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Original scientific paper

Wooden breast, white striping and spaghetti meat: chemical composition, technological quality, microbiological profile and sensory attributes of broiler breasts

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ABSTRACT

Poultry meat is consumed worldwide and its production is expected to increase in the upcoming years. Genetic selection in poultry focused on growth rate, feed conversion, and breast yield, resulting in the occurrence of white striping and wooden breast abnormalities and, most recently, spaghetti meat. These myopathies affect the quality traits of raw meat, including pH, color, water holding capacity, and cooking loss, which limit its further processing and decrease consumer acceptance. Additionally, the effects of myopathies on the chemical composition, i.e., reduced protein and essential amino acid content and increased fat contents, impair to some extent the nutritional value of the meat.

1. Introduction

Fast growth of poultry production with estimated increase of 16% by 2029 (FAO, 2020) is owed to the higher need for protein following rapid population growth (*UN*, 2019). The selection for fast weight gain puts excessive pressure on the *Pectoralis major* (*P. major*) muscle, resulting in high breast yield but also in a high occurrence of myopathies such as white striping (WS), wooden breast (WB) and spaghetti meat (SM) (*Baldi et al.*, 2021; *Petracci et al.,* 2019; *Trocino et al.,* 2015; *Kuttappan et al.,* 2013). On WS muscles, the presence of the white lines of intramuscular fat deposits can be seen (*Kuttappan et al.*, 2013), whereas WB is characterized by hardening of the muscle, and in severe cases, prominent ridge-like bulge, edema and/or scattered petechiae on the breast surface (*Sihvo et al.*, 2014). *P. major* muscle with SM shows an overall impaired integrity with the separation of the fiber bundles composing the muscle tissue itself, resembling the appearance of spaghetti (*Baldi et al.,* 2018). Although myopathies do not pose a threat to meat shelf life and microbiological safety (*Gratta et al.*, 2019), they impair meat quality to some extent, affecting technological characteristics of raw meat and limiting their further processing (*Gratta et al.*, 2019; *Baldi et al.*, 2018; *Mudalal et al.*, 2015; *Trocino et al.*, 2015; Petracci et al., 2013). Despite carcasses affected by myopathies meeting the market quality standards (*Baéza et*

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al., 2022) for weight and yield, muscle abnormalities impair the visual aspect of the meat, preventing the commercialization of whole breasts or, in cases of severe structural changes, requiring the breasts to be discarded as a waste (*Zanetti et al*., 2018).

2. Chemical composition of abnormal breast meat

Pathological alterations related to myopathies result in changes in the chemical composition of muscle tissue. Higher water and fat contents and lower ash and protein contents were reported in breasts affected by WS, WB, WB/WS and SM compared to their normal counterpart (*Dalle Zotte et al*., 2020; *Gratta et al*., 2019; *Cai et al*., 2018; *Soglia et al*., 2016 a, b; *Zambonelli et al*., 2016). The greater water content of WB and WS breasts is likely a consequence of inflammatory processes leading to fluid accumulation (*Thanatsang et al*., 2020; *Sihvo et al*., 2014). Indeed, *Gratta et al*., (2019) found higher moisture content in WB than in normal meat during the first 24 h *post-mortem*, while the differences among groups disappeared due to protein denaturation during 7 and 11 days of storage.

The reduction of protein content in WS, WB, and WB/WS meats due to fibrosis has been attributed to the replacement of muscle fibers with connective tissue and the aforementioned accumulation of adipose tissue (*Dalle Zotte et al*., 2020; *Baldi et al*., 2018; *Soglia et al*., 2016 a,b; *Zambonelli et al*., 2016), where a relationship between protein reduction and the degree of WS (*Petracci et al*., 2015; *Kuttappan et al*., 2013) has been also outlined. The protein decrease compared to normal breasts is followed by a reduction in essential amino acids in WS/WB and WB breast (*Dalle Zotte et al*., 2020; *Thanatsang et al*., 2020), which could seriously impair the meat nutritional value. The few studies about SM breasts found a reduction of protein content up to 10% compared to unaffected muscles (*Baldi et al*., 2018; 2019). Some authors found meat affected by SM, WB, WS/WB and WS/SM to display an increased collagen content compared to normal muscles, while others did not observe any difference (*Baldi et al*., 2018; *Cai et al*., 2018; *Soglia et al*., 2016 a,b). The degradation in the nutritional value of WS meat is also due to a lower digestibility and quality of amino acids in collagen compared to myofibrillar proteins (*Huang and Ahn*, 2018; *Mudalal et al*., 2014).

Compared with normal meat, the decrease in ash content in breast muscles associated with WS (*Soglia et al*., 2018b; *Mudalal et al*., 2014), WB (*Gratta et al*., 2019; *Cai et al*., 2018; *Soglia et al*., 2016 a,b), and WS/WB (*Dalle Zotte et al*., 2020; *Zambonelli et al*., 2016) is probably due to pathological changes at cellular levels. After the initial degeneration, the damage to the sarcoplasmic reticulum surrounding muscle fibers increases Ca influx and activates Ca-dependent protease, triggering myofibers necrosis (*Huang and Ahn*, 2018). Increased Fe levels in WB could be due to hemorrhagic lesions (*Thanatsang et al.,* 2020). In fact, *Thanatsang et al*., (2020) reported lower P and K and higher contents of Al, Ca, Fe, Na, and S in WB, and elevated Ca and Na content in SM compared to unaffected breasts. Zambonelli et al. (2016) found increased Ca and Na and decreased Mg and P, whereas *Tasoniero et al*., (2016) reported increased Fe and Na and reduced K and P contents in WS breasts.

Higher lipid content in WS and WB in comparison to normal meat are attributed to myodegeneration and replacement of degenerated muscle fibers by adipose tissue (*Soglia et al.,* 2016a), often accompanied by changes in fatty acid profile. *Baldi et al.* (2018, 2019) reported a decrease in EPA and DHA in meat affected by SM compared to normal breasts, likely due to a different expression of the genes encoding for $\Delta5$ and $\Delta6$ desaturases (Soglia et al., 2016a). *Gratta et al.* (2019) reported chicken breasts affected by WB and WS display lower SFA and MUFA and higher PUFA due to an increase of both n-3 and n-6 FA compared to normal breasts. Lower SFA in WS and WB meat compared to the normal breasts was also reported in other studies (*Soglia et al*., 2016a; *Kuttappan et al*., 2012a). The mechanism behind changes in the FA profile of chicken meat affected by abnormalities is not completely clear. Possible explanations are related to the presence of inflammatory cells with a relatively high proportion of n-6 arachidonic acid in their membrane phospholipids (*Calder*, 2012) or the tendency of fiber type switching from fast, glycolytic IIB fibers, in which lipids are generally more saturated, to those within slow and oxidative fibers (*Realini et al*., 2013). Contrarily, *Traffano-Schiffo et al.* (2017) found that superficial meat layers affected by WS had higher SFA and MUFA and lower PUFA compared to normal meat. In fact, while most of the aforementioned studies reported changes in the overall *P. major*, some research found proximate composition changes only within the surface of the breast muscle *(Baldi et al.* 2019; *Traffano-Schiffo et al*., 2017). The chemical composition likely depends on the degree of structural changes: severe myopathies will alter breast chemical composition at more profound parts of the muscle, whereas mild changes could only affect superficial meat layers.

Regarding oxidative stability, *Soglia et al.* (2016b) reported higher protein and lipid oxidation in WB and WS/WB compared to normal breasts, although no differences in total SFA, and PUFA were found between the former and the latter. The higher susceptibility of WB meat to protein oxidation was confirmed by *Thanatsang et al.* (2020). Despite higher lipid content, WS breasts do not seem to be more susceptible to lipid oxidation than unaffected ones (*Alnahhas et al.*, 2016; *Soglia et al.*, 2016b).

3. Technological quality of abnormal meat

In the presence of myopathies, reduction in protein content and degeneration of muscle fibers and myofibrils that usually entrap the majority of intracellular water are responsible for lower water holding capacity (WHC), marinade uptake and retention, emulsifying and gelling properties compared to normal breasts (*Petracci et al.*, 2019; *Xing et al.,* 2017; *Bowker and Zhuang*, 2016; *Soglia et al.*, 2016b). Whereas most of the findings on how WB affects WHC and drip and cooking losses are consistent (*Gratta et al.,* 2019; *Dalle Zotte et al.,* 2017; *Kuttappan et al.*, 2017a; *Trocino et al.*, 2015), the results on WS impact vary between studies. *Kuttapan et al.* (2017a) reported a decrease in drip loss in severe WB and WS/WB, but without differences between breasts with severe WS and normal ones as observed by *Kuttappan et al.* (2013) for cooking losses. Differently, *Petracci et al.* (2013) and *Tijare et al.* (2016) found an increase in cooking losses in raw breasts with severe WS. Because of the decreased total protein content but increased collagen and fat contents in WS breasts, their WHC, protein solubility and marinade uptake are lower than the normal muscles (*Sihvo et al.*, 2014). Regarding SM, this myopathy alone, or in combination with WS/WB, significantly increases drip losses (*Wang et al.*, 2023; *Tasoniero et al.*, 2020; *Baldi et al.*, 2018).

In terms of pH, some studies did not find changes in ultimate pH of muscle affected by myopathies (*Pascual et al.*, 2021; *Baldi et al.* 2018; *Trocino et al.,* 2015), while others reported elevated pH in WS, WB and SM breasts compared to their normal counterpart (*Wang et al.*, 2023; *Bordignon et al.*, 2022; *Tasoniero et al.*, 2016; *Mudalal et al.*, 2015; *Dalle Zotte et al.*, 2014; *Petracci et al.*, 2013). A proteomic study (*Kuttappan et al.*, 2017b) suggested down-regulation of carbohydrate metabolic pathways related to reduced glycolysis, gluconeogenesis, TCA (tricarboxylic acid) cycle, glycogen degradation and pyruvate fermentation to lactate to be responsible for the reduced glycolytic potential and higher ultimate pH in affected breasts.

Regarding the effect of myopathies on breast color, inconsistent results have been reported. The meta-study of *Bordignon et al.* (2022) did not report an impact of WS, WB, or SM presence on breast color indices, in agreement with *Zambonelli et al.*, (2016) on WB and WS/WB breasts. Contrarily, *Mazzoni et al.* (2015) found a decrease in red and yellow indexes of WS breasts, whereas *Kuttapan et al.* (2017) reported an increase in yellowness in both WB and WS breasts when compared to control ones. Further, *Dalle Zotte et al.* (2017) noted elevated lightness in WB meat. Some authors suggested higher alteration in breast color as myopathy evolves to a severe degree (*Campo et al.*, 2020; *Tasoniero et al.*, 2016). *Campo et al.* (2020) observed a tendency to increase in lightness and yellowness in severe WB compared to unaffected meat, whereas the presence of WS also resulted in lighter, less red, and more yellow breasts. The presence of moderate SM resulted in higher yellowness. The higher yellowness of defective breasts arises from the elevated fat content (*Kuttappan et al.*, 2012a; 2013; *Petracci et al.*, 2015) and likely a high accumulation of dietary liposoluble pigments (*Campo et al*., 2020).

Although the changes in texture of breasts affected by myopathies are documented, results differ between studies due to sample preparation (raw vs. cooked, surface layers vs. whole muscle), methods and parameters used (*Pascual et al.,* 2021; *Baldi et al.*, 2019; *Soglia et al.,* 2016a). The WB are often characterized by increased hardness of the muscle likely due to the higher collagen content of WB fillets (*Baldi et al.,* 2019). However, the fibrosis in WB and WS/WB may not necessarily affect the texture properties of the breast, which was confirmed in several studies (*Xing et al.,* 2020; *Maxwell et al.*, 2018; *Sihvo et al.*, 2017; *Mudalal et al.*, 2015). Contrarily, SM and WS breasts usually display lower shear force than normal breasts (*Bordignon et al.*, 2022; *Baldi et al.*, 2019; *Tasoniero et al.*, 2016). Compared to normal breasts, lower hardness can be explained due to the higher fat content in WS breasts (*Radaelli et al.*, 2017; *Soglia et al.*, 2016a; *Mudalal et al.*, 2015) and to the reduced collagen cross-linking degree in SM ones (*Baldi et al.*, 2019, 2021). However, *Baldi et al.* (2019) did not find differences in the texture between raw SM and normal samples, whereas cooking decreased hardness in SM. *Pascual et al.* (2021) reported only the Meullenet-Owens razor blade test to be able to detect the difference between SM and normal cooked breasts.

4. Microbiological quality of abnormal meat

To date, only a few studies investigated the microbiological status of meat with myopathies, suggesting it to be safe for human consumption. *Gratta et al.* (2019) reported higher initial total viable counts (TVC) and *Pseudomonas* spp. counts in normal breasts compared to WS and WB ones. Furthermore, normal breasts had the shortest TVC and *Pseudomonas* spp. Lag phase compared to WS and WB meat, resulting in the later microbial spoilage of breasts-affected abnormalities (5 vs. 6 days). *Enterobacteriaceae* spp. and lactic acid bacteria counts were also highest in unaffected breasts, followed by WS, and lowest in WB meat. *Pereira et al.* (2022) found lower *Staphylococcus* spp. and higher coliform counts in WS breasts, although bacterial counts neither in normal nor defective meat exceeded permitted limits after 12 months of freezing.

5. Sensory attributes of breasts with myopathies

As aforementioned, the impaired visual appearance and quality results in lower consumer acceptance and purchase intention of meat affected by myopathies (De Carvalho et al*.,* 2020; *Petracci et al.,* 2015). Consumers' acceptance of meat with myopathies strongly depends on the degree of muscle tissue changes. *Kuttappan et al.* (2012b) reported a decrease in consumer acceptance along with the severity of white striping, while *Xing et al.* (2020) found moderate and severe raw WB fillets to affect sensory acceptance due to their undesirable appearance, texture and drip loss, but found no differences between normal and mild WB. Indeed, the visual appearance of raw meat leads to meat rejection, which is why some sensory studies are performed on cooked meat. Still, *Tasoniero et al.* (2016) reported more intensive off-odors in cooked WS fillets than in the normal ones, while *López et al.* (2022) observed a decrease in the cohesiveness and increase in the juiciness of severe WB. Although, in most of the studies, a deterioration of eating parameters is evident, *de Almeida Assunção et al.* (2020) found an increase in succulence in WB, probably due to a higher water content, to be well accepted by untrained panelists and increased final satisfaction with this meat. Furthermore, *De Carvalho et al.* (2020) reported lower acceptability of raw WS breast than unaffected counterparts, while upon cooking, consumers did not note differences between WS and normal chicken breasts for color, flavor, and overall acceptability but WS meat achieved higher scores for odor and texture compared to the normal breasts. Some efforts are made to eliminate or decrease the changes related to myopathies by marinating meat. However, *Maxwell et al.* (2018) reported differences in cooked meat sensory texture attributes related to WB to be lessened but not eliminated by vacuum-tumbling marination. Similarly, *Jarvis et al.* (2020) found neither traditional nor clean-label marinades to mask eating characteristics of severe WB, but, to some extent, a positive effect of marination was observed on mild WB. As far as SM goes, the effect of this muscle abnormality on sensory characteristics of breast meat has not yet been investigated.

6. Conclusion

Although the results between studies are sometimes inconsistent regarding how the different myopathies affect *P. major* in broilers, all studies reported at least one or multiple quality traits to be changed compared to unaffected breasts. Some underlying mechanisms behind changes in chemical compositions and quality of breasts affected by myopathies, especially less known SM, are not completely clear, emphasizing the need for further investigation on a molecular level.

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