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Review article

Meat defects and emergent muscle myopathies in broiler chickens: implications for the modern poultry industry

Giuseppe Maiorano

University of Molise, Department of Agricultural, Environmental and Food Sciences
Via F. de Sanctis snc, 86100 Campobasso, Italy

Due to intensive selection, broiler chickens have become the most efficient meat producing animals, attaining exceptionally rapid growth. However, several studies indicate that fast--growing varieties exhibit various muscle tissue defects – myopathies – which adversely affect the poultry meat industry. In particular, recent decades have seen an increase in the incidence of breast muscle abnormalities such as myopathy of the minor (deep) pectoral muscles and pale, soft and exudative (PSE) meat, and more recently white fibres called 'white striping', hardening of the breast muscle known as 'wooden breast', and intramuscular connective tissue defects ('spaghetti meat'). These abnormalities increase the occurrence of lower quality fresh meat for the retail market and to some extent reduce the nutritional, sensory and technological properties of raw meat used for further processing. The prevalence of these conditions indicates that further improvements in the efficiency of the meat industry and meat production may be constrained by the physiological capabilities of broilers, as their internal organs, vascular system and skeleton appear to be close to their functional limit. Hence, a problematic question is whether it is better to continue to set new performance goals for animals or to consider a step back in the selection process and attempt to reduce the extent of these emergent quality issues.

KEY WORDS: broilers / pectoralis minor muscle / PSE meat / white striping / wooden breast / poor meat cohesion

Over the last 50 years, the world population has multiplied more rapidly than ever before, and more rapidly than it is projected to grow in the future. Consequently the demand for meat will increase as well. Chicken meat is an important source of nutritious food and protein for much of the world's population. The increase in consumption of

poultry meat is due to its versatility, its relatively low cost in comparison to other meat, the absence of religious constraints, and the perception that it is healthier and of better quality than other meats. Increased consumer demand has forced chicken producers to explore methods to increase production efficiency and guarantee consumers meat of good quality. However, the use of intensive genetic selection in birds to improve their growth rate, body weight, breast yield and feed conversion has led to a variety of muscle defects, or myopathies, which adversely affect the poultry meat industry. In particular, the last 30 years have seen an increase in the incidence of breast muscle abnormalities, such as deep pectoral myopathy and pale, soft and exudative (PSE) meat, and more recently, white striping, hardening of the breast muscles known as wooden breast, and intramuscular connective tissue defects (separation of muscle fibre bundles, termed 'spaghetti meat').

MEAT DEFECTS AND EMERGENT MUSCLE MYOPATHIES

Deep Pectoral Myopathy (DPM)

Deep pectoral myopathy (DPM), also known as Oregon disease or green muscle disease, was first described in 1968 as 'degenerative myopathy' in turkeys. Although this condition was first recognized in mature breeder turkeys and broiler breeders, it has become increasingly common in meat birds; in fact, it has been estimated that DPM occurs exclusively in birds that have been selected for high breast meat yield, and its incidence is higher in modern intensive farming systems. DPM is an ischaemic necrosis that develops in the deep pectoral muscles (*supracoracoideus* or *pectoralis minor*), mainly because these muscles are surrounded by inelastic fascia and the sternum. The supracoracoid muscle, sandwiched between the sternum and the large breast muscle (fillet), cannot fully expand during movement, and the swollen muscles impair the blood supply, leading to oxygen deficiency and ischaemia [8]. The resultant necrotic muscle varies in colour, progressing from pink petechiae to a greyish-green discolouration (Photo 1). It can be either unilateral or bilateral and is identified only during carcass dissection. Apart from being aesthetically undesirable, DPM is of no consequence for public health. The condition usually remains unnoticed when birds are sold as carcasses or parts. The affected fillet should be removed, but the rest of the carcass is still fit for human consumption. However, the required trimming operations reduce the quality grade of the products, leading to economic losses for the industry, especially as the most valuable part of the carcass is affected. The occurrence of this defect in broilers is estimated to vary between 0.02% and 1.9% [9]; the incidence of DPM increases with the body weight of broilers, with more cases reported in higher-yielding strains and in males [5]. Lien et al. [13] reported that DPM appears at approximately 26 and 36 days of age in male and female broilers, respectively. Castellini et al. [6], in a study of the behaviour of fast-growing chickens under organic farming conditions, observed that their lack of movement was more due to a genetic predisposition than the effect of rearing conditions. As a consequence, genetic selection against DPM has been initiated. The recent development in whole-genome

selection using high-density DNA markers may provide effective tools for reducing the future occurrence of DPM [23].

Photo 1. Deep pectoral myopathy (photo G. Maiorano)

Pale, Soft, Exudative (PSE) meat

The PSE condition affects the colour (paler than normal), texture (softer than normal) and water-holding capacity (lower than normal) of meat. The causes of this condition in chickens may be linked to pre-slaughter stress, environmental factors (heat stress) and genetic selection. It is usually attributed to a rapid post-mortem decline in pH while the temperature of the meat remains high (rapidly acidifying meat and acidic meat) [23, 24]. It has been suggested that genetic selection for increased growth rate and muscle size has altered intracellular calcium homeostasis, leading to changes in sarcolemma integrity, with major implications for meat quality [28]. Moreover, modern chicken hybrids have been shown to be more susceptible to heat stress and to stress-induced myopathies which may have a considerable effect on meat quality. The PSE defect is estimated to affect about 5% to 40% of the meat in the poultry industry, leading to significant economic losses [20].

White Striping (WS)

Breast fillets from broiler birds of market age have recently been identified with white striations of varying size, parallel to the muscle fibres and mainly visible on the ventral surface of the muscle, typically in larger broilers. This condition is referred to as white striping (WS). It is raising concern among broiler chicken producers because this meat is less appealing to consumers. The presence of white striations, particular when the condition is severe (Photo 2), gives the fillets a fatty appearance, which consumers perceive as unhealthy. Based on visual assessment, fillets can be classified as normal (no stri-

ping), moderately defective, or severely defective [11]. The aetiology of WS is currently unknown, but there are several factors which may influence its occurrence in breast meat: genotype (high breast yield > standard), sex (males > females), growth rate (fast > slow), diet (high-energy > low-energy) and slaughter weight (heavy > light) [7, 23]. Histopathological studies have demonstrated that WS is usually associated with muscle degeneration and myopathic changes beneath the striation area, involving the loss of cross striations, abnormal fibre growth, floccular or vacuolar degeneration and lysis of fibres, mild mineralization, occasional regeneration, lipidosis, interstitial inflammation and fibrosis [10]. Various studies have also shown that fillets with severe WS have increased fat content, with an altered fatty acid composition, decreased protein content, and increased total collagen as compared with normal fillets, which diminishes the nutritional value of the meat [10, 17, 21]. Kuttappan et al. [12] demonstrated that as the severity of white striping increased, the percentage of fat in the dry weight of the muscle increased. Furthermore, a negative impact of WS on technological quality traits of poultry meat has been observed (lower WHC and a softer texture than normal meat) [15]. Various studies conducted by independent research groups from the United States and Italy have reported that the incidence of severe WS has increased dramatically from 1.4-8.7% (on average 5%) in 2012 [10, 22] to 25.7-32.3% (on average 29%) in 2015 [27, 30]. In addition, a recent study by Gratta et al. [7] found that the rate of WS at slaughter was about 75.5%, but the occurrence of breasts with severe white striping was higher in Ross 308 chickens than in Cobb 500 chickens (25.9% vs 7.41%); Maiorano found that 30% of breast muscles of Ross chickens slaughtered at the age of 42 days were affected by WS, and 5% of heavier muscles exhibited severe WS (unpublished data). Most of these studies were conducted in controlled environments with ideal growing conditions.

Photo 2. Fillet with severe white striping (photo G. Maiorano)

Wooden Breast (WB)

It has recently been observed that WS can be accompanied by a new muscle disease called 'wooden breast' (WB), which affects meat quality in commercial broiler productions. Muscles affected by WB (Photo 3) exhibit pale expansive areas in the caudal part of the fillet which are quite hard; in some cases, a colourless viscous fluid and small petechial lesions are observed on the fillet surface [29]. Various studies have found that WS and WB muscles have similar histopathological changes and thus may have a common aetiology, even if it remains as yet unknown. Evidence from RNA-seq analysis supports localized hypoxia (lower oxygen concentration), oxidative stress, increased intracellular calcium, and lower glycogen content, as well as the possibility of muscle fibre-type switching, as key features of WB disease [1, 18]. In other words, WB is a myopathy that results in the necrosis of muscle fibre with macrophage infiltration. Professor Velleman seems to be correct in stating that 'in response to the necrosis, fibrosis takes place, leading to connective tissue synthesis and the replacement of muscle-specific proteins with highly cross-linked collagen'.

The increase in collagen cross-linking in WB may be due to the higher level of decorin expression observed in WB muscles [31]. The highly cross-linked collagen gives the muscle its wooden, i.e. very stiff phenotype. Abasht et al. [1] have concluded that WB-affected tissues possess a unique metabolic signature.

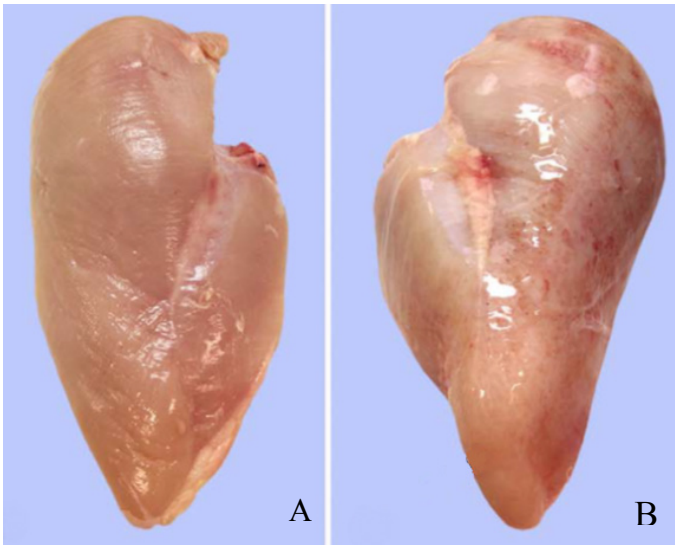

Photo 3. Comparison of normal (A) and wooden breast fillets (B); Sihvo et al. [29]

The incidence rate of WB in commercial chickens is not yet well documented. Owens [19] reports that it may affect up to 50% of individuals in affected flocks, while Gratta et al. [7] and Maiorano (unpublished data) reported WB in an average of 5.1% and 2% of broilers, respectively. Fillets with WB have been shown to exhibit changes in proximate composition similar to WS. The WB defect also has an adverse effect on the poultry industry, which is facing substantial economic losses due to customer complaints regarding fillets affected by these myopathies.

Intramuscular connective tissue defects

Recently the problem of poor cohesiveness of meat has begun to appear as a meat quality defect. It is associated with immature intramuscular connective tissue, which exhibits altered structural integrity in the breast fillet. This defect is termed 'spaghetti meat' (Photo 4A, B). Meat affected by this defect is so loose in structure that the muscle fibre bundles can be pulled away with the fingers (Photo 4A). Collagen (0.2-0.4% of lean meat), the major component of the intramuscular connective tissue, forms the scaffold responsible for maintaining the structural integrity of skeletal muscle and plays a key role in determining the toughness of the meat [16, 26] of various livestock animals, including birds [3, 14]. Crosslinks are known to progress from immature to more mature forms with chronological age [16]. In 'spaghetti meat', the thickness of the endomysium and perimysium of the breast muscles was found to be greater and much smaller, respectively, in fast-growing broilers than in slow-growing ones, resulting in low heat stability. Thus, the fluid lost from the myofibrils during the postmortem period may result in muscle disintegration [4]. Furthermore, Ahn et al. [2] detected that the perimysium of the breast muscles in fast-growing birds was thinner than in their slow-growing counterparts. Consequently, the meat is tender, but may become fragile or even mushy [25]. The cooked meat is generally very soft and fragmented [32], making it suitable only for processed products, causing considerable economic losses.

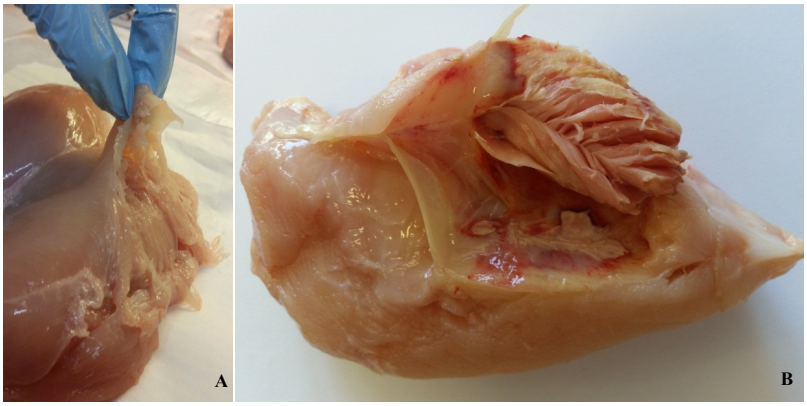

Photo 4. Fillet with the 'spaghetti meat' defect (photo G. Maiorano)

CONCLUSIONS

A great deal of research has shown that intensive genetic selection primarily aimed at increasing growth rates has increased the incidence of various types of myopathies, which adversely affect the poultry meat industry. The prevalence of these conditions indicates that further improvements in industry efficiency and meat production may be constrained by the physiological capabilities of broilers, as their internal organs, vascular system and skeleton appear to be close to their functional limit. Hence, a problematic question is whether it is better to continue to set new performance goals or to consider a step back in the selection process and attempt to reduce the extent of these new emergent quality issues.

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