REVIEW PAPER

The occurrence of myopathies and meat abnormalities in modern broiler farming

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Abstract

Over the past few decades, there has been a significant increase in the production and consumption of poultry meat due to its high-quality nutritional profile, relatively low production costs, and ease of meat processing. This growing demand has led to progressive improvements in genetic selection for fast-growing broilers, triggering several spontaneous idiopathic muscle abnormalities along with an increased susceptibility to stress-induced myopathy. These muscle abnormalities have a negative impact on the quality of both fresh and processed chicken meat, primarily affecting the large breast muscle (*m. pectoralis major*) of broilers, which is also the most valuable part of the carcass.

Frequent meat abnormalities include the occurrence of pale, soft, and exudative meat, primarily characterized by reduced water-holding capacity, while Deep Pectoral Myopathy results in a change in colour and a significant reduction in the attractive appearance of the small breast muscle (*m. pectoralis minor*). Myopathies labelled as "White Striping" are characterized by superficial white stripes, "Wooden Breast" is marked by pale and bulging areas of significant hardness, while "Spaghetti Meat" is described by the separation of muscle fibres resembling spaghetti pasta. These mentioned abnormalities and myopathies negatively impact the economic aspect of the poultry industry during the removal of affected parts and, furthermore, reduce the qualitative and nutritional value of the meat, posing challenges during technological processes. This paper describes recent findings on the occurrence, characteristics, and prevalence of the most common myopathies affecting modern broiler farming.

Keywords: broilers, PSE meat, deep pectoral myopathy, "White Striping", "Wooden Breast", "Spaghetti Meat"

Introduction

Commercial chicken meat production is based on intensive agricultural systems utilizing fast-growing genetic lines (broilers) with high yields of breast muscles that provide consistently high-quality products (Petracci et al., 2014). The increase in the world's population over the last 50 years has been faster than ever before, leading to an increased demand for meat. Consequently, chicken meat producers have been forced to explore new methods to enhance production efficiency while maintaining

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meat quality (Maiorano, 2017). Genetic selection programs in the last 60 years have resulted in faster growth rates, increased meat yields, reduced slaughter age, and decreased amounts of feed and energy required for broiler cultivation to market weight (Hartcher and Lum, 2020). Growth rates have increased by over 400 % between 1957 and 2005, with 85-90 % of the increase attributed to genetic selection and the remainder to feeding (Zuidhof et al., 2014).
The rise in chicken meat consumption is a consequence of its diversity, relatively low costs compared to other meats, absence of religious restrictions, and the perception that it is healthier and of higher quality than other meats. However, the implementation of intensive selection of broiler chickens, alongside achieving higher body weights and improved feed conversion, has led to various muscle abnormalities negatively impacting the poultry meat industry (Maiorano, 2017). Indeed, profound changes in muscle structure and metabolism resulting from selection procedures are considered major factors responsible for the occurrence of muscle myopathies (Soglia et al., 2021).

Abnormalities include the appearance of Pale, Soft, and Exudative meat (PSE), Deep Pectoral Myopathy (DPM), "Spaghetti Meat" (SM), "White Striping" (WS), and "Wooden Breast" (WB), all of which have negative consequences for broilers in the meat industry. While the occurrences and economic impacts of PSE and DPM have been recognized for several decades, the emergence of other abnormalities or myopathies is a relatively recent phenomenon. Despite their manifestations being known for some time, they have not been fully explored. The current trend of selling poultry in larger quantities in parts, such as breasts and drumsticks, and the further processing into products like sausages and hot dogs has made it more apparent to detect these meat abnormalities compared to when they were sold as whole birds (Barbut, 2019).

These newly identified myopathies are predominantly associated with the large breast muscle of broilers (*m. pectoralis major*), and their frequency has witnessed a significant increase in recent years. Each myopathy exhibits distinct phenotypic features, such as parallel white stripes in "White Striping," hardened and pale areas with petechial bleeding in "Wooden Breast," and weakened muscle integrity with separated fibres causing excess exudate in "Spaghetti Meat" (Petracci et al., 2015). As the poultry industry faces these challenges, further research and exploration are crucial to understanding and mitigating the impact of these emerging myopathies on both the industry and consumers. Hence, the aim of this paper is to thoroughly investigate these recently identified myopathies, providing insights into their characteristics, underlying causes, and potential repercussions for the poultry meat industry.

Pale, soft and exudative meat

The occurrence of pale, soft, and exudative (PSE) chicken meat has been known for 40 years. However, the industry and researchers have only begun to address the issue and its significance for the poultry industry in recent decades. PSE meat is estimated to represent 5 %-40 % of the meat produced in the poultry industry (Owens et al., 2009), leading to an annual loss of $200 million for the broiler industry in the United States.

The concept of PSE meat was originally associated with pork, characterized by a light colour, flabby texture, low water-holding capacity, and substantial cooking losses (Strasburg and Chiang, 2009). It is generally known that a genetic mutation in the ryanodine receptor in the sarcoplasmic reticulum, which regulates calcium uptake and release, is associated with stress sensitivity and the development of PSE meat in pigs (Huang and Ahn, 2018). However, it is still unclear whether the genetic mutation is the primary cause of PSE chicken meat (Strasbourg and Chiang, 2009).

The occurrence of PSE meat results from an accelerated postmortem glycolysis process (rapid pH decline) while the carcass is still warm (Barbut, 2019), especially in individuals more prone to stress (Strasburg and Chiang, 2009). Furthermore, broilers belong to fast-growing species, displaying reduced thermoregulatory capacity, making them more susceptible to heat stress before slaughter. Heat stress causes various issues such as muscle damage, disturbance of acid-base balance, and ultimately reduced meat quality (Sandercock et al., 2009). Additionally, broiler muscles mainly consist of fast-contracting fibres associated with anaerobic glycolysis (Huang and Ahn, 2018). Increased stress before slaughter accelerates the anaerobic glycolysis process during the conversion of muscle to meat, reducing the muscle pH while the carcass temperature is still high. The combination of low pH and high temperature leads to protein denaturation, resulting in the PSE condition (Huang

and Ahn, 2018: Petracci et al., 2015).

Under normal conditions, the pH of the breast muscle before slaughter is 7, decreasing to 5.8-5.9 six hours after slaughter. However, there are two types of PSE meat development, both resulting in lighter-coloured meat with reduced water-holding capacity (Petracci et al., 2015). In the first development type, the acidification rate is normal, but the final pH is lower than normal (<5.8), termed "acid meat". In this case, PSE meat originates from individuals with high glycolytic potential. After slaughter, a high amount of initial glycogen causes a lower final pH close to the isoelectric point of myofibrillar proteins, resulting in reduced water-holding capacity and a lighter meat colour (Barbut, 2001). In the second case, the meat pH drops below 6 within 1 hour after death due to altered cationic regulation in muscle cells (Petracci et al., 2015). Sandercock et al. (2009) state that genetic selection for increased growth rate and muscle yield in modern hybrids has negatively affected the altered cationic regulation. Specifically, an increase in intracellular calcium concentration and free radicals in the muscle changes membrane integrity, leading to an increased postmortem acidification rate at high temperatures (Sandercock et al., 2009). Such conditions cause the denaturation of sarcoplasmic proteins, altering membrane integrity, ultimately reducing water-holding capacity and resulting in a lighter meat colour (Van Laack et al., 2000), as shown in Figure 1.

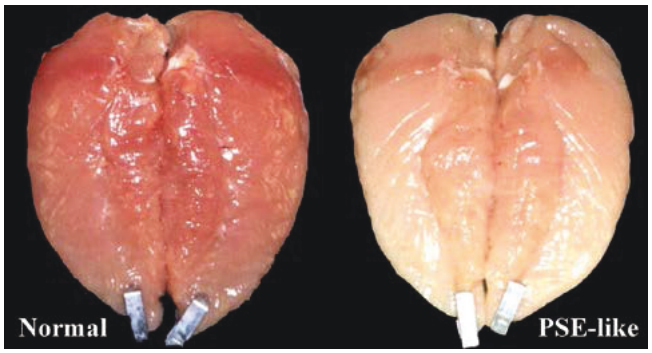

Figure 1. The appearance of normal (left) and PSE-like pectoral muscle (right) (Source: Petracci and Cavani, 2012)

It is well-known that the primary attributes of meat quality include its appearance, texture, juiciness, taste, as well as functional and technological properties. However, consumer choices during purchase are primarily based on appearance (Droval et al., 2012). Considering that PSE meat exhibits an unappealing pale colour, soft texture, and a weak water-holding capacity, consumers easily detect such abnormalities in exposed meat and tend to avoid purchasing fresh meat with these characteristics. Nevertheless, such meat can be effectively utilized in meat processing; however, the identification and separation of such meat in large-scale productions remains questionable.

Deep Pectoral Myopathy

Deep Pectoral Myopathy (DPM) is an abnormality of the small pectoral muscle in poultry (*m. pectoralis minor*). It was first described in adult turkeys in 1968 as "degenerative myopathy." Although initially recognized in turkeys, DPM is estimated to occur exclusively in poultry selected for high meat yield, specifically in broilers, and its frequency is higher in modern intensive farming systems (Maiorano, 2017). Cases of DPM have not been reported in extensive, organic management systems where individuals have slower growth rates and muscle development (Kijowski and Kupinska, 2013).

The mechanism of myopathy development is well-known and is associated with ischemic necrosis of the small pectoral muscle. The tendon of the small pectoral muscle is attached to the upper part of the shoulder bone and simultaneously passes between the coracoid and scapular bones (Kijowski and Kupinska, 2013). During muscle contraction, there is a reduction in the length of the tendon, causing the elevation of the shoulder bone and the upward movement of the wing. When stress occurs in poultry due to noise, food and water shortages, or human factors, uncontrolled wing movement takes place. During wing movement, the small pectoral muscle expands its volume by 20 to 25 % to increase blood flow to the muscle. However, as it is located between the breastbone and the inelastic fascia, it cannot fully expand, creating pressure on the small pectoral muscle and blocking blood vessels, leading to oxygen deficiency and causing fibrosis of muscle tissue. In lighter birds, the pressure returns to normal relatively quickly, but in heavier birds, the pressure can persist long enough to cause irreversible necrotic changes, resulting in DPM (Huang and Ahn, 2018). Another issue contributing to oxygen deficiency in the muscle is the proportion of white muscle cells (fast-contracting) in the small pectoral muscle, which contains a lower proportion of myoglobin, making the circulatory system less efficient compared to the large

pectoral muscle (Kijowski et al., 2014).

Deep Pectoral Myopathy is observed as a change in appearance, and the symptoms are similar in both turkeys and broilers. The condition can only be detected upon dissection of the carcasses. Symptoms primarily affect the centre of the small pectoral muscle, and less frequently, the large pectoral muscle (Kijowski et al., 2014). The necrotic muscle varies in colour, progressing from pink to greyish-green, depending on the progression of DPM symptoms (Figure 2).

Figure 2. Deep pectoral myopathy of small pectoral muscle seen as greyish-green colour (Source: Maiorano, 2017)

Bianchi et al. (2006) identified two phases, early and late, while Kijowski and Kupinska (2013) proposed four stages of macroscopic changes in muscle characteristics. The first phase of DPM is characterized by the appearance of blood coagulation in blood vessels. The second phase involves necrotic changes in tissue and the appearance of a pale-pink colour in the muscle. In the third phase, a green colour appears in the central part of the muscle, and in the fourth phase, the muscle takes on a white-greyish-green colour and completely necrotizes. The muscle can be affected unilaterally or bilaterally. According to Kijowski and Kupinska (2013), DPM occurs bilaterally in 85 % of cases and unilaterally in 15 %, affecting not only the small pectoral muscle but also the large pectoral muscle. Apart from being aesthetically undesirable, it has no impact on public health and often goes unnoticed if whole carcasses are sold. The affected part of the fillet is removed, and the rest remains suitable for human consumption. However, the necessary removal operations result in a reduction in product quality, leading to significant economic losses, especially since it is the most valuable part of the carcass (Maiorano, 2017).

The reported incidence of DPM varies significantly depending on breeding conditions, age, weight, gender, and individual genotype. Broiler farming conditions are one of the main factors influencing the occurrence of DPM. Necrotic changes in pectoral muscles occur due to sudden movements caused by stress, making animal welfare of the greatest importance. According to EU recommendations for poultry farming systems, the stocking rate should not exceed 25 kg per square meter, but in practice, these recommendations are often exceeded (Kijowski et al., 2014). Furthermore, symptoms are primarily observed in heavier broilers with larger pectoral muscle yields. Bilgili and Hess (2002) found a higher incidence rate in broilers with greater body mass; broilers weighing less than 3.6 kg had an incidence rate of 2.5 %, while in broilers weighing more than 3.6 kg, the rate increased to 8 %. Furthermore, DPM degeneration is more common in older male individuals than females. The reason is that male individuals achieve greater body weight and higher pectoral muscle yields in the same period, with the difference increasing with age (Kijowski et al., 2014). Finally, the most significant factor in the occurrence of DPM is genotype. All recorded cases of DPM were found in genetic lines selected for high muscle yield like Ross 308 and 508, Cobb 500, or Flex Hubbard (Kijowski et al., 2014).

Over the past decade, research at Auburn University has tracked the incidence rate of DPM in commercially produced broilers. In conducted studies, the spontaneous occurrence rate of DPM varied from 3 % to 17 %, being higher in broilers with a faster growth rate, decreasing during warmer weather, and being more common in males than females (Lien et al., 2011). Bianchi et al. (2006) reported that the incidence rate of affected carcasses was 0.84 %, but the overall range of DPM varied from 0 % to 16.7 %. Huang and Ahn (2018) mentioned an incidence rate of 4.4 % in broilers during slaughter and carcass dissection. Kijowski et al. (2014) reported that in Poland, the incidence rate of DPM in commercially produced broilers ranged from 0.02 % to 1.9 %. Overall, addressing DPM in broilers requires a comprehensive approach that takes into account breeding practices, welfare standards, and environmental factors, aiming to mitigate the impact on poultry health and industry practices.

“White stripping”

The emergence of “White Striping” (WS) on the surface of the large breast muscle of poultry is a new issue affecting the quality of chicken fillets.

WS can be seen grossly as white lines extending down along with the muscle fibres demonstrating signs of tissue degeneration caused by fat infiltration (lipidosis) and connective tissue degeneration (fibrosis) (Huang and Ahn, 2018). WS manifests from the progressive deterioration of the muscle structure as dysfunction occurs in physiological processes of muscle metabolism, growth, and vascular homeostasis (Lee and Mienaltowski, 2023). Studies have shown that white striping myopathy is associated with muscle degeneration and myopathic changes beneath the area of muscle cross-striation, including the loss of muscle cross-striation, abnormal growth of muscle fibres, floccular or vacuolar degeneration, fibre lysis, mild mineralization, lipidosis with interstitial (between connective and supportive tissue) inflammation, and fibrosis (Kuttappan et al., 2012). While it is not associated with the nutritional properties of cooked poultry, it has a negative impact on the appearance of raw meat (Figure 3), perceived by consumers as unhealthy (Petracci and Cavani, 2012). Chicken fillets affected by WS myopathy reduced protein functionality in further processed products (Kuttappan et al., 2012).

Figure 3. White striping on pectoral muscle (Source: Maiorano, 2017)

Hypoxia is also involved in the formation of the white stripes. In hypoxic conditions, there is a reduction in the production of ATP in the cells, as there is no oxygen input for cellular respiration, which also affects the cells' abilities to control the influx and efflux of ions such as sodium and potassium, as there is an inhibition of the energy-dependent sodium and potassium pumps, and ion gradients are disturbed (Lee and Mienaltowski, 2023). Dysregulation in ion gradient homeostasis leads to cell swelling, cell rupture, and necrosis as stated by Sarhan et al. (2018). Furthermore, with an increased incidence of hypoxia, a broiler's metabolism can be described as becoming increasingly anaerobic. The pectoral muscles are mostly made up of fast-contracting fibres with low numbers of mitochondria, which makes the broilers more susceptible to damage and explains the localization of the white striping compared to the rest of the body (Hudson et al., 2017). Modern diets, developed in recent years, now contain higher energy levels, primarily derived from increased quantities of corn and fat compared to diets used over sixty years ago (Havenstein et al., 2003). Commercial growers at the present time benefit from these dietary advancements, made possible by decades of genetic selection aimed at enhancing growth and yield. Therefore, it is crucial to acknowledge that the primary cause of WS lies in selection processes and, consequently, genetics (Lee and Mienaltowski, 2023).

White stripes are mostly found on the ventral side of the muscle, especially in broilers with larger final masses (Maiorano, 2017). Still, the factors influencing or enhancing WS condition are not fully known. However, there are various causative factors that can contribute to the occurrence of white striping. One important factor is the genotype, as it appears only in broilers selected for high meat yield. Intensive genetic selection of broilers has led to certain negative changes in anatomy and metabolism (Petracci et al., 2014). Additionally, gender, growth rate, nutrition, and the final mass of broilers play a role. Huang and Ahn (2018) state that feeding high-energy diets to broilers with larger final masses increases the likelihood of white striping in fillets, as well as a decreased amount of protein in the diet. Furthermore, the higher likelihood of white striping in fillets occurs in older broilers (8 weeks) than in younger ones (6 weeks) due to larger body masses.

Tijare et al. (2016) reported that the incidence of WS myopathy among a total of 285 birds was 96.1 %, with 63.8 % of breast fillets receiving a moderate score, while 32.3 % received a severe score. Similarly, Kuttappan et al. (2017) have shown that white striping has an incidence of 90 % in all chicken breast products. Given that more than half of today's broilers are processed at higher body masses, with the meat being boned and used for portioning and further processing, the occurrence of WS in fillets has

detrimental effects on the industry and poses challenges in consumer acceptance (Huang and Ahn, 2018). This emphasizes the need for ongoing research and strategies to address various factors like genetics, nutrition, and development that contribute to white striping in poultry.

"Wooden Breast"

A new muscle myopathy called "Wooden Breast" (WB) has recently emerged in the poultry meat industry, significantly affecting muscle health and the quality of meat in commercially raised broilers (Abasht et al., 2016). WB involves severe hardening of the large breast muscle (*m. pectoralis major*) during growth and development until reaching market weight. Detecting more severe cases of this disease can be done through palpation of the live broiler's breast muscle (Velleman and Clark, 2015). Although the fundamental cause of this disease is yet to be determined, recent research has approximated the disease incidence rate (Mutryn et al., 2015), its impact on meat quality (Mudalal et al., 2015; Mazzoni et al., 2015), and potential biological mechanisms (Abasht et al., 2016) contributing to the onset and progression of this disease.

The incidence rate of WB myopathy in commercially raised broilers is not fully documented. However, cases have been reported in various countries such as the United States, Finland, Italy, and Brazil. While it's challenging to ascertain the overall incidence rate in the entire chicken meat industry, Huang and Ahn (2018) stated that the occurrence of severe WB myopathy in muscles has been established to range from 5 % to 10 %, which corresponds with the results showed by Gratta et al. (2017) who reported a 5.1 % occurrence in commercially raised broilers. Various factors influence its occurrence, and results may vary depending on the age of broilers, gender, feeding practices, and hybrid type (genotype). According to the study presented by Owens et al. (2014), even 30 %-50 % of broilers aged 56 days and weighing 4.2 kg exhibited severe symptoms of WB myopathy. Much higher occurrence was reported by Cruz et al. (2017), who observed up to 85.9 % positive samples at 35 days and 89.2 % at 42 days. In a study presented by Tijare et al. (2016), the incidence of WB myopathy was 96.1 %, with 48 % scored as mild, 28 % scored as moderate, and 20 % of fillets scored as severe. Considering the large discrepancies in observed incidence rates, it appears that proper detection and validation of WB myopathy needs further harmonization.

Muscles affected by this myopathy show pale, expansive areas in the caudal part of the fillet, which are notably firm. This requires more force during compression compared to unaffected muscles (Figure 4.). In some cases, colourless viscous fluid and small petechial lesions are observed on the surface of the fillet (Kuttappan et al., 2016). In cases of severe involvement of the large breast muscle by WB myopathy, a characteristic ridge can be observed at the lower part, not typical for normal chicken breasts (Kuttappan et al., 2016).

Various studies have revealed that WB myopathy and WS myopathy share similar histopathological changes, suggesting a potential common etiology (Maiorano, 2017). Trocino et al. (2015) observed, based on the macroscopic appearance of degenerated muscle tissue, that the breast muscle affected by WB myopathy has more pronounced fibrosis compared to lipidosis. However, Huang and Ahn (2018) mention

Figure 4. Breast fillets characterized as "Wooden Breast" (left) and normal breast (right) (Source: Owens, 2018)

that some broilers had severely hardened breast muscles without histologically visible fibrosis, indicating that fibrosis is not the sole factor behind the occurrence of this myopathy, and lesions are not limited to the large pectoral muscle of poultry. Muscles affected by WB myopathy are characterized by increased amounts of degenerative and atrophic fibres, variability in the size of muscle fibres, floccular and vacuolar degeneration, fibre lysis, hyalinization, lipidosis, extensive fibrillar collagen deposition (fibrosis), and macrophage infiltration (Huang and Ahn, 2018). Moreover, RNA sequence analysis demonstrates the presence of hypoxia (reduced oxygen levels), oxidative stress, increased intracellular calcium levels, lower glycogen content, and fibre type switching (Mutryn et al., 2015). After initial degeneration, damage in the sarcoplasmic reticulum, which surrounds muscle fibres, increases the influx of calcium, activating calcium-dependent protease that initiates necrosis. Increased levels of calcium and sodium alter intracellular homeostasis, leading to increased glycolytic activity that reduces glycogen reserves in the muscle, resulting in increased final pH in affected muscles. Somehow different explanation is given by Velleman and Clark (2015), who conclude that it is probable that lactic acid produced from the anaerobic respiration is not efficiently removed, resulting in a decrease in pH, muscle damage (necrosis and fibrosis), satellite cell–mediated regeneration and excessive collagen crosslinking. In other words, WB myopathy results in necrosis of muscle fibres with macrophage infiltration (Maiorano, 2017).

"Spaghetti Meat"

Recently, a new muscle abnormality known as "Spaghetti Meat" (SM) has emerged in the poultry meat industry, significantly affecting the muscle health and meat quality of commercially produced broilers (Baldi et al., 2021). The condition phenotypically manifests as a loss of integrity in the pectoral muscle, which feels soft, mushy, and rarely taut, resembling spaghetti pasta (Figure 5), from which it derives its name. Generally, the condition mainly manifests in the ventrocranial part of the fillet, but increasing evidence suggests that the caudal part and leg muscles may be affected in the future (Baldi et al., 2021). The degree of muscle involvement in this myopathy is variable, and Sirri et al. (2016) proposed a classification criterion based on three levels (normal, moderately affected, and severely affected). Depending on the degree of involvement, the appearance can be visually detected due to extended surface ulcerations or palpation of the muscle (Baldi et al., 2021).

Regarding the frequency of this myopathy, data is limited and sometimes contradictory. The reason is the different classification of affected muscles in slaughterhouses and the simultaneous presence of other myopathies within the same muscle, as SM myopathy can coexist with WS and WB myopathies. According to an Italian study on 16 thousand chicken breasts, about 21 % of samples were affected by SM myopathy (Baldi et al., 2021), while a Brazilian study conducted on 5580 chicken breasts reported about 10 % affected samples (Montagna et al., 2019). Furthermore, concerning the rearing system, a higher occurrence rate was observed in broilers raised in dark systems than those raised in tunnel systems, indicating that environmental conditions can influence the frequency of myopathy occurrence. Also, Ross broilers had a higher percentage of normal pectoral muscles compared to Cobb and Hubbard broilers (Montagna et al., 2019). Although a higher occurrence rate of WS and WB myopathies has been established in broilers with a higher growth rate, greater muscle yield, higher body weight, and older age at slaughter (Kuttappan et al., 2016), such a trend is not fully confirmed for the occurrence of SM myopathy. However, Pascual et al. (2020) found a significantly higher occurrence rate in female individuals than males (25 % compared to 3.1 %), contrary to what was found for WS and WB myopathies, whose occurrence rates were higher in males than females. The reason for the higher occurrence rate in female individuals

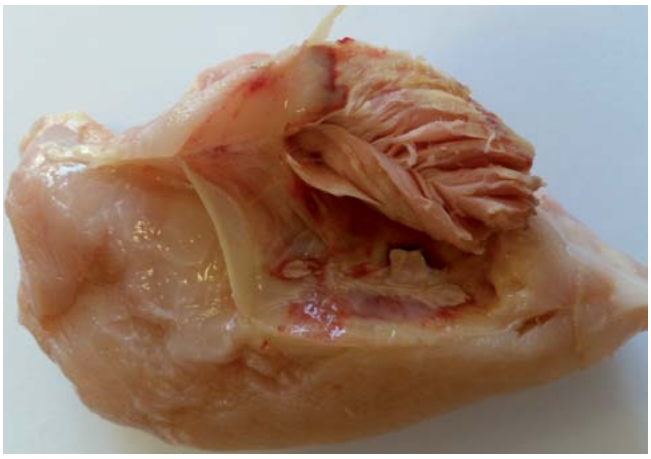

Figure 5. Pectoral muscle with a "Spaghetti Meat" defect (Source: Maiorano, 2017)

is still unknown, although recent research highlights increased expression of genes related to connective tissue proliferation in male individuals, making them more susceptible to the development of WB myopathy (Baldi et al., 2021). Due to its recent emergence, the causal mechanisms are still partially unknown and less researched compared to other myopathies where cellular stress and hypoxia caused by muscle hypertrophy are believed to be the main triggering factors (Baldi et al., 2021).

Microscopic studies conducted on muscles affected by SM myopathy have shown several similar histological changes to muscles affected by WS and WB myopathies. These include nuclear internalization, infiltration of inflammatory cells, necrosis, deposition of fatty tissue, fibre lysis, and the simultaneous presence of small regenerative fibres in combination with abnormal fibres showing a larger diameter (Baldi et al., 2018). On the other hand, the distinctive macroscopic appearance of muscles affected by SM myopathy is a consequence of progressive thinning of endomysial and perimysial connective tissue, leading to the separation of muscle fibres from each other (Baldi et al., 2018). Baldi et al. (2021) observed thin and split fibres surrounded by immature connective tissue and abundant infiltrations of inflammatory cells along the longitudinal section of the muscle. The presence of these fibres, significantly different in cross-sectional area, suggests the continuation of regenerative processes occurring in the muscles as a natural response to cellular necrosis (Baldi et al., 2021).

Conclusion

Research has indicated that genetic selection has increased the frequency of various types of myopathies, negatively impacting the poultry industry. While they do not affect the safety of the meat, they do influence the perception of the quality of poultry meat. Meat affected by these myopathies is of lower quality compared to unaffected meat, leading to negative changes in appearance, colour, tenderness, and consumer willingness to buy. The current trend of selling poultry in larger quantities in parts, such as breasts and drumsticks, and further processing into products like sausages and hot dogs has made myopathies more apparent to producers and consumers than before. Although meat affected with abnormalities can be utilized in meat processing, a shift in technological and sensory traits could develop. Also, the identification and separation of such meat during portioning in large-scale productions remains questionable. Therefore, there is an urgent need for harmonization of procedures for determining myopathies and abnormalities, especially those determined more subjectively by individuals rather than by instruments. Considering all, most researchers agree that the main cause of these myopathies is the progressive nature of genetic selection, raising the question of whether it is better to continue selecting broilers for higher meat yield or to reconsider and try to reduce the scope of newly emerged abnormalities and myopathies. After all, there is a question of economic gain when a higher amount of the most valuable meat parts should be discarded into a lower quality class.

Acknowledgments

This work is partially derived from the thesis of Marija Vučković, B.Sc. in Animal Science, titled "The appearance of myopathies and abnormality of meat in modern broiler breeding." The research implementation was supported by the project "Food Safety and Quality Centre" (KK.01.1.1.02.0004) funded by the European Regional Development Fund.

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Received/Dostavljeno: 6.01.2024. **Accepted/Prihvaćeno: 30.01.2024.**

Pojava miopatija i abnormalnosti mesa u suvremenom uzgoju brojlera

Sažetak

Tijekom posljednjih nekoliko desetljeća značajno je povećana proizvodnja i konzumacija pilećeg mesa upravo zbog njegovog visokokvalitetnog nutritivnog profila, relativno niskih proizvodnih troškova i jednostavnosti obrade. Ovaj rastući zahtjev doveo je do progresivnih poboljšanja genetske selekcije za brzorastuće brojlere, pokrećući pritom nekoliko spontanih idiopatskih mišićnih abnormalnosti, zajedno s povećanom osjetljivošću na stresom potaknute miopatije. Te mišićne abnormalnosti negativno utječu na kvalitetu svježeg i obrađenog pilećeg mesa, prvenstveno velikog prsnog mišića (m. pectoralis major) brojlera, koji je istovremeno i najvrjedniji dio trupa.

Učestale abnormalnosti mesa uključuju pojavu blijedog, mekanog i vodnjikavog mesa, uglavnom karakteriziranog smanjenom sposobnošću zadržavanja vode, dok miopatija dubokog prsnog mišića rezultira promjenom boje i značajno manjom privlačnošću izgleda malog prsnog mišića (m. pectoralis minor). Miopatije označene kao "bijele pruge" karakterizirane su površinskim bijelim prugama, "drvena prsa" su obilježena blijedim i ispupčenim područjima značajne tvrdoće, dok je "špageti meso" opisano odvajanjem mišićnih vlakana prsnog mišića, nalikujući špagetima. Navedene abnormalnosti i miopatije negativno utječu na ekonomski aspekt peradarske industrije, zbog nužnog uklanjanja zahvaćenih dijelova mišića, a dodatno smanjuju kvalitativnu i nutritivnu vrijednost mesa, postavljajući izazove tijekom tehnoloških procesa prerade. Ovaj rad opisuje recentna saznanja o pojavnosti, karakteristikama i učestalosti najčešćih miopatija koje pogađaju suvremeni uzgoj brojlera.

Ključne riječi: brojleri, BMV meso, miopatija dubokog prsnog mišića, "bijele pruge", "drvena prsa", "špageti meso"

Das Auftreten von Myopathien und Fleischanomalien in der modernen Masthähnchenhaltung

Zusammenfassung

In den letzten Jahrzehnten sind die Produktion und der Verzehr von Geflügelfleisch aufgrund des hochwertigen Nährwertprofils, der relativ niedrigen Produktionskosten und der einfachen Verarbeitung des Fleisches erheblich gestiegen. Diese wachsende Nachfrage hat zu einer fortschreitenden Verbesserung der genetischen Selektion für schnell wachsende Masthühner geführt, was mehrere spontane idiopathische Muskelanomalien sowie eine erhöhte Anfälligkeit für stressbedingte Myopathie zur Folge hatte. Diese Muskelanomalien wirken sich negativ auf die Qualität von frischem und verarbeitetem Hähnchenfleisch aus und betreffen vor allem den großen Brustmuskel (m. pectoralis major) von Masthähnchen, der auch der wertvollste Teil des Schlachtkörpers ist.

Zu den häufigen Fleischanomalien gehört das Auftreten von blassem, weichem und exsudativem Fleisch, das in erster Linie durch eine verringerte Wasserbindungskapazität gekennzeichnet ist, während die tiefe Brustmuskelmyopathie zu einer Farbveränderung und einer deutlichen Verminderung des attraktiven Aussehens des kleinen Brustmuskels (m. pectoralis minor) führt. Myopathien mit der Bezeichnung "White Striping" sind durch oberflächliche weiße Streifen gekennzeichnet, "Wooden Breast" ist durch blasse und wulstige Bereiche von erheblicher Härte gekennzeichnet, während "Spaghetti Meat" durch die Trennung von Muskelfasern beschrieben wird, die an Spaghetti-Nudeln erinnern. Die genannten Anomalien und Myopathien wirken sich bei der Entfernung der betroffenen Teile negativ auf den wirtschaftlichen Aspekt der Geflügelindustrie aus und verringern darüber hinaus den qualitativen und ernährungsphysiologischen Wert des Fleisches, was bei technologischen Prozessen zu Problemen führt. In diesem Beitrag werden aktuelle Erkenntnisse über das Auftreten, die Merkmale und die Prävalenz der häufigsten Myopathien in der modernen Masthähnchenhaltung beschrieben.

Schlüsselwörter: Masthähnchen, PSE-Fleisch, tiefe pektorale Myopathie, "White Striping", " Wooden Breast , "Spaghetti-Meat"

Aparición de miopatías y anormalidades en la carne en la cría moderna de pollos de engorde

Resumen

Durante las últimas décadas, ha habido un aumento significativo en la producción y consumo de carne de pollo debido a su perfil nutricional de alta calidad, costos de producción relativamente bajos y facilidad de procesamiento. Esta creciente demanda ha llevado a mejoras progresivas en la selección genética para pollos de engorde de crecimiento rápido, desencadenando varias miopatías musculares idiopáticas espontáneas, junto con una mayor sensibilidad a las miopatías inducidas por el estrés. Estas anormalidades musculares afectan negativamente la calidad de la carne fresca y procesada de pollo, principalmente en el músculo pectoral mayor (m. pectoralis major) de los pollos de engorde, que al mismo tiempo es la parte más valiosa del cuerpo.

Las anormalidades frecuentes en la carne incluyen la aparición de carne pálida, blanda y acuosa, generalmente caracterizada por una capacidad reducida para retener agua, mientras que la miopatía del músculo pectoral profundo resulta en un cambio de color y una apariencia significativamente menos atractiva del músculo pectoral menor (m. pectoralis minor). Las miopatías denominadas “estriaciones blancas" se caracterizan por líneas blancas superficiales, las "pechugas de madera" se caracterizan por áreas pálidas y abultadas de considerable dureza, mientras que la "pechuga espagueti" se describe por la separación de las fibras musculares del músculo pectoral, pareciendo fideos. Estas anormalidades y miopatías afectan negativamente el aspecto económico de la industria avícola debido a la necesidad de

eliminar las partes afectadas del músculo y reducen aún más el valor cualitativo y nutricional de la carne, presentando desafíos durante los procesos tecnológicos de procesamiento. Este trabajo describe los conocimientos recientes sobre la prevalencia, características y frecuencia de las miopatías más comunes que afectan a la cría moderna de pollos de engorde.

Palabras claves: pollos de engorde, carne PSE, miopatía del músculo pectoral profundo, "estriaciones blancas", "pechuga de madera", “pechuga espagueti"

Presenza di miopatie e anomalie della carne nel moderno allevamento dei polli da carne

Riassunto

Negli ultimi decenni la produzione e il consumo di carne di pollo sono aumentati in modo significativo proprio per il suo elevato profilo nutrizionale, i costi di produzione relativamente bassi e la facilità di lavorazione. Questa crescente domanda ha portato a progressivi miglioramenti nella selezione genetica dei broiler (polli da carne) a crescita rapida, determinando però diverse anomalie muscolari idiopatiche spontanee, insieme ad una maggiore suscettibilità alla miopatia indotta dallo stress. Queste anomalie muscolari influiscono negativamente sulla qualità della carne di pollo fresca e lavorata, in primo luogo sul grande muscolo pettorale (M. pectoralis major) dei polli da carne, che è anche la parte più pregiata della carcassa.

Tra le anomalie più frequenti segnaliamo quella in cui la carne del pollo si presenta pallida, morbida e acquosa (carne PSE), caratterizzata principalmente da una ridotta capacità di trattenere l'acqua, mentre la miopatia del pettorale profondo determina un cambiamento di colore e un aspetto significativamente meno attraente del muscolo piccolo pettorale (m. pectoralis minor). La miopatia definita a “strisce bianche” è caratterizzata da striature bianche superficiali, quella definita del “petto legnoso” è caratterizzata da zone pallide e rigonfie di notevole durezza, mentre quella del “muscolo a spaghetti” è caratterizzata dalla separazione delle miofibre del muscolo pettorale, somiglianti a degli spaghetti. Le suddette anomalie e miopatie influiscono negativamente sull'aspetto economico dell'industria del pollame, vista la necessità di rimuovere le parti muscolari interessate, e riducono altresì il valore qualitativo e nutrizionale della carne, rendendo più complicato il processo tecnologico di lavorazione. Questo articolo descrive le recenti conoscenze sulla comparsa, le caratteristiche e la frequenza delle miopatie più comuni che colpiscono il moderno allevamento dei polli da carne.

Parole chiave: polli da carne, carne PSE, miopatia del pettorale profondo, “strisce bianche”, “petto legnoso”, “muscolo a spaghetti”