficient dietary treatment for synthesis and deposition of carnosine in chicken muscle tissues [19, 100, 101, 107–109]. In order to enrich chicken meat with carnosine, Kralik et al. added to chicken feed, apart of 0.10% L-histidine, also 0.20%  $\beta$ -alanine and 0.24% MgO as a catalyzer [110]. The research results proved more efficient synthesis and deposition of carnosine in broiler meat of experimental group than in the control group (breasts 1443.35:664.1 mg/kg,  $P < 0.01$ ; thighs 452.62:342.14 mg/kg,  $P = 0.057$ ). Carnosine plays an important role in physiological functions of an organism. Recent researches into enrichment of chicken meat with carnosine as a functional ingredient confirmed that carnosine influences regulation of intracellular pH, it prevents oxidation and it is also important for maintaining the neurotransmission [111, 112]. Poultry meat is susceptible to oxidative processes which cause the changes in color, smell and taste [101]. Lipid oxidation can be controlled during meat storage by means of antioxidants (vitamin C, selenium and carnosine).

#### 4.4. Enrichment of chicken meat with selenium

In the food chain, plants are the main source of selenium for animals. Plants get selenium from the soil, so it is important that soil is well supplied with this microelement. The supply of plant with selenium depends on its availability in the soil, therefore, plants from different areas have different selenium content. As poultry feeding mixtures are made from grains produced on different fields, the content of selenium is not equalized. If inorganic fertilizers that contain sulfur are used in agricultural production, then the selenium availability for plants is reduced. Also, acidification of soil significantly reduces the availability of selenium for plants. Instead of the inorganic form of selenium, scientists pointed out that organic form of selenium produced in form of selenized yeast shall be introduced as an animal feed supplement [17, 113, 114]. Recently, biofortification of plants with selenium has been carried out in arable crop production in order to increase the availability of selenium to plants, and to make them further available as a feed for animals, to consequently enrich final animal products with selenium [115, 116]. The source of selenium (inorganic—sodium selenite or organic—selenomethionine in the form of yeasts or algae) used in animal feed has



significant effect on its exploitation in the organism [15, 117, 118]. Wang and Hu determined statistically significant higher activity of GPx in blood of fattening chicken that consumed diet with higher content of selenium ( $P < 0.05$ ), [15]. Furthermore, they stated that the source of selenium influenced the selenium content and GPx activity in chicken blood ( $P = 0.01$ ). Better results were obtained in chickens fed diet supplemented with organic selenium. In their research into the influence of selenium sources on chicken meat quality, Ševčíková et al. used chickens of the Ross 308 provenience and fed them for 42 days with three feeding mixtures (C = without selenium, P1 = 0.3 mg/kg Se-yeast and P2 = 0.3 mg/kg Se-Chlorella), [119]. In their results, the authors reported that the content of selenium in chicken thighs (C = 52.11, P1 = 217.39 and P2 = 123.21  $\mu\text{g/kg}$ ) and in breasts (C = 70.95, P1 = 247.87 and P2 = 147.61  $\mu\text{g/kg}$ ) increased in experimental groups in comparison with the control group ( $P < 0.05$ ). Choct et al. stated that the increased content of selenium in chicken feed from 0.1 to 0.25 mg/kg affected the increase of selenium content in breast muscles from 0.232 to 0.278 mg/kg [120]. Kralik et al. investigated the influence of selenium content in chicken feed on the selenium content in breast muscles, by using 60 male chickens of the Ross 308 provenience, divided into three groups: P1 = without selenium, P2 = 0.3 mg Se/kg feed and P3 = 0.5 mg Se/kg feed [79]. All groups of chickens had feed that contained a total of 6% oils (3% sunflower oil and 3% linseed oil). Experimental groups' feed were supplemented by organic selenium Sel-Plex<sup>®</sup>, produced by Alltech. The authors pointed out that breast muscle tissue in the group P3 contained significantly more selenium (0.265 mg/kg tissue) than groups P2 (0.183 mg Se/kg tissue) and P1 (0.087 mg/kg tissue,  $P < 0.05$ ). The increase in the content of selenium in feed from 0.0 to 0.3 mg/kg influenced the change of the fatty acid profile in breast muscle tissue. More precisely, it caused the increase in portion of ALA, EPA, DPA and DHA, that is, in portion of total n-3 PUFA, and it affected also the lowering of the total SFA and MUFA portion. The results that support the mentioned fact are also pointed out by Haug et al., as they reported significant influence of selenium contained in chicken feed on the content of EPA, DPA and DHA in thigh muscles [121]. This means that the increased content of selenium in feed affects the increase of the mentioned fatty acids in thigh muscles ( $P < 0.05$ ). The authors explained this fact by confirming that higher content of selenium in feed had influence on the activity of  $\Delta 6$ -,  $\Delta 5$ - and  $\Delta 4$ - desaturase and elongase, which catalyze elongation and desaturation of short-chain fatty acids to long-chain fatty acids, or that such intake led to slowed speed of long-chain fatty acids degradation within peroxidation processes. Furthermore, Kralik et al. stated that the increase of selenium content in feed to a level of 0.5 mg/kg caused the portion of n-3 PUFA to equalize with the values recorded in the P1 group, which did not have organic selenium added to feed [79]. The authors assumed that the surplus of selenium in feed of the P3 group was required for saturation of various antioxidative selenoenzymes in cells, since it was noticed that the value of lipid oxidation in that group was the lowest. The values of lipid oxidation in meat (TBARS) measured in fresh and frozen meat 28 days in a freezer at  $-20^{\circ}\text{C}$ ) were similar in all groups (fresh meat: P1 = 3.97 nmol MDA (Malondialdehyde)/g tissue, P2 = 3.56 nmol MDA/g tissue, P3 = 3.44 nmol MDA/g tissue and frozen meat: P1 = 5.50 nmol MDA/g tissue, P2 = 5.44 nmol MDA/g tissue and P3 = 4.94 nmol MDA/g tissue;  $P > 0.05$ ). Dlouhá et al. reported that organic selenium in chicken feed reduced the lipid oxidation in breast muscle tissue, both in fresh and in stored meat [122]. Wang et al. pointed out that the level of selenium in feed (0.0 and 0.6 mg/kg) statistically significantly reduced the lipid oxidation in breast muscle tissue (0.34–0.30 mg/kg MDA;  $P < 0.001$ ), [123].



## 5. Effects of omega-3 fatty acids, carnosine and selenium on human health

In recent years, many studies have been performed to determine the effect of **omega-3 fatty acids** on human health. In human nutrition,  $\alpha$ -linolenic acid is the most represented fatty acid because it is found in vegetable sources (vegetable oils, seeds, nuts leafy vegetables). However, ALA has less expressed positive effect on human health than EPA and DHA, and its efficiency of conversion to EPA and DHA in the human body is only 2–10% [124] or even less. Therefore, it is necessary to introduce into diet some foodstuffs rich in EPA and DHA (fish and oils of fish and marine organisms), or to consume products enriched with these fatty acids, such as eggs and poultry meat. Omega-3 fatty acids are associated with many positive effects on human health. Since they are a constituent part of cell membranes, they are spread throughout the body. In the cells, these fatty acids act anti-inflammatory and help to maintain membrane viscosity [125]. DHA is an integral part of all cell membranes, and it is especially represented in the brain tissue. When compared to EPA, the researches proved that DHA has a more important role in maintenance of normal cell membrane function and that it is crucial for proper development of fetal brain and retina [126]. It was also found that the intake of EPA and DHA during pregnancy helps to reduce the incidence of premature birth, which causes many diseases in newborns. It is assumed that EPA and DHA reduce the production of prostaglandins E<sub>2</sub> and F<sub>2</sub> $\alpha$ , thus helping to reduce uterine inflammation associated with premature birth [127]. Omega-3 fatty acids are usually mentioned in association with the prevention of heart and blood vessel diseases, which are usually caused by chronic inflammation processes in the body. EPA and DHA have anti-inflammatory and antioxidative activity [128] and help to maintain good condition of heart and blood vessels. The researches into the use of EPA and DHA in prevention of heart diseases are often controversial, but many of them prove positive effects of the stated fatty acids. For example, Kris-Etherton et al. [129] and Tavazzi et al. [130] determined a positive correlation between the intake of EPA and DHA and the reduced risk of reoccurring cardiac artery disease, sudden cardiac death after acute myocardial infarct and reduced heart failure occurrence. In addition, the omega-3 fatty acids have a positive role in prevention of atherosclerosis and peripheral artery diseases. It is believed that EPA and DHA improve plaque stability, reduce endothelial activation and improve blood vessel permeability, thus reducing the risk of cardiovascular disease occurrence [131]. Since DHA is largely present in phospholipids of the nerve cell membranes, where it is involved in the proper functioning of the nervous system, it is considered to have a preventive role in the development of Alzheimer's disease [132]. When considering the contradictory results of research into the effects of omega-3 fatty acids on various diseases, there is further research required to determine the exact protective mechanism of these fatty acids not only against the abovementioned diseases, but also against some other diseases.

**Carnosine** is a natural dipeptide composed of amino acids  $\beta$ -alanine and L-histidine through the action of the carnosine synthase enzyme. It is synthesized and present in large quantities in muscular and nervous tissue of mammals, birds and fish. It easily absorbs into the digestive

tract, penetrates through the blood and brain barrier, and with its great bioavailability it acts as a cell membrane stabilizer [133]. In general, carnosine is more concentrated in white muscle tissue than in dark tissue [134], which was also confirmed in the research by Kralik et al., within which it was determined that chicken breast muscle contained higher concentrations of carnosine than the thigh muscle [101]. There are many physiological roles attributed to carnosine, such as: buffer activity, antioxidative activity, hydroxyl radicals, aldehydes and carbonyls scavenger, copper and zinc ions chelator, protein degradation stimulator, reaction with protein carbonyls, activator of enzyme action, suppressor of protein networking [135]. Still, carnosine is the best known by its buffer activity in the organism. It is assumed that this buffer activity is the reason for carnosine's predominant association with white muscles in the organism. White, glycolytic muscle fibers contain few mitochondria and therefore, they produce lactic acid, within which the ability of carnosine to directly suppress the growth of hydrogen ion concentration is being emphasized [135]. As a chelator of metal ions (calcium, copper and zinc), carnosine participates in regulation of their metabolism in muscle and brain tissue [136]. Carnosine has also an important role in antioxidant protection, as it has the ability to catch reactive oxygen species (ROS), of which hydroxyl radical is the most dangerous one. Hydroxyl radical is formed from hydrogen peroxide in the presence of bivalent ions, such as copper. By catching and neutralizing the activity of free radicals, carnosine prevents oxidative damage occurrence. Researches confirmed its protective role in lipid oxidation [137] and protein oxidation [138]. The activity of carnosine in the process of slowing down glycosylation and protein networking is actually a consequence of its antioxidative activity, that is, its ability to block oxidation of biomolecules [133]. There is further research required to determine the role of carnosine in physiological processes that occur in human organism.

**Selenium** is one of the important trace elements required for the normal functioning of a living organism. If there is deficit of any micro- or macro-element in the body, health can be disturbed and serious disorders or illness may arise. The occurrence of Keshan (endemic cardiomyopathy) and Kashin-Beck (endemic osteochondropathy) diseases are known to happen due to low selenium status in human population, which is a consequence of selenium-deficient soil, especially in northeastern to southwestern China [139]. Selenium concentration in tissues, plasma or serum depends on the intake and varies by country. It is generally lower in Eastern Europe than in North America [140]. Selenium in the body is a part of selenoproteins that have a wide range of health benefits. The most important of them are glutathione peroxidases (GPxs), thioredoxin reductases (TrxR) and iodothyronine deiodinases. They show antioxidant and anti-inflammatory effects and are included in the production of active thyroid hormone [140]. One of the most important health benefits of selenium is its role in cancer prevention. Duffield-Lillico et al. showed that treatment with 200 µg selenium per day (as selenium yeast) for a mean of 4.5 years resulted in a significant reduction in cancer mortality (50%) and in the incidence of total (37%), prostate (67%), colorectal (58%) and lung (46%) cancers after a follow-up of 6.4 years [141]. Low selenium status is associated with poor immune function. Selenium supplementation enhances proliferation of activated T cells and increase total T cell count, hence boosting immune response [142]. Selenium is also very important to human fertility and reproduction. It is shown that glutathione peroxidase GPx4 protects spermatozoa by its antioxidant function and with other proteins forms structural component of the flagellum which is essential for

sperm motility [143]. Low selenium status was connected with pre-eclampsia [144] and premature birth [145] in women. At the end, it is important to note that additional selenium intake may benefit people with low selenium status, while those who have adequate or high status should be careful and not take selenium supplements, since it may have adverse effect [140].

## 6. Conclusion

World poultry meat consumption is constantly growing. Chicken meat is a source of high-quality protein with a relatively low content of fat. The quality of chicken meat is influenced by a number of factors like genotype, sex, feeding treatment, production technology, transport and pre-slaughter handling, all of which should be taken into account. In the production of chicken meat, it is very important to choose a good chicken genotype and to have good production conditions. It is also important to have devices on the slaughter line that can quickly provide meat quality data. It is necessary to improve chicken meat production technology year after year and to offer new products to the market. The production of enriched or functional products of animal origin is on this track. In poultry production, meat and eggs stand out. Functional ingredients are supplemented to chicken feed to improve the nutritional value of chicken meat, thus making chicken meat a foodstuff with added value (enriched or functional product), as it contains ingredients that are beneficial to human health. Chicken meat has become a functional food through the increase in the content of bioactive substances (n-3 PUFA, carnosine, selenium, etc.) that have beneficial effects on consumers' health.

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## Author details

Gordana Kralik<sup>1,2\*</sup>, Zlata Kralik<sup>1,2</sup>, Manuela Grčević<sup>1,2</sup> and Danica Hanžek<sup>1,2</sup>

\*Address all correspondence to: gkralik@pfos.hr

1 Department of Applied Zootechnics, Faculty of Agriculture in Osijek, Josip Juraj Strossmayer University of Osijek, Osijek, Croatia

2 The Scientific Centre of Excellence for Personalized Health Care, Josip Juraj Strossmayer University of Osijek, Osijek, Croatia

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