The European perspective on pale, soft, exudative conditions in poultry[1]

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ABSTRACT Over the past 15 yr, the European poultry processing industry has gradually increased the availability of poultry meat in a large variety of processed ready meals following what occurred a few years before in North America. This shift toward further processed products has emphasized the necessity for higher standards in poultry meat to improve sensory characteristics and functional properties. In parallel to this market change, the consciousness of the pale, soft, and exudative (PSE)-like meat issue has extensively grown. In poultry, PSE-like meat can be generally considered meat having low ultimate pH, pale color, and poor functional properties (i.e., low water-holding capacity). In the last 10 yr, some studies have been undertaken in Europe to both characterize and evaluate the overall incidence of PSE-like chicken and turkey breast meat. According to these studies, the occurrence of PSE-like meat can be up to 40% within a flock during hot climate. Several key factors have been identified and their effects have been analyzed, including genetics, season, antemortem factors, and slaughtering conditions.

Key words: poultry, breast meat, pale, soft, and exudative-like meat, Europe

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INTRODUCTION

In the past decades, worldwide poultry meat production and consumption have increased rapidly and, in many parts of the world, per capita consumption of poultry meat will continue to grow. However, North and Central America as well as Europe have been gradually losing market share, whereas China and Brazil have become new centers of production in Asia and South America (Windhorst, 2006). European poultry meat production is approximately 11 and 6 million tons for chicken and turkey, with a world share of 15 and 30%, respectively, and it is almost spread across all European countries (Figure 1; FAOSTAT, 2008).

Reasons for the success of poultry meat in developed countries are the healthy image of the product, which is considered lean and rich in protein, the increased availability of further processed products, and the relatively low price of this type of meat. As previously occurred in North America, the European processing industry has gradually increased the availability of poultry meat in a large variety of processed ready meals (Magdelaine et al., 2008). As shown in Figure 2, the distribution of poultry products in the United Kingdom and Germany is very close to that existing in the United States and Canada, whereas Mediterranean countries such Spain, France, and Italy still have a limited percentage of poultry marketed as further processed products.

There are some peculiarities of the European poultry market in respect to the North American market. These include the lower variety of marketed processed products and that consumers express their preference toward meat products with a recognizable meat structure (such as products prepared using comminuted meat or chunks) instead of highly comminuted emulsified products. Also, the European Union (**EU**) policy encourages limiting the use of food additives (e.g., phosphates) and favoring the preparation of minimally processed foods (Houghton et al., 2008). Moreover, some studies have shown that among meat quality attributes, after sensory properties, most importance is attributed by EU consumers to products being free from medicine residues, pesticide residues, and additives (Bernués et al., 2003; Verbeke and Vackier, 2004). The market shift toward further processed products has underscored the necessity for higher standards in poultry meat to improve sensory characteristics and functional properties (Fletcher, 2002).

Problems with meat quality are usually caused by aberrations in the biochemistry and morphology of individual muscles, as well as by postmortem events (Solomon et al., 1998). Through the years, poultry have been subjected to intense genetic selection for rapid lean muscle growth. It is generally recognized that this selection for muscle growth has resulted in poorer wa-

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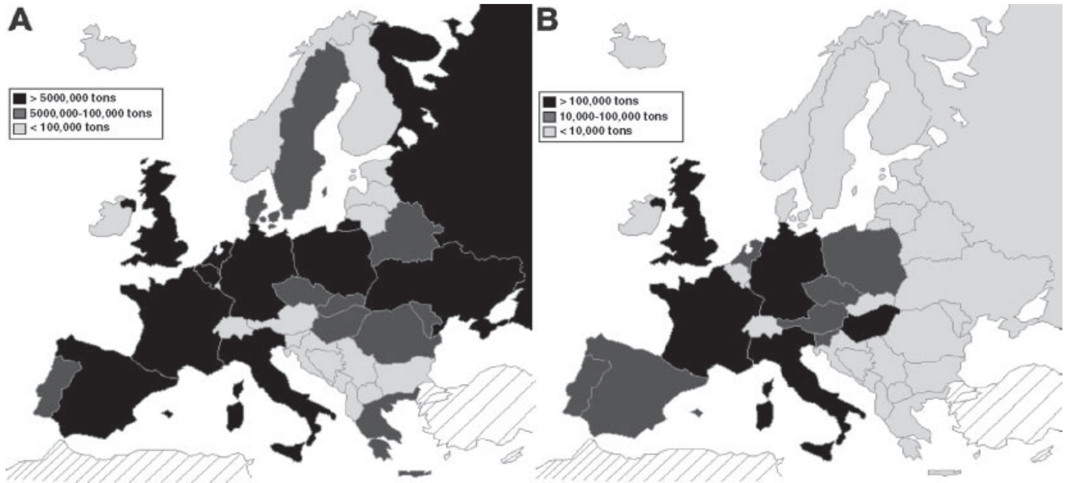

Figure 1. Chicken (A) and turkey (B) meat production in Europe in 2006 (FAOSTAT, 2008).

ter-holding capacity (**WHC**) of breast muscles during processing and storage (Dransfield and Sosnicki, 1999). The loss in functionality of the poultry breast meat is often associated with an increase of the meat paleness so that this condition is often referred as pale, soft, and exudative (**PSE**)-like, to stress the similarity with the PSE syndrome in porcine muscle that it is well known to generate meat with poor characteristics for further processing. Pale, soft, and exudative-like in poultry meat has started to gain a certain interest to the European industry only in the last decade because several industry personnel have indicated that the occurrence of the "light meat problem" can range from 5 to 30% depending on the flock, time of the year, and

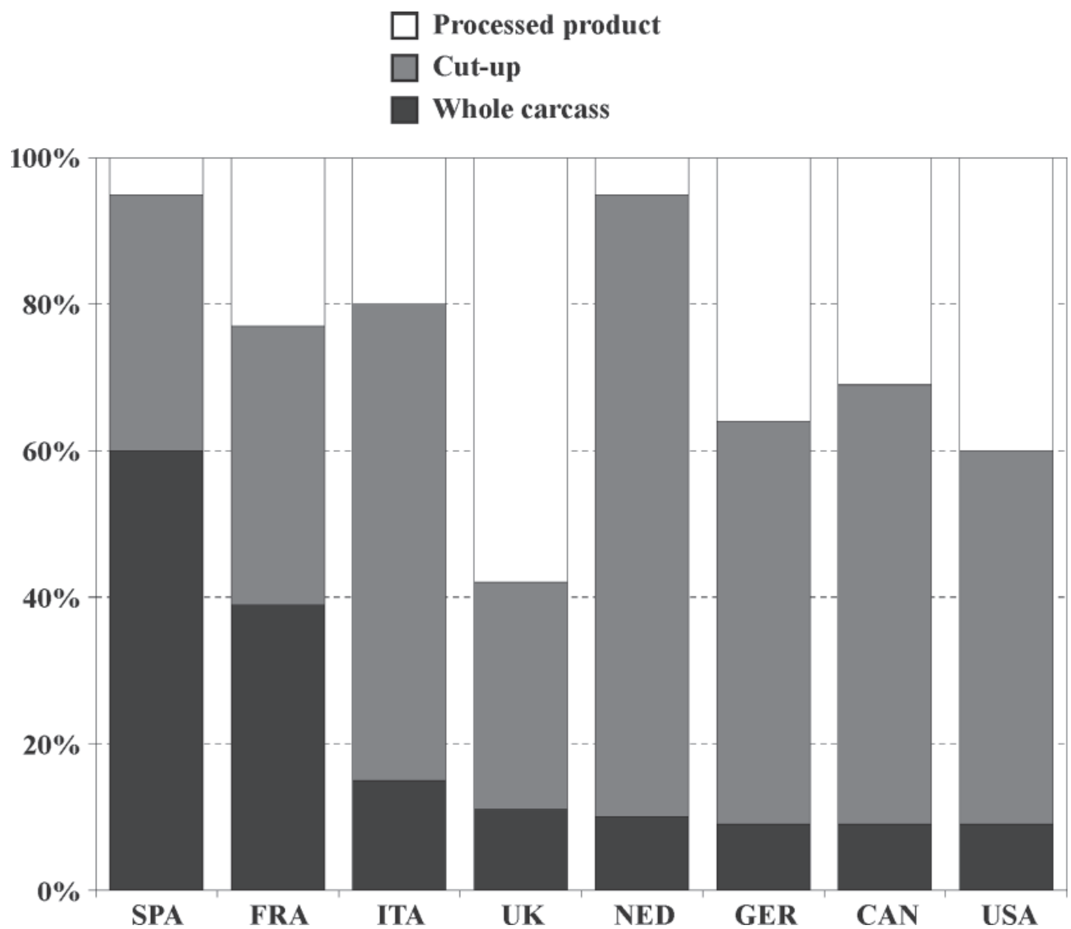

Figure 2. Market distribution of poultry meat products in some European and North American Countries (Magdelaine et al., 2008). SPA = Spain; FRA = France; ITA = Italy; UK = United Kingdom; NED = the Netherlands; GER = Germany; CAN = Canada; USA = United States.

Table 1. Estimation of chicken and turkey breast meat color variation and pale, soft, and exudative (PSE)-like incidence in studies conducted in Europe and North America

Study	Species	Country	Observations	L* range[1]	L* cut-off	PSE-like incidence (%)
Barbut, 1998	Chicken	Canada	700	41 to 56	>49/50	10
Wilkins et al., 2000	Chicken	United Kingdom	7,538	45 to 67		
Woelfel et al., 2002	Chicken	United States	3,554	42 to 71	>54	47
Petracci et al., 2004	Chicken	Italy	6,997	41 to 66	>56	10
Lesiów et al., 2007	Chicken	Poland	250	43 to 56	>53	5
Barbut, 1998	Turkey	Canada	4,000	38 to 57	>50/51	12
Owens et al., 2000	Turkey	United States	2,995	41 to 63	>53	40
Fraqueza et al., 2006	Turkey	Portugal	977	35 to 55	>50	8

[1]L* = lightness.

factors associated with transportation (Lesiów and Kijowski, 2003; Remignon et al., 2007). In this paper, the European perspective of the poultry PSE-like problem will be given, examining the magnitude and the consequences of its presence on meat quality and the related consequence for the poultry industry.

BREAST MEAT COLOR VARIATION AND INCIDENCE OF PSE-LIKE MEAT

In the last decade, both in Europe and North America, some researchers have suggested the possibility of using objective color measurements to estimate breast meat color variation and the prevalence of PSE-like condition in poultry (Barbut, 1998; Owens et al., 2000; Wilkins et al., 2000; Woelfel et al., 2002; Petracci et al., 2004; Fraqueza et al., 2006; Lesiów et al., 2007; Table 1). Wilkins et al. (2000) carried out the first study in Europe with the aim to evaluate the poultry meat color variation in a commercial processing plant in the United Kingdom, using 7,538 broiler breasts belonging to 23 flocks. The overall range in measured lightness (**L***) was fairly large and varied from 45 (dark) to 67 (pale). Subsequently, in a similar study (Petracci et al., 2004) conducted in Italy on a total of 6,997 broiler breast fillets from 79 flocks slaughtered in a single major commercial processing plant, the magnitude of the L* values range (41 to 66) was similar to that reported by Wilkins et al. (2000). Moreover, they proposed an L* cut-off value of 56 to discriminate breast meat with PSE properties and observed that approximately 10% can be considered as PSE-like.

The overall color lightness distribution found in both European studies is similar with that reported in the United States (Woelfel et al., 2002), whereas it is considerably higher in respect with the findings of Barbut (1998) in Canada. Also, in Poland, some surveys were conducted to evaluate the occurrence of PSE-like broiler breast meat and recently they found an average PSE-like incidence of 5% (Lesiów et al., 2007). A further study was conducted on turkey in Portugal by Fraqueza et al. (2006), who classified breast meat as PSE-like if L* > 50 and ultimate pH < 5.8 determining a PSE-like incidence of 8%. The overall distribution suggested that turkey breast meat lightness in Portugal is similar with that reported by Barbut (1998), whereas it was considerably lower in respect with the findings by Owens et al. (2000).

On the whole, these studies evidenced an extreme difference of absolute L* values and overall distribution among different studies both within Europe and in comparison with those conducted in North America. This large variation can be due to differences in production factors such as genotype, feeding, housing, antemortem management, and processing techniques, but further problems in establishing the L* cut-off point to use as a meat quality indicator during processing might be due to differences in sample and color measurement conditions. For example, Petracci and Fletcher (2002) reported that color measurements are greatly affected by early aging times during processing. Also, the meat thickness (Sandusky and Heath, 1996; Bianchi and Fletcher, 2002) as well as the color measurement position on the fillet (Goshaw et al., 2000) represent important factors to take into account when measuring color of poultry for meat functionality sorting purposes.

It has been suggested that each plant would have to determine its own lightness values for sorting PSE-like meat depending on type of birds, processing factors, and final product specifications. For example, if lightness values indicated by Barbut (1998; L* > 50) and Woelfel et al. (2002; L* > 54) to discriminate the pale breast are applied to the study conducted by Petracci et al. (2004), the rejection rate would be 80.3 and 28.1%, respectively (Table 2). These values would be very far from the 9.8% incidence established by using the cut-off value of L* = 56 determined in the same study (Petracci et al., 2004) considering the mean and SD of the color data of 6,997 broiler breast fillets.

CHARACTERIZATION OF PSE-LIKE BREAST MEAT

Some authors have studied pale broiler breast meat characteristics by sorting dark, normal, and pale fillets on the deboning lines of processing plants with both visual scores and objective measurements of meat lightness. In the study conducted by Petracci et al. (2004), broiler breast fillets were collected based on visual appearance followed by L* measure for selecting darker than normal (L* < 50), normal (50 < L* < 56), or lighter than normal (L* > 56). Class L* limits were established based on color variation reported in the same study. The selection of breast fillets based on L* values resulted in a clear differentiation of the ultimate pH and WHC evaluated with cooking loss method. Darker meat (L* < 50) is associated with higher pH values and cooking yield, whereas paler meat (L* > 56) is associated with lower muscle pH and WHC. These data were consistent with those from the study conducted in the United Kingdom, in which a close relationship between the lightness and pH measured at 24 h postmortem was evidenced (Wilkins et al., 2000). In the study carried out by Fraqueza et al. (2006) on turkey breast meat, samples were collected as being darker than normal (L* < 44), normal (44 < L* < 50), or lighter than normal (L* > 50). They also evidenced that in turkeys paler breast meat is associated with lower ultimate pH and WHC assessed by drip and cooking losses.

The results found in both broilers and turkeys are consistent with similar studies conducted in North America (Fletcher et al., 2000; Owens et al., 2000; Van Laack et al., 2000; Galobart and Moran, 2004; Bianchi et al., 2005) and indicate that wide differences in raw broiler breast meat color are mainly due to difference in ultimate pH and result in variations in the WHC of the meat. Nevertheless, there were no consistent effects on meat tenderness (shear value) as stated by Fletcher (2002).

Other studies indicate that the PSE-like condition in poultry breast muscles may be determined by an accelerated rate of postmortem muscle glycolytic metabolism. Fernandez et al. (2001) collected turkey breasts based on early pH measured at 20 min postmortem selecting slow-glycolyzing (6.55 ± 0.08), normal (6.24 ± 0.04), or fast-glycolyzing (5.90 ± 0.07) muscles. They observed that fast-glycolyzing muscles exhibited lower ultimate pH, paler color, and lower technological yield in agreement with other authors (Sosnicki et al., 1998). On the contrary, Fraqueza et al. (2006) found that turkey muscles classified by pH decline rate as fast glycolytic (pH at 15 min postmortem lower than 6.20) did not present final quality characteristics that could relate them with PSE-like meat because there was no relationship between early pH and lightness, drip loss, or cooking loss. Thus, the relationship between early postmortem glycolysis, ultimate pH, and the incidence of PSE-like meat in poultry should be better clarified.

MAIN CAUSES OF PSE-LIKE CONDITION

Several studies have been conducted in Europe to establish directly or indirectly the main causes of PSE-like condition. These studies can be divided into 2 categories: those evaluating the role exerted by genetic selection and those concerning the effect of environmental factors.

As for genetics, it has been shown that selection for BW or muscle development has induced histological and biochemical modifications of the muscle tissue, which can be related with PSE-like condition. Numerous studies conducted in the United Kingdom evidenced that modern rapidly growing strains of meat poultry exhibited an elevated incidence of spontaneous or idiopathic myopathy and an increased susceptibility to stress-induced myopathy (Mitchell, 1999; Sandercock et al., 2006). These pathologies are attributable to alterations in intracellular calcium homeostasis (Sandercock and Mitchell, 2003; Sandercock et al., 2006) and consequent changes in sarcolemmal integrity and may result from excessive myofiber hypertrophy and inadequate development of support tissues and vascular supply (MacRae et al., 2006, 2007). These authors stated that these myopathies may have profound implications for meat quality and the incidence of specific conditions such as PSE-like meat.

Different conclusions have been found by French researchers, who estimated genetic correlations for meat quality and body traits in broilers (Le Bihan-Duval, 2001). They found that selection for growth and muscle development did not alter the pH of the meat but weakly modified its color by decreasing the redness (a*) and yellowness (b*). Moreover, Berri et al. (2005) suggested that selection for increased muscle yields and against fat deposition could exert cumulative effects on muscle metabolism, decreasing glycogen storage and thereby reducing the extent of postmortem acidification. As a consequence of higher ultimate pH, the WHC and processing ability of the meat was improved.

In a recent study done by Berri et al. (2007), breast meat obtained by chickens slaughtered at different ages was compared and breast samples were divided according to average fiber cross-sectional area. They found higher creatine kinase levels (an indicator of stress sensitivity and muscle damage) by the increasing fiber dimensions according to the results found by Sandercock et al. (2001, 2006). However, when meat properties are taken into account, they observed lower muscle glycolytic potential with the increase of fiber size, which determined the production of meat with higher ultimate pH, paler appearance, and lower drip loss. The results found by French researchers do not support the idea that selection has a negative effect on meat quality, suggesting that further studies should be done on

Table 2. Comparison of the incidence of pale, soft, and exudative (PSE)-like broiler breast meat under different lightness (L*) value limits applied to the data found by Petracci et al. (2004)

L* value limit	Incidence of PSE-like meat (%)
L* > 50[1]	80.3
L* > 52	55.7
L* > 54[2]	28.1
L* > 56[3]	9.8
L* > 58	2.2
L* > 60	0.6
L* > 62	0.1

[1]Limit value proposed by Barbut (1998).
[2]Limit value proposed by Woelfel et al. (2002).
[3]Limit value proposed by Petracci et al. (2004).

this topic to evidence the involved underlying genetic mechanisms (Duclos et al., 2007).

Among environmental factors to induce PSE-like meat occurrence, heat stress during the end of the growing phase or preslaughter period seems to play the major role. Taking into account the color data found by Petracci et al. (2004) considering 3 different seasons, it clearly appears that the incidence of PSE-like meat is higher in hot than in cold seasons. During the summer, the broiler breast muscle fillets exhibited significant higher lightness values (53.1) in respect with those obtained during autumn (52.8) and winter (51.3). Moreover, considering an L* cut-off value of 56, PSE-like incidences were 15.5, 11.3, and 2.7% in summer, autumn, and winter, respectively. This evidence was also confirmed in recent studies by Bianchi et al. (2006, 2007) and overall agrees with the findings of McCurdy et al. (1996). On the contrary Wilkins et al. (2000) did not find any color difference according different seasons of the year. However, it should be considered that high temperatures reached during summer in the United Kingdom are not comparable with those achieved in southern European countries.

The seasonal effect was also confirmed in turkeys when breast meat quality characteristics from birds slaughtered in winter or summer were studied (Bianchi et al., 2004). In this study, color data were not different between groups; however, turkeys processed during summer showed lower pH values at 15 min and 24 h postmortem as well as an impairment of WHC with higher values of drip and cooking losses. Moreover, cluster analysis of the raw nuclear magnetic resonance relaxation curves showed 2 main groups of meat samples. The first group included the majority of the turkeys processed during the winter season, whereas the second group included all of the birds processed during the summer season. These data evidence the extreme variability in water distribution and protein-water interactions in turkeys processed during different periods of the year.

Overall, these results are consistent with those presented by other authors (Holm and Fletcher, 1997; McKee and Sams, 1997; Petracci et al., 2001). The authors all found that birds held at higher temperatures before slaughter had significantly lower ultimate pH values than birds subjected to cooler temperatures.

Sandercock et al. (2001, 2006) found that rapidly growing lines of birds may exhibit a reduced thermoregulatory capacity compared with their genetic predecessors and may thus be more susceptible to heat stress during the preslaughter period and to consequent problems including muscle damage, acid-base disturbances, and reduced meat quality. Acute heat stress has been demonstrated to increase superoxide free radical production in chicken skeletal muscle (Mujahid et al., 2005). This mechanism may be responsible for the transport stress- and heat stress-induced muscle damage and for the changes in muscle and meat quality observed in broilers. Thus, derangements of antemortem muscle cell metabolism and alterations in sarcolemmal integrity and tissue structure associated with oxidative damage and myopathy may have profound implications for meat quality and the incidence of specific conditions such as PSE-like meat. A recent study of Akşit et al. (2006) tested the effects of heat stress during rearing and preslaughter crating on broiler stress parameters and meat quality traits. Heat-stressed birds both during farming and preslaughter time evidenced a higher heterophil:lymphocyte ratio, which is a sensitive stress indicator, and after slaughter, lower ultimate pH and paler breast meat. This study also indicated that heat stress during farming predisposes birds to produce breast meat with PSE-like characteristics.

CONCLUSIONS

The preference of European consumers toward more traditional products coupled with the EU policy to limit additive use increases the importance of raw meat quality used for the preparation of further processed products. This makes European processing industries more vulnerable to the PSE-like condition. In several studies, it has been evidenced that the incidence of poultry PSE-like meat in Europe is around 10%. However, the extreme variability of absolute color detected through different studies suggests that application of an online vision machine or visual selection to discriminate PSE-like meat should be preceded by color variability assessment within each processing plant.

The causes of PSE-like condition seem to be related to selection of the birds for growth rate and breast yield, even if some authors evidenced that involved underlying genetic mechanisms should be further clarified. However, it is generally recognized that heat stress both at the end of the farming period and during the preslaughter phases seems to exert the major role in predisposing birds to produce PSE meat. Some strategies to reduce the incidence of PSE-like meat can be to mild preslaughter stress by avoiding extreme preslaughter environmental conditions, minimizing transport and lairage with long duration, and improving catching operations. Moreover, modification of the diet for a short period immediately before preslaughter transport or providing a relatively small amount of key nutrients (e.g., vitamins, minerals, amino acids), or both, offers potential to reduce meat quality defects.

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