Pale, soft, and exudative poultry meat—Reviewing ways to manage at the processing plant¹

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ABSTRACT This review focuses on ways the industry can currently deal with pale, soft, and exudative (PSE) poultry meat. Overall, the rapid increase in poultry meat consumption and the move toward selling more cut-up parts have resulted in some complaints associated with meat quality. Because no genetic marker related to PSE in poultry used by breeders has yet been identified, processors can employ several pre- and postrigor strategies to minimize the magnitude of the problem. They include reducing stress before slaughter (e.g., during catching, transportation, waiting period, unloading) and during stunning (gas vs. electrical). Later, there is a need to better understand and adjust processing conditions such as electrical stimulation, chilling rate, and maturation. When dealing with cut-up parts or deboned meat, strategies such as identifying and separating PSE meat, diverting it to no or low moisture-added products, and including additives to compensate for the poor water holding and texture can be beneficial. The potential contribution of ingredients such as starches (regular, modified), carrageenans, and enzymes is discussed. When it comes to formed products (e.g., nuggets), gentle brine addition and the use of low-pressure forming equipment can also help to minimize the effects of using PSE meat.

Key words: broiler, chicken, meat, poultry, pale, soft, and exudative

INTRODUCTION

Global poultry meat consumption has increased at a tremendous rate over the past 5 decades (Magdelaine et al., 2008). In addition, more poultry is sold as cut-up parts or further-processed products (i.e., in 1967, over 80% of poultry was sold as whole birds in North America, whereas today the number is less than 20%; Smith, 1999; Roberts, 2008). One of the consequences is that processors as well as consumers are currently experiencing some meat quality problems not seen in the past when live or whole dressed birds or smaller birds were sold. It should also be recognized that when selling parts or deboned meat, meat quality issues such as water holding, color, and texture became the responsibility of the processors. The fact that most of the poultry grading systems around the world are still based on aesthetics criteria rather than meat quality parameters (e.g., missing wing vs. low water-holding capacity, respectively) does not help to address meat quality issues.

DISCUSSION

The suggestion that a pale, soft, and exudative (PSE)-like condition exists in poultry meat was already mentioned about 40 yr ago (Vanderstoep and Richards, 1974). However, only during the past decade have industry and research personnel started to look at the PSE problem and its relevance to the poultry industry.

The occurrence of PSE poultry meat is believed to be the result of accelerated postmortem glycolysis (rapid pH decline) while the carcass is still warm (Pietrzak et al., 1997), especially in some birds that are more susceptible to stress (Strasburg and Chiang, 2009). It is hard to get accurate figures for the monetary losses, but some estimates suggest about $200 million a year to processors in the US broiler industry alone (Lubritz, 2007).

Some processors in the fresh and cut-up meat sectors are currently concerned with the appearance of very pale meat when selling tray packs. One can expect some color variation in biological samples and meat color is no exception. The lightness variation in commercial broiler breast meat samples (700) is presented in Figure 1. However, when samples from both extreme sides of the curve are presented side by side, in a tray

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pack, the consumer starts to be concerned. In general, the color seen is the result of numerous chemical and physical factors within the muscle. It should be noted that myofibrillar reflection contributes to differences in light scattering between PSE and dark, firm, and dry (DFD) meat as it does in pork and beef meat (Swatland, 2008). Swatland also indicated that pH-related scattering has a major effect on the translucency of chicken breast meat, causing low pH meat (5.91 in his experiment) to appear pale and high pH meat (6.36) to appear dark. Several market surveys have shown that certain processors are actually sorting and packaging the deboned meat according to its color (Table 1). In the United Kingdom, Wilkins et al. (2000) measured consumer reaction to color differences in trays of skinless chicken breast meat and noted that color “extremes are likely to be discriminated against at the point of purchase.”

Over the past decade, various estimates have been published regarding the magnitude of the PSE problem in poultry. McCurdy et al. (1996) reported 25% of turkeys in Ontario in a survey of 4,000 turkeys. Owens et al. (2000) indicated 40% in a group of 3,000 turkeys evaluated in Texas (L* > 53 according to their cut-off point). Woelfel et al. (2002) reported that 47% of the 3,554 broiler fillets they evaluated were pale (L* > 54 according to their cut-off point) in Texas. Smolinksa and Korzeniowska (2005) indicated that 35% of chicken breast meat samples they evaluated in Poland were pale.

It has also been reported that occurrence of the PSE problem can be related to factors such as climate (season). McCurdy et al. (1996) showed that during the Canadian summer months, the incidence of PSE was higher compared with the winter (Figure 2). Later, a similar season effect was reported by McKee and Sams (1997).

The question of how many processors are actually monitoring the situation is not easy to answer. Furthermore, the question of how many processors take action or modify practices to handle such meat is even more difficult to answer. In an unofficial small-scale survey, the author estimated that less than 50% of the processors in North America are concerned or take any action to deal with PSE poultry meat. This is obviously very different from the pork meat industry, in which almost all processors are monitoring the situation and remove or divert the PSE meat to a different production stream (Barbut et al., 2008). In any case, the poul-

Table 1. Incidence of noticeable chicken breast fillet color differences in multifillet packages (number defects/total packages) and percentage.

<table>
<thead>
<tr>
<th>Company/store</th>
<th>Defects/total</th>
<th>Defects (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9/72</td>
<td>12.5</td>
</tr>
<tr>
<td>B</td>
<td>13/77</td>
<td>16.8</td>
</tr>
<tr>
<td>C</td>
<td>6/39</td>
<td>15.4</td>
</tr>
<tr>
<td>D</td>
<td>6/28</td>
<td>21.4</td>
</tr>
<tr>
<td>E</td>
<td>2/8</td>
<td>25.0</td>
</tr>
<tr>
<td>F</td>
<td>0/10</td>
<td>0.0</td>
</tr>
<tr>
<td>G</td>
<td>1/117</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total packages</strong></td>
<td><strong>71/997</strong></td>
<td><strong>7.12</strong></td>
</tr>
</tbody>
</table>

*Data from Fletcher (1999).*

Figure 1. Histogram of L* value distributions of breast meat color in 700 chicken broilers (data from Barbut, 1997). VA70 = chemically modified potato starch; T420 = chemically modified tapioca starch.
Try processors who monitor and segregate PSE meat employ strategies that can be divided into:

- sort out PSE meat and not include in high water-added products;
- use nonmeat ingredients that can help bind water;
- add ingredients that can improve bind or texture in further-processed products;
- mix a known amount of PSE meat (usually small) with normal meat to mask the PSE effect; however, this is usually applied to ground or chopped products and not to a whole-muscle product such as a turkey roast;
- use special processing equipment;
- control temperature regimens before and during the rigor process; and
- control or modify preslaughter conditions.

It is hoped that in the future we could also add genetic improvement as was successfully done by the pork industry, after several genetic markers have been identified (Strasburg and Chiang, 2009).

The first option mentioned above of separating the PSE meat can be done by color evaluation or pH reading because there are good correlations among color, pH, and cook loss. Barbut (1993) reported correlations in the neighborhood of 0.67 to 0.87. Northcutt et al. (1994) have reported changes in drip loss and cook loss to be directly influenced by pH. Allen et al. (1998) indicated significant negative correlation (0.78) between L* tumbled and water-holding capacity of chicken breast fillets, but not between raw meat pH and cook loss.

Overall, a processor can select a certain cut-off point (L* when based on color, or a certain pH value) to achieve a specific processing value (Table 2). It is recommended that such values will be determined by each processor so he or she can match specific processing requirements (e.g., yield) for a given product. In general, color evaluation by a person or a machine vision system is usually faster because there is no need to wait for a pH electrode reading and no need to perform an invasive test.

Another alternative is to add various nonmeat ingredients to compensate for the lower protein functionality of the PSE meat (i.e., can add to the sorted-out meat or the whole batch). The ingredients range from starch, used to increase water-holding capacity, to proteins or gums that can independently form a gel and therefore improve texture as well as contribute to water-holding

Table 2. L* value cut-off point for water-holding capacity (WHC) found in the breast meat of young toms

<table>
<thead>
<tr>
<th>Season</th>
<th>WHC (%)</th>
</tr>
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<tbody>
<tr>
<td>Spring</td>
<td>51.3</td>
</tr>
<tr>
<td>Summer</td>
<td>47.1</td>
</tr>
<tr>
<td>Autumn</td>
<td>49.8</td>
</tr>
<tr>
<td>Winter</td>
<td>50.5</td>
</tr>
</tbody>
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1Data from McCurdy et al. (1996).
capacity. Enzymes that can induce protein-protein interactions are another category of ingredients that will be discussed below.

Results of using different starches with regular, PSE, and dark, firm, and dry broiler meat are shown in Figure 3. It can be seen that regular potato starch, modified potato starch (VA70, mid to high cross-link and high substitution), and regular tapioca starch helped to reduce cook loss by about 2-fold. However, chemically modified tapioca starch (T420, low cross-link and mid to high substitution) had a much larger effect on reducing cook loss. This appears to be due to the modification of this particular tapioca starch as well as its very small granule size (light microscopy results), which allowed it to be in contact with a large area of the meat protein matrix. Results of the modulus of rigidity during heating and cooling (i.e., measure of gel structure formation) were also provided in that publication and show a synergistic effect of the meat and starch.

Carrageenan is an example of a seaweed hydrocolloid that can be used to enhance water binding (e.g., jelly desserts can be made with 1% of the gum; i.e., 99% water); the gum is commonly used in oven-roasted turkey breast products. In this case, it should be remembered that this gum would only start to bind water during the cooling phase after its structure has been opened up during the heating step. This is similar to Jello (Kraft Foods Global Inc., Northfield, IL; made from collagen, which also gels during cooling and forms a reversible gel). Bater et al. (1992) showed that adding carrageenan to juices from turkey meat was very beneficial in enhancing gelation. Kerry et al. (1999) added carrageenan to exudates from pork meat and by using a control stress rheometer showed that during heating and cooling a higher increase in storage modulus was observed in the carrageenan and in carrageenan + whey protein concentrate treatments compared with the control. Significant synergies were observed when blending carrageenan and whey proteins. Recently, there has been an introduction of a new modified carrageenan preparation claiming to bind water even before cooking.

Enzymes such as transglutaminase (TG) can also be used. Transglutaminase is used in a range of protein cross-linking or modifying activities. These include reactions as diverse as fusing fibrinogen to increase the mechanical strength of the blood-clotting cascade to cross-link of cytoskeletal proteins. The enzyme can be extracted from fish meat, or produced by microbial fermentation (Zhu et al., 1995) and is marketed as an enzyme to improve the general texture of different protein-containing foods (Ramírez-Suárez and Xiong, 2003). In an experiment using TG and different soy protein isolates, it was shown that all chicken breast meat treatments resulted in significantly higher hardness values compared with the corresponding controls (Barbut, 2008). The combination of TG and soy further enhanced texture. However, employing TG by itself caused higher cook loss as a result of forming a highly cross-linked and dense gel structure (microscopy results). This example illustrates the important message, that processors should be aware of such effects and evaluate each nonmeat additive in terms of its performance and overall cost benefit.

Selecting and modifying equipment used to deal with PSE meat is another strategy that can be separated
into several options. The important issue is to understand the reason(s) for the changes needed. Various machines are currently used to add brine or moisture to the product (injectors), help distribute the brine, and assist in extracting salt-soluble proteins (tumblers or massagers). The equipment is used for large whole-muscle pieces (turkey breast), smaller muscle chunks (e.g., chicken tenders), ground poultry meat, or their combinations.

Various injectors are available on the markets and the processor has to select the one that best fits the product to be injected. The selection is related to the number of needles (measured as number per unit area), their thickness, injection pressure, belt speed, etc. These parameters are very important because using thick needles, in the case of PSE meat, which is already soft, or meat with a relatively low amount of connective tissue (young broiler or turkey breast meat; see additional discussion below), can result in too much disruption-breakage of the meat structure. Such mechanical disruption can lead to inadequate binding and eventually poor sliceability or even the product falling apart during sectioning.

Tumblers or massagers are used to marinate the meat, which means adding or distributing moisture, salt, phosphate (where permitted), nonmeat proteins, and gums to whole-muscle-sectioned meats. These operations are designed to accelerate brine introduction and later distribution within the meat as well as help extract the salt-soluble proteins. It should be noted that small pieces of meat can be tumbled without prior injection because the ratio of volume to surface area is high. Overall, tumbling is done to improve yield, juiciness, tenderness, and control cost. One of the practices of enhancing the quality of PSE poultry meat includes marinating with salt and phosphate. Woelfel and Sams, (2001) reported that when using a marinade at pH 9 to treat or tumble normal and PSE chicken breast meat fillets (average L* 52.4 and 60.2, respectively), there were no differences in percentage of brine uptake and drip loss, but cook loss was higher in PSE meat. When a marinade at pH 11 was used, no difference between the normal and PSE meat was observed. Overall, the authors suggested that the PSE conditions could not be reversed by the marinade treatments used.

Later in the process, different forming machines can be used to shape the product (e.g., nuggets, restructured breast fillet shape). They include the traditional high-pressure forming machines and the new generation of low-pressure formers. The high-pressure formers (8 to 15 bars at the forming head) use a meat pump that transfers meat mass into open cavities blocked by a plate. In the following cycle, the plate is removed, and meat is pushed out by a plunger. In a low-pressure machine, cavities (different shapes are formed within a special stainless steel drum) are filled and later the meat is pushed out by air pressure from behind. In this case, the back of the cavity is made of porous metal (small metal beads fused together), which allows air passage and hence low-pressure operation (1 to 2 bars at the head). One of the main advantages is avoiding high pressure that can result in squeezing out water from the myofilaments of the muscle (i.e., lean muscle contains ~70% water) as well as the elimination of water that is used as a processing aid in the high-pressure equipment.

Controlling or modifying postmortem conditions is another key factor because maintaining muscles at high postmortem temperature can induce PSE conditions. Molette et al. (2003) kept turkey pectoralis major muscles (n = 15) at 4, 20, or 40°C for 6 h. They observed higher drip and cook losses from the samples kept at 40°C than at 4 and 20°C. Also, myofibrillar protein extractability was lower at 40°C. As a result, all the 40°C treated muscles showed similar characteristics to PSE muscles obtained under a normal chilling process (naturally occurring).

Prerigor stresses can also play an important role. The immediate prerigor conditions include factors such as transportation, rest period at the plant, and stunning method. Guarnieri et al. (2004) showed that a pre-slaughter shower treatment (at the plant) reduced PSE in broiler breast meat processed in a commercial plant. The treatment seems to help cool down the birds in the hot Brazilian climate, and reduced heat stress. However, dietary factors have also been proposed, where certain vitamins and minerals have been suggested to help reduce the rate of PSE. Olivio et al. (2001) suggested that high dietary vitamin E reduced the incidences of poultry PSE and improved meat functional properties; dietary vitamin E was claimed to be capable of inhibiting the development of PSE and hence improved water holding.

In terms of stunning, there are currently 2 generally accepted methods for poultry including electrical and gas stunning (single and 2 phases). The objective in this context is to reduce stress before slaughter. Stress can also be induced by prestunning activities such as manual removal from crates and hanging on the shackle line. Gas stunning offers the possibility of stunning in the crate or after birds were mechanically unloaded from the crates (the latter requires less gas displacement and therefore lower operating costs). The single-stage stunning is usually applied by anoxia conditions (using argon or CO₂), whereas the 2-stage process is based on an initial anesthesia phase (40% CO₂ + 30% O₂) followed by high CO₂ stunning. Because the 2-stage process results in less muscle cramps and convulsions (McKeegan et al., 2007), it can provide a higher quality product.

Another problem that the industry faces is poor sliceability of certain whole-muscle products such as oven-roasted turkey breast (i.e., birds selected for fast growth and sometimes weak connective tissue; see discussion below). When this is combined with the use of PSE meat, product quality can be seriously affected. Swatland (1990) measured the growth of connective tissue in commercial fast-growing turkeys raised from 1 to 15 wk
and showed a 35-fold increase in cross-sectional areas of muscle fiber. Endomysium doubled in thickness and perimysium increased 5-fold in width during this time (Figure 4), meaning that connective tissue growth is not catching up with muscle fiber development. Overall, structure fragmentation during slicing is seen more in products from heavier birds (e.g., turkeys). The final trigger for the poor sliceability might be the postmortem formation of large intercellular spaces when fluid is released from the myofibrils during an accelerated postmortem process. Therefore, when a muscle integrity problem is compounded by the occurrence of PSE meat, a cooked whole-muscle product would not be acceptable (e.g., poor water-holding capacity and sliceability).

It appears that the poor integrity and PSE problems have also been affected by selection for fast-growing birds. Overall, the average BW of market broilers more than doubled over the past 30 yr, and the average market age decreased by more than half.

Some industry personnel also point out that another meat quality problem, the so-called deep-muscle myopathy, has increased over the past few years. This problem is associated with poor or interrupted blood supply to the enlarged breast muscle, which can result in death of muscle fibers in certain areas (Macrae et al., 2006), sometimes also referred to as the green muscle disease. Postmortem chilling rate is another important factor that can be adjusted by the processor (Barbut, 1998). Pietrzak et al. (1997) concluded “the results indicate that the irreversible myosin insolubility due to low pH and high temperature conditions is decisive in the development of PSE turkey breast muscle.” Sams and Alvarado (2004) mentioned “to varying degrees, slower chilling rates resulted in lower pH, greater degree of lightness, greater cook loss and reduced gel strength (in turkey breast meat muscle). However, chilling rate had no effect on total protein solubility or myofibrillar phosphorylase for any of the treatment. Chilling rate seems to contribute to PSE turkey meat characteristics by a mechanism independent of total protein solubility.”

In summary, the answer to the question of what the industry can do to reduce or eliminate the PSE problem could be divided into short- and long-term approaches. In the short term, attention should be given to factors currently known to trigger the formation of PSE meat in susceptible birds. As described in this review, they can include stress reduction during transportation (e.g., heat), adjusted postmortem chilling rate of meat, selection or separation of PSE meat and diverting it to special products (e.g., formulations with binders), and use of low-pressure forming equipment.

In the long-term, more attention should be given to genetics and selection, focusing on various meat quality traits (i.e., WHC as well as birds less susceptible to stress; not only focusing on yield and growth rate), as is described in greater detail in the companion articles in this issue. Finding a reliable genetic marker(s) for selection is one of the first steps. Overall, the genetic basis of PSE in poultry is still not fully understood, but it is likely that one or more mutations predispose the birds to develop PSE conditions.

REFERENCES
