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Current Status of Poultry Meat Abnormalities

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Abstract: Over the past decade, the poultry industry has faced an increasing occurrence of growth-related muscular abnormalities that mainly affect fast-growing genotypes selected for their production performances (high growth rate and breast yield). These abnormalities, termed white striping (WS), wooden breast (WB) and spaghetti meat (SM), primarily affect the superficial portion of *pectoralis major* muscles. Despite their distinctive phenotypes, WS, WB, and SM conditions entail common histological features, i.e., they might share common causative mechanisms underpinning their occurrence. Meat affected by growth-related abnormalities is harmless for human nutrition since no specific biological or chemical hazards have been found to be related to its consumption. However, WS, WB, and SM abnormalities negatively affect both quality traits and technological properties of raw and processed meat, causing relevant economic damages in the poultry industry. This paper aims to provide an update about the current status of poultry meat abnormalities, giving useful insights about their impact on meat quality, the possible causative mechanisms, methods for mitigation, and future perspectives.

Key words: muscular abnormalities, white striping, wooden breast, spaghetti meat, broiler, meat quality
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Introduction

With an average of 314.2 kg/capita consumed per year worldwide, poultry meat is the most widely eaten type of meat in the world (OECD, 2019). Poultry production and consumption have increased substantially over the last 40 to 50 y and are expected to further increase, especially in developing countries, which may make chicken meat the most valuable meat protein source for a growing global population. The universal success of chicken meat is found in its affordability, nutritional and sensory properties, ease of preparation, and absence of religious restraints (Petracci et al., 2019). In response to consumer requests, in 2018 more than 9 billion broiler chickens (weighing 56.8 billion pounds, liveweight) were produced in the United States alone, and more than 42.1 billion pounds of processed chicken products were marketed (NCC, 2019). Indeed, due to the shift of consumers' propensity for the convenience of ready-to-cook meals, nowadays almost half of the American meat market involves the commercialization of processed products (NCC, 2019). Variability in both the manner and the extent of chicken meat consumption recorded in the past 50 y has inevitably led to genetic selection that is aimed at obtaining fast-growing birds to keep up with the increasing request for chicken meat. According to data, actual slaughter weight of broiler chickens is 35% higher than their 1960s counterparts, while the slaughter age has been reduced by 16 d (NCC, 2019). Furthermore, selection criteria have been addressed to increase both the size and yield of *pectoralis major* muscle in particular—since it is the most profitable and valuable portion for the broiler industry—to such an extent that nowadays, this muscle constitutes up to 25% of animal weight (Aviagen, 2019). While the large decline in days to market, coupled with the remarkable boost in breast size, has disclosed huge advancements in broiler productivity, it has also coincided with the development and expansion of muscular defects that affect the breast muscles of fast-growing broiler chickens. Among the first recognized diseases is deep pectoral myopathy, caused by acute inflammation of the *pectoralis minor* muscle that results in ischemic necrosis (Wight and Siller, 1980). The enhancements in muscle size induced by artificial selection put excessive pressure on the *pectoralis minor* muscle, which—being tightly confined between sternum and inelastic fascia—might not be sufficiently vascularized and therefore may be more susceptible to developing ischemia (Siller, 1985).

Growth-Related Muscular Abnormalities: Macroscopic and Microscopic Features

In the past 10 y, a new group of emerging muscular defects, termed white striping (WS), wooden breast (WB), and spaghetti meat (SM), have raised the attention of the scientific community due to their noteworthy incidence levels along with the detrimental implications for meat quality and salability (Figure 1). Although occurrence levels of affected meat might vary depending on country, animal age, and weight at slaughter as well as the applied classification criteria, it is assumed that these muscular defects appear in all countries where fast-growing strains are used for meat production (commercial hybrids slaughtered at the young age of 30 to 55 d, at weights ranging from 1.5 to 5.0 kg) (Petracci et al., 2019). Furthermore, because their occurrence is associated with intensive animal farming conditions, animal welfare concerns have also arisen. The WS condition was first described in 2012 by Kuttappan et al. (2012a) as the occurrence of white or grayish striations parallel to muscle fiber direction on the surface of *pectoralis major* muscle of heavy birds. Depending on the severity grade, white stripes could present variable thickness (from 1 to 3 mm) and extend from the cranial to caudal region of the fillets. Although it is predominantly reported in the breast meat, this condition can also occur in thighs, tenders, and drumsticks (Petracci et al., 2019). WB myopathy, often associated with the WS defect, occurs as a focally or diffusely hardened consistency of *pectoralis major* muscle, which appears pale, rigid, and swollen and may present viscous exudate and hemorrhages on its surface (Sihvo et al., 2014). On the contrary, the most recent SM condition gets its name from the threadlike and detached muscle fiber bundles that make up *pectoralis major*, which appears mushy and sparsely tight (Baldi et al., 2018).

Despite their distinctive phenotypes, WS, WB, and SM conditions entail common histological features, thus suggesting that they might share at least some common causative mechanisms that trigger their occurrence. In detail, all affected muscles exhibit an altered muscular architecture, the presence of abnormal fibers exhibiting a rounded profile, nuclear internalization,

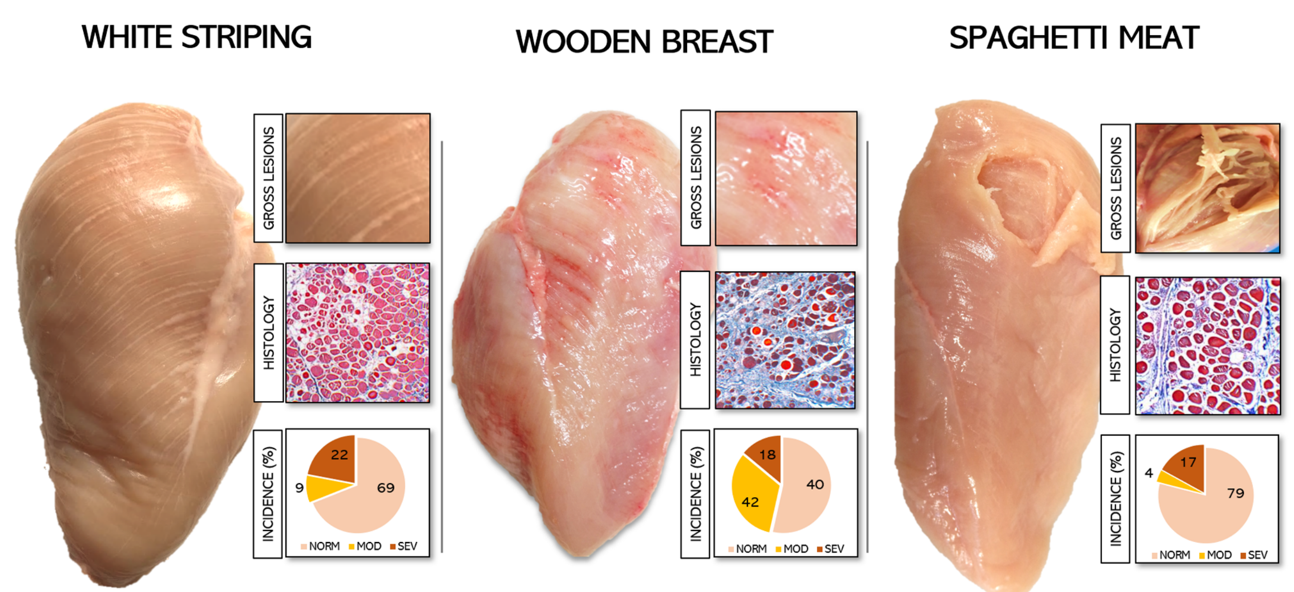

Figure 1. Scheme reporting representative images of macroscopic and microscopic features of the main growth-related muscular abnormalities affecting the *pectoralis major* of fast-growing broiler chickens. Histology pictures are adapted from Baldi et al. (2018) and Soglia et al. (2017). Data concerning incidence levels of normal (NORM), moderate (MOD), and severe (SEV) cases of white striping, wooden breast, and spaghetti meat conditions belong to a survey conducted in Italy between 2017 and 2018 on 16,000 chicken breasts (Petracci, unpublished data).

macrophage infiltration, and necrosis up to lysis of the fibers coupled with occasional regenerative processes (Soglia et al., 2019a). In addition to the previously mentioned shared histological features, the WS condition is usually linked to an abnormal deposition of adipose tissue (i.e., lipidosis) at the perimysial compartment, with the severity of histopathological lesions intensifying with the thickness of the striae (Kuttappan et al., 2013). On the other hand, WB is associated with the proliferation of connective tissue (i.e., fibrosis) that results in a severe thickening of the perimysial network (Soglia et al., 2019a). On the contrary, the hallmark of the SM condition lies in the progressive rarefaction of the connective tissue at both the endo- and perimysial level, which appears loose (immature) and leads to the detachment of muscle fibers from each other (Baldi et al., 2018).

A new emerging quality issue affecting the *pectoralis minor* muscle and phenotypically analogous to the SM condition deserves to be mentioned. This condition is termed "gaping defect" and was first described in 2019 by Soglia et al (2019b). Its name originated from the separation of the fiber bundles of the external portion of the *pectoralis minor* muscle of fast-growing hybrid birds. Although preliminary findings suggest that its occurrence is mainly related to perimortem and slaughtering procedures, further research is needed to increase knowledge about this condition, which was found to negatively impact quality traits of *pectoralis minor* meat.

Mechanisms Underpinning Their Occurrence

It has been demonstrated that several genes are differentially expressed between affected and unaffected muscles, but it has not been possible to identify a specific gene capable of differentiating muscular abnormalities from each other, thus suggesting a common etiology behind their occurrence (Abasht et al., 2016; Pampouille et al., 2018). Within this scenario, the specific phenotype of WB, WS, and SM might be seen as a distinct approach by the muscle itself to respond to the alterations induced by genetic selection. Once it was established that the occurrence of the previously mentioned muscular defects was not linked to a specific biomarker, several studies were conducted over the years to identify the underlying mechanisms involved in the manifestation of muscular abnormalities, as reported in the comprehensive review of Petracci et al. (2019). Nowadays, the scientific community agrees that hypoxia is the triggering factor responsible for the occurrence of these muscular defects (Abasht et al., 2016; Sihvo et al., 2018; Malila et al., 2019). Indeed, the intensive artificial selection practices carried out during past decades have resulted in impressive changes in pectoral muscle size and thickness, which is achieved through fiber hypertrophy (Berri et al., 2007; Mudalal et al., 2015; Baldi et al., 2018). However, these alterations in pectoral muscle physiology have not been followed by an adequate variation in muscle capillary density. Thus, the reduced capillary-to-fiber ratio modified the transportation of oxygen and nutrients to muscle tissue as well as the displacement of metabolic waste products, thus resulting in an accumulation of reactive oxygen species and the development of inflammatory processes (Sihvo et al., 2018). Once the inflammation is triggered, muscle tissue tries to combat hypoxia through several defensive mechanisms, such as enhancing blood flow through increasing the synthesis of vasodilators (i.e., nitric oxide) (Petracci et al., 2019). From there on, a network of complex biological reactions coupled with regenerative processes take place in the muscle, in a futile attempt to limit inflammation and tissue necrosis, since the overall weak and defective repair mechanisms of myopathic muscles is believed to be associated with the reduction in satellite cell number and ability to proliferate (Daughtry et al., 2017). When myodegeneration catches up with muscle's regenerative capacity, the end-outcome is fiber necrosis and the occurrence of fibrosis and lipidosis, distinctive traits of these growth-related abnormalities (Soglia et al., 2019a).

Implications for Meat Quality and Issues of Cost

Meats affected by WS, WB, and SM can be designated for human food purposes, since neither biological nor chemical hazards have been associated with their consumption. Depending on the severity of the defect and the eventual coexistence in the same muscle, the occurrence of muscular abnormalities negatively affects not only quality and technological traits of raw and processed meat but also consumers' willingness to buy (Kuttappan et al., 2012b). The main implications of growth-related abnormalities for poultry meat quality have been widely reported in the comprehensive review of Petracci et al. (2019). Overall, the occurrence of muscular abnormalities causes a major reduction in meat nutritional value, since abnormal muscles usually show an increased amount of moisture, collagen, and fat to the detriment of proteins. Moreover, meat affected by WB exhibits increased carbonylation and lipid oxidation levels (+21.6 and 86.3%, respectively, if compared to unaffected fillets) (Soglia et al., 2016). The changes in meat chemical composition are the direct result of degenerative processes that are associated with WS, WB, and SM, such as the replacement of necrotic fibers with adipose and connective tissue and the increase in extracellular water (i.e., edemas) as a consequence of the inflammatory processes that takes place in the muscle during the injury (Petracci et al., 2019). Affected meats also display impaired technological properties, with a particular reference to their scarce ability to hold both constitutional and added water due to the completely altered muscle structure as well as the presence of oxidized proteins (Soglia et al., 2016; Baldi et al., 2019). The occurrence of WB also affects the textural properties of meat (i.e., is associated with remarkably higher compression and shear forces of raw chicken meat) (Soglia et al., 2017), while WS and SM conditions only sparsely affect raw meat texture. The cooking process might tenderize WB meat due to the solubilization of the thermally labile collagen cross-links (Baldi et al., 2019). Indeed, there is evidence that the texture of cooked WB meat is comparable to that of cooked unaffected meat (Soglia et al., 2017; Baldi et al., 2019). Conversely, results from texture profile analysis conducted by both Chatterjee et al. (2016) and Brambila et al. (2017) showed that cooked WB meat displays higher scores for hardness compared to normal meat.

Although WS defect might also occur in *pectoralis major* muscles of fast-growing turkey hybrids (Zampiga et al., 2020), its occurrence does not impact turkey breast meat's nutritional and technological properties to the same extent exerted on broilers (Soglia et al., 2018). The authors suggested a different response of the muscle to the pressure induced by selection that resulted in a slight effect on turkey meat quality.

The previously mentioned detrimental effects on poultry meat technological properties may account for economic losses related to the decreased yield during processing. Indeed, severely affected fillets are usually downgraded for the manufacturing of nuggets, sausages, burger, etc., while moderate cases are marketed for fresh retailing. Thus, the important economic damages linked to the occurrence of WS, WB, and SM is related both to retailers (due to consumers' complaints and/or reduced willingness to buy) and to poultry industry (due to discarding and/or downgrading of meat, breast trimmings as well as the training of expert personnel designated for grading and sorting). In addition to the economic implications, there is increasing concern for the welfare of birds exhibiting these myopathies (Griffin et al., 2018).

Attempts to Mitigate

Within this scenario, solutions for avoiding and/or mitigating the occurrence of muscular abnormalities are calling for the attention of the scientific community. It is universally documented that the incidence of muscular defects increases with increasing growth rate, slaughter age, and weight (Lorenzi et al., 2014; Papah et al., 2017). Radaelli et al. (2017) reported that the first signs of muscle fiber degeneration associated with muscular abnormalities are visible at only 14 d of age. Thus, attempts in the field of animal nutrition have been made with the purpose of reducing both the severity and the occurrence of WS, WB, and SM by the modulation of dietary intake (i.e., feed restriction) or feed formulation (e.g., supplementation of antioxidants, organic minerals, amino acids, vitamins, etc.) (Sirri et al., 2016; Bodle et al., 2018; Livingston et al., 2018; Meloche et al., 2018; Zampiga et al., 2018). However, it is important to highlight that these strategies might not result in any efficient mitigation effect because a possible decreased slaughter weight and breast size of the animals might be cited as the causes for the reduction of the incidence of breast abnormalities (Petracci et al., 2019). Thus, it seems that, actually, the most efficient solution is represented by the incorporation of abnormal meat into the formulation of processed products, since mincing procedures as well as the addition of functional ingredients might mask the impaired sensory and technological properties of abnormal meat (Brambila et al., 2017; Xing et al., 2017). Furthermore, because muscular abnormalities mainly alter the superficial section of breast muscles, one efficient approach is to address the breast fillet's surface for the manufacture of processed products, while the deep section can still be suitable for fresh retailing, thus limiting the extent that the meat is downgraded (Baldi et al., 2019).

Another relevant matter for the broiler industry is the early detection and objective grading of meat affected by muscular abnormalities through reliable and nondestructive methods, which may prevent the need to hire and train online personnel. Traffano-Schiffo et al. (2017) proposed radiofrequency spectra as an effective technique to detect WS in chicken carcasses with skin, while hyperspectral imaging (i.e., a novel technique that combines spectroscopy with imaging) was successfully applied to discriminate between normal and WS breast muscles by simultaneously providing information related to chemical and physical characteristics of meat (Jiang et al., 2019). Moreover, near-infrared spectroscopy has also been used to detect WB meat in chicken slaughtering lines (Geronimo et al., 2019) and turkey fillets with severe WS (Zaid et al., 2020).

Conclusions

Despite all the efforts made by the scientific community during the past decade, no efficient solutions capable of inhibiting the onset of muscular abnormalities—or at least lessening the symptoms and consequences for animal welfare and the quality of the forthcoming meat—have been elucidated. Taking a step back seems unavoidable by now: further pressure exerted on breast muscle development might be restrained by muscle biological potential (Tallentire et al., 2018) and animal welfare concerns, since consumers are becoming more aware of these issues. In this scenario, although solving the issue at its root appears complex so far, the meat industry will need to reevaluate selection strategies and opt for more sustainable solutions. In addition, further scientific research should address embryonic formation of additional myofibers and feeding strategies, as well as innovative processing solutions aimed at reducing both the economic- and meat-quality–related impact of growth-related abnormalities.

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