Research developments in pale, soft, and exudative turkey meat in North America[1]

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ABSTRACT Pale, soft, and exudative (PSE) refers to meat that is pale in color, forms soft gels, and has poor water-holding ability. Most frequently used in reference to pork, this defective meat is being seen with increasing frequency in turkey and broiler processing plants. It has been estimated that this PSE-type meat represents 5 to 40% of meat that is produced in the poultry industry. With the increased production of further-processed products, this PSE problem has become more apparent in the turkey industry. It has been estimated that due to the high incidence, a single turkey processing plant could be losing $2 to 4 million per year, resulting in a loss in excess of $200 million dollars by the turkey industry alone.

Key words: pale, soft, and exudative meat, meat quality

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INTRODUCTION

The causes of pale, soft, and exudative (**PSE**) meat seem to be genetic, environmental, or a combination of both. In swine, a genetic mutation in the ryanodine receptor has been identified and has been associated with animals that are stress-susceptible and prone to developing PSE meat. Although this genetic mutation is well understood in swine, to date, there is no evidence to support or refute a genetic mutation in turkeys as related to PSE development. Pale, soft, exudative meat is also associated with antemortem and postmortem stressors including heat stress, preslaughter handling practices, and carcass chilling regimens.

Animals with this condition can have such an adverse reaction to stress that they die. However, this is rare or unrecognized in poultry. Either it does not happen or is simply attributed to handling and transportation. More commonly, birds enter the processing plant and are killed in an excited state with profound implications for the quality of their meat. They have an accelerated rate of metabolism, accelerating the decline in muscle pH that normally occurs with rigor mortis development (Owens et al., 2000a; Table 1). The abnormally low pH at an early postmortem time when the carcass is still warm causes the denaturation of the muscle proteins responsible for muscle color and the ability of the meat to hold water during cooking. These proteins are also responsible for the firmness of gels made from cooking meat proteins.

GENETIC CAUSES

Pale, soft, and exudative meat is the result of the inability of an animal to tolerate stress. In swine, this condition is also referred to as stress susceptibility. The cause of the condition seems to be an inability to regulate the flow of calcium ions in the different compartments of the muscle cell. Because calcium is a key regulator of muscle contraction-relaxation, calcium imbalances can drastically alter energy metabolism and muscle activity. In some affected swine, the cause is a clear genetic error. There is a single point mutation in the calcium channel gate-keeper protein (the ryanodine receptor, **RyR**) that controls the flow of calcium from storage compartments to the fluid surrounding the contraction proteins, actin and myosin (Fujii et al., 1991). This mistake in the amino acid sequence causes the protein gate to leak or, in the extreme case, to get locked open (MacLennan et al., 1994). When this happens, the contraction apparatus is flooded with calcium, metabolism is accelerated, and body temperature increases. Elevated body temperature is the source of another name for this syndrome in other species, malignant hyperthermia. Malignant hyperthermia is known

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to occur in humans, dogs, cats, and many types of livestock animals (Klein, 1975; O'Brien, 1994; Harrison, 1994; Benumof, 1998).

Complicating the picture is that animals can have multiple forms of the RyR protein, each of which may be normal or defective. Given this, an animal can be homozygous or heterozygous for each of the protein forms. In an animal such as swine that has just 1 RyR form in skeletal muscle, there is a simple dominant (normal) and recessive (defective) relationship. Poultry are much more complicated because they have 2 RyR forms in skeletal muscle (Percival et al., 1994), each with 2 copies that can potentially be independently normal or defective. Obviously, the number of potential combinations of normal and defective proteins is greatly increased. If a turkey has some of its RyR gatekeeper proteins functioning correctly, it may be able to tolerate the stresses it encounters. However, if enough of its RyR proteins are defective, stressors may be able to trigger a release of calcium and an adverse response. Recently, researchers identified mutations in turkey RyR. Chiang and Strasburg (2003) reported 3 transcript variants in the RyR resulting in deletions in the amino acid sequence at different locations. These variants could lead to a nonfunctional ryanodine receptor protein resulting in abnormal calcium regulation in the muscle, which could then alter postmortem metabolism. Researchers studied commercial and random-bred turkeys and found that RyR from these populations had variations in affinity for ryanodine (a measure of the RyR function) suggesting a heterogeneity of RyR channel activity among turkey strains, specifically in the modern commercial strains (Wang et al., 1999; Chiang and Strasburg, 2003). Although mutations were identified in turkey, it is not the same mutation that has been identified in swine, although it is in a similar region of the amino acid sequence. Therefore, the function of the defective RyR is not fully understood yet in turkey as it is in swine, and the relationship between these mutations in the turkey RyR and stress tolerance in poultry is not known. In the future, it will be imperative to determine the function of the RyR forms in an animal and then to relate that information to the animals tolerance of stress and meat quality.

Screening methods have been studied as a means to reduce the incidence of PSE meat in swine and poultry. The use of halothane has been effective in identifying swine that carry the genetic defect in the RyR and are therefore stress susceptible and prone to developing PSE meat. Estimates are that only 20 to 40% of the PSE problem in swine can be explained by the genetic defect. The remainder seems to have more of an environmental cause. Similar tests have been studied for use in turkeys and broilers, but the tests have never been fully developed (Wheeler et al., 1999; Owens et al., 2000b, Cavitt et al., 2004). Because our genetic knowledge of this condition has not sufficiently developed, we cannot yet use birds of known genetic typing to assess the accuracy of this test.

Table 1. Characteristics of pale and normal turkey breast meat from a commercial plant (from Owens et al., 2000a)[1]

Measurement	Normal[2]	Pale[2]
Lightness (1.5 h postmortem)	47.31[b]	56.85[a]
Lightness (24 h postmortem)	48.99[b]	54.72[a]
pH (1.5 h postmortem)	6.09[a]	5.72[b]
Expressible moisture (%)	23.41[b]	32.31[a]
Drip loss (%)	0.72[b]	2.52[a]
Cook loss[3] (%)	15.17[b]	17.56[a]

[a,b]Means with no common superscript differ significantly ($P < 0.05$).

[1]Groups selected based on subjective color evaluation.

[2]n = 67 per mean excluding cook loss.

[3]n = 30 per mean for cook loss percentage.

Basically, we do not yet have enough information to address the genetic causes of this syndrome and allow selective breeding of poultry. It appears that the commercial incidence of PSE meat in broilers and turkeys ranges from approximately 5 to 40% of the birds (Barbut, 1996; Owens et al., 2000a; Woelfel et al., 2002). However, there seems to be a small incidence (about 5 to 10% of all meat or about 20 to 25% of the PSE meat) that is present all the time, the background. Above this background appear spikes that vary with the day, week, or season, even if the breed or strain is constant. It therefore appears that the background represents a rough estimate of the genetic component of the syndrome, whereas the spikes represent the environmental components. Thus, there are times when genetic factors cause the problem, whereas environmental factors are more important at other times. Lacking such ability to genetically type poultry, it is not possible to verify or separate the relative involvement of genetic or environmental causes. However, most processors can accommodate the background incidence and only have problems when the incidence increases.

ENVIRONMENTAL CAUSES: ANTEMORTEM STRESS FACTORS

Various antemortem stress factors including environmental temperatures, preslaughter handling practices, and transportation have been associated with porcine stress syndrome and PSE meat. Poultry are subjected to similar antemortem environmental conditions as swine. Therefore, stressful conditions along with rapid growth in poultry may also influence the development of PSE in poultry meat.

Environmental temperatures can play a major role in antemortem stress and consequently postmortem meat quality. Heat stress, chronic or acute, is one of the primary causes of stress during preslaughter activities because it can be associated with other physical stressors to birds such as crowding during catching, transportation, and holding before slaughter and result in additive stress effects. Heat stress in poultry has been extensively studied, and in general, research has shown that heavier birds are more susceptible to heat and high humidity (Bohren et al., 1982; Mills et al., 1999; Lu et

Table 2. Quality attributes of meat from heat-stressed or control (non-heat-stressed) turkeys (from McKee and Sams, 1997)

Attribute	Heat stress	Control
pH 2 h postmortem[1]	5.85[b]	6.07[a]
L* value[1]	53[a]	49.75[b]
Cook loss (%)	24.56[a]	19.08[b]

[a,b]Means with no common superscript within a row differ significantly ($P < 0.05$).

[1]Values estimated from graphs. n = 61 per mean

al., 2007). At high temperatures, evaporative cooling is the primary mechanism of the bird for heat loss; however, at high RH and high temperatures, evaporative cooling is impeded, thereby making it harder for birds to dissipate heat (Yahav et al., 1995) and resulting in stress on the bird.

The turkey industry reports substantial losses in product yield due to decreased water-holding capacity during the early summer season when higher environmental temperatures are high. McKee and Sams (1997) reported that chronically heat-stressed turkeys exhibited lower muscle pH, higher L* values indicating paler color, and higher drip loss and cook loss as compared with turkeys grown at ambient temperatures (Table 2). McCurdy et al. (1996) evaluated the effect of season on the incidence of PSE in turkeys and reported the highest L* values in the summer season and the lowest in the winter. There seems to be more PSE in the summer but predominantly the early summer months, tapering off toward the later months. Birds growing rapidly in the spring would be larger at the same age when the heat of summer arrives than the bird growing more slowly through the summer, being acclimated to the heat by the time it reaches a large market size. The spring-growing bird would be less tolerant of the heat than the summer-grown bird.

Transportation is another potential stress associated with meat quality problems. Transportation stress is very complex because it not only includes the act of transporting (vibration and noise), but it also includes thermal stress, RH, air flow, and crowding. Turkeys and broilers are often transported to processing plants for 30 min to 3 h before processing. The transportation process can be stressful to the birds and it may consequently affect meat quality. However, research related to transportation stress and meat quality in poultry is not conclusive. Results have shown an improvement, no change, or a decrease in meat quality (Kannan et al., 1998; Owens and Sams, 2000; Debut et al., 2003). These studies have varied in numerous conditions including time, processing methods, environmental temperatures, and stocking density. However, based on research in swine and poultry, it can be concluded that there is potential for transportation to lead to increased postmortem metabolism, which can ultimately affect meat quality. Therefore, it is important to be aware of conditions that may lead to stressful situations for the bird such as crowding, elevated temperatures, and transportation duration.

RAPID GROWTH

In recent years, intense genetic selection of turkeys and chickens has contributed to the fast-growing birds. Additional contributing factors to modern poultry include better feed efficiency and better management. Over the past 20 to 30 yr, BW of broilers and turkeys have nearly doubled. Faster growing or heavier birds have been shown to be more susceptible to heat stress indicated by great metabolic heat production, increased body temperatures, and mortality (Hunt et al., 1999; Mills et al., 1999). Furthermore, in a review by Mahon (1999), the author concluded that commercial lines of turkeys selected for enhanced growth exhibit a greater incidence of muscle abnormalities than nonselected turkey lines.

ENVIRONMENTAL CAUSES: PROCESSING FACTORS

Along with genetic and environmental conditions antemortem, PSE can develop in normal, nonstressed animals if improperly processed. Primarily, chilling conditions can have a great effect on the development of PSE in turkey meat. Turkeys are more susceptible to inadequate chilling due to their large body size and muscle mass. As previously mentioned, this condition results from a rapid decline in muscle pH at high carcass temperatures, which causes protein denaturation leading to the poor meat quality traits. Previous research has shown that inadequate chilling results in meat with lower pH, lighter color, higher drip losses and cook losses, and fewer extractable myofibrillar proteins (McKee and Sams, 1998, Table 3; Rathgeber et al., 1999; Alvarado and Sams, 2002; Molette et al., 2006).

STRATEGIES TO IMPROVE FUNCTIONAL QUALITY OF PSE MEAT

Regardless of how or why it occurs, processors are faced with this defective meat and want to know what they can do to use it in their products without sacrificing yield or quality. Extreme cases produce up to 20% purge loss in a cook-in bag and cook losses over 30% from a breast fillet. An additional defect is that the poor protein function in PSE meat causes poor binding of meat pieces in formed products, a condition

Table 3. Quality attributes of meat from turkeys chilled at 0°C or held at 40°C for 4 h after slaughter (from McKee and Sams, 1998)

Attribute	0°C	40°C
pH 2 h postmortem[1]	6.02[a]	5.87[b]
L* value[1]	51[b]	57[a]
Cook loss (%)	24.05[b]	28.86[a]

[a,b]Means with no common superscript within a row differ significantly ($P < 0.05$).

[1]Values estimated from graphs. n = 12 per mean

called cracking. Furthermore, these defective cook-in bag products need repackaging, which further increases costs.

There are limited strategies for dealing with this defective meat. The reduced water-holding capacity of the meat is the result of protein damage from the low pH condition of the muscle early after death. It is thought that this damage is at least partially reversible by adjustment of pH or ionic strength in the meat through the use of salts, phosphates, or other ingredients. However, there is no strong evidence to show that adjusting the pH or ionic strength alone can reverse the problem (Woelfel and Sams, 2001). New marinade ingredients and formulations are currently being studied to provide processors more options to utilize PSE in specific products. Ideally, the new marinades could be used on all meat and would correct the PSE meat without adversely affecting the normal meat. The use of modified food starch (**MFS**) in marinades for poultry meat successfully reduced cooking losses in PSE poultry meat, resulting in similar cooking losses as non-PSE meat marinated with MFS; also, both MFS treatments had reduced cooking losses compared with a control marinade consisting of only salt and phosphate (Cavitt and Owens, 2001). Zhang and Barbut (2005) also reported that using MFS can significantly improve water-holding capacity of PSE meat, suggesting that these starches can compensate for the lost protein functionality of PSE meat. They also reported that regular (nonmodified) starches can also improve cook losses. However, with the growing trend of natural products, those with minimal processing or ingredients, or both, the inclusion of functional ingredients to improve PSE meat may be an issue in itself.

Another strategy for PSE meat that has been investigated is using high-phosphate marination to improve the functional properties of this poor-quality meat (Gorsuch and Alvarado, 2002). High-pH phosphates (~pH 11) have been shown to increase the pH values of the pale fillets but were still significantly lower than the pH values of the marinated normal fillets, indicating that the treatments did not increase pH of the pale fillets to that of the normal fillets. When comparing treatments on pale fillets, the high-pH phosphate worked significantly better than the other treatments at increasing pH, improving water-holding capacity. In addition, the high-pH phosphate had no adverse effects on sensory properties, oxidation values, or shelf-life.

The only strategy that is currently available is to sort the meat so that the pale meat is directed to uses in which the PSE meat is not a problem (comminuted, breaded patties) or into formulations containing ingredients or conditions to restore protein function and water-holding capacity. Experience has indicated that PSE meat causes its greatest problem in whole-muscle products to which no or low amounts of salt and phosphates are added. These are ingredients that help hold the water in the meat and thereby reduce cook losses and purge. If PSE meat were directed away from these products and toward the formulations containing these agents, the effect of the PSE meat would be reduced. This sorting process may initially seem like a difficult task, but fillets are already being sorted for other purposes such as defects, size, and grade. Color is an easy and rapid characteristic to assess and could easily be accomplished with employee eyes or optical scanning equipment currently available for food processing. The sorting equipment is also already in place in many plants sorting fillets for size. Meat pH could be another sorting characteristic. Although pH measurement is more complicated, automated systems are already in development in the pork and beef industries for the very same purpose, to sort meat for optimum meat function.

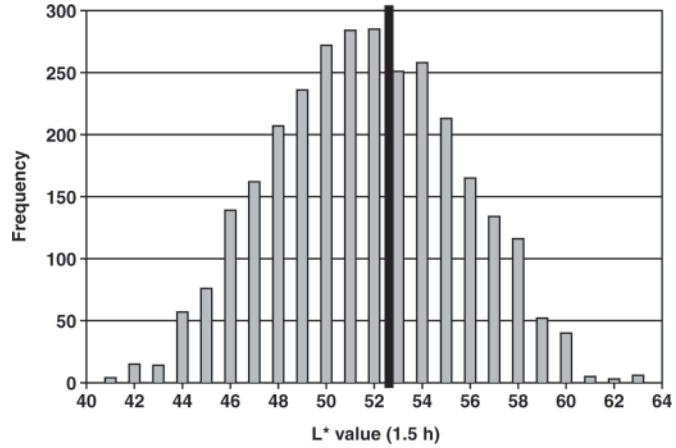

Figure 1. Frequency of L* values (1.5 h postmortem) from turkey breast fillets (n = 2,995) in a commercial processing plant (from Owens et al., 2000a).

A sorting system requires a threshold value for lightness (or pH) above which (or below which for pH) the meat is considered to potentially be PSE. Researchers have used threshold L* values ranging from 49 to 54 for identifying PSE meat (McCurdy et al., 1996; Barbut, 1997; Owens et al., 2000a; Qiao et al., 2001; Woelfel et al., 2002). Owens et al. (2000a) used a threshold of L* value >53 because it repeated the lower limit of lightness measurements obtained from several groups of pale fillets and it was also the L* value that corresponded with impaired water-holding capacity. Using this threshold (L* value >53), PSE incidence was estimated at approximately 40% in a commercial turkey plant (Owens et al., 2000a; Figure 1). Even though the lightness of the meat in a slaughter plant can vary somewhat with flock and season, such a threshold can be a useful tool in monitoring the PSE incidence in a commercial plant. However, the threshold for L* value should be determined by each processor depending on the product.

CONCLUSIONS

The future has both long- and short-term strategies for the problem of stress susceptibility and PSE poultry meat. Genetic typing, screening tests, and selective breeding are all possibilities but are many years away. The number of parameters needing to be addressed in this research is enormous and will require more research. Environmental stress is a set of issues that the industry can address now and should already be addressing for reasons of health, feed conversion, and growth. Finally, in the absence of a selective breeding program and in the inevitability of environmental extremes, the industry will continue to see PSE meat in processing plants. Better characterization of the meat and control of its flow-distribution among products will reduce the effect of this defective meat.

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