Poultry meat quality

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The two most important quality attributes for poultry meat are appearance and texture. Appearance is critical for both the consumers' initial selection of the product as well as for final product satisfaction. Texture is the single most important sensory property affecting final quality assessment. Appearance quality attributes include skin colour, meat colour, cooked meat pinkness, and appearance defects such as bruises and haemorrhages. Since appearance is so critical for consumer selection, poultry producers go to great lengths to produce products with the appropriate colour for a particular market and to avoid appearance defects which will negatively effect product selection or price. Historically, meat tenderness was primarily associated with live bird quality factors such as breed, sex, or age. However, modern production practices produce highly uniform young birds in which the major problems associated with meat texture are the result of processing errors or early deboning. Although other quality issues such as juiciness and flavour are important, they are more a function of product preparation and infrequent, but acute, production or processing errors which are usually easily corrected or avoided. An understanding of the major issues contributing to poultry colour and meat tenderness is critical to producing uniform quality products.

Keywords: meat quality; meat colour; meat tenderness; discolouration, toughness

Introduction

The major poultry meat quality attributes are appearance, texture, juiciness, flavour, and functionality. Of these, the most important have traditionally been appearance and texture since they most influence consumers' initial selection and ultimate satisfaction with traditional poultry meat products. Although juiciness and flavour are extremely important, except for isolated defects they are most often more a function of preparation than of the product itself. With the increasing trends in further processing, meat functionality and all of the sensory quality attributes have increased in relative importance. Complex products such as sausages, marinated fillets, breaded products, fully cooked heat-and-serve items, frozen entrees, and complete dinners require an understanding of the contribution of poultry meat to these products as well as their influence on sensory properties of the food. Functional properties such as water holding capacity are critical for successful product formulation. A basic understanding of the live production and processing factors that influence these poultry meat quality attributes, especially colour and texture, is necessary to produce consistently high quality poultry products.

Although the scientific literature has a considerable amount of information on the subjects of poultry processing and poultry meat quality, there has been, up to recently, a shortage of comprehensive source books on the subject. For many years, the only text book in this area was *Poultry Products Technology* first published in 1966, by George Mountney. This was a good college text and resource book during the first two editions, however, by the third edition (Mountney and Parkhurst, 1995) it was no longer current or relevant to the modern processing industry. Stadelman, Olson, Shemwell, and Pasch, published *Egg and Poultry-Meat Processing* in 1988. This also was a good introductory text, but generally lacked depth, was not a good general reference book, and was not widely accepted. In 1989, a book, entitled *Processing of Poultry* was published. This book, edited by G.C. Mead, was an excellent resource book with chapters authored by outstanding individuals in their area. However, this book was written from the European perspective and has begun to show its age.

In the late 1990s and early 2000, Elsevier International (Khan, 2000) published the *Poultry Production Guide* in a series of installments, which included chapters on the poultry market and product quality. In the past year, two new books have reached the market, both of which are current and have excellent chapters relative to poultry processing and meat quality issues. The first is *Poultry Meat Processing*, edited by A.R. Sams (2001) and the second *Poultry Products Processing: An Industry Guide*, written by S. Barbut (2002).

Appearance

Of all the quality attributes, appearance is the most critical for the selection of many food commodities, including poultry products. Consumers most often select or reject a product based solely on its appearance. Appearance is also critical for final product evaluation since it often affects other sensory properties. One of the major contributing components of appearance is colour. Colour has long been known to be a major selection criterion for fresh poultry and meat products as well as for final product satisfaction.

For poultry meat products, colour is important for skin, meat, and bone. Skin colour is most critical for the marketing of fresh whole birds or parts. Meat colour is most important both for the selection of deboned and skinless raw meat as well as being critical for the final evaluation of many cooked products. Pink or red appearance of cooked poultry meat is generally associated with undercooking and is highly undesirable. Dark or black bones are also considered to be a defect in fully cooked products. Bone darkening is primarily associated with frozen products prior to cooking. Other visual defects are associated with bruises, haemorrhages, blood pooling, or any number of other possible discolourations.

SKIN COLOUR

Market studies in the early 1960's clearly showed pronounced regional differences in consumers preferences for fresh whole broilers based solely on skin colour (Raskopf *et al.*, 1961; Courtenay and Branson, 1962; Davis, 1963; Heffner *et al.*, 1964). These studies showed that consumers generally prefer broiler skin colours ranging from white, to pale yellow, to deeply pigmented based on traditional regional supplies. In 1987, Marion and Peterson showed that skin colour still influenced consumers' attitudes towards fresh poultry. Thus consumers tend to favour skin colours which were traditionally available and which were based on local feeding practices as well as genetic stock. In modern markets, consumers still tend to favour their traditional market forms. In the Eastern United States, deeply pigmented birds are the most desired; in the South-eastern US, moderately pigmented birds are preferred; in the North-western US, pale skin colour is preferred; in the United Kingdom, consumers prefer a white, non-pigmented skin. Similar differences in colour preferences exist all over the world, and are based primarily on historical and regional supplies, traditional genetic stock (ability of some breeds to deposit carotenoid pigments in the skin), and availability of carotenoid containing feedstuffs.

Because of its market impact, much is known about the factors affecting skin pigmentation. As early as 1915, researchers recognized the principal pigment involved in the colouration of egg yolks and tissues of poultry (Palmer, 1915). Pigmentation, or the deposition of pigments in the skin of the bird, depends upon the genetic capability of the bird, dietary source of pigments, health of the bird, and processing. A review of the many factors affecting poultry pigmentation was published by Fletcher (1989) and the state of the art for pigmenting poultry products was published in symposium form (Sunde, 1992; Hencken, 1992; Hamilton, 1992; Fletcher, 1992; Williams, 1992). A summary of the major factors affecting skin pigmentation are presented in *Table 1*. Broilers must have the genetic ability to deposit carotenoid pigments in the epidermis. With the exception of the Cornish breed, English Class birds lack this genetic ability to deposit carotenoid pigments in the skin thus these birds have a white appearance regardless of diet or other factors. Those birds that have the genetic disposition to deposit the carotenoid pigments in the skin must also have the pigments supplied in the diet. For this reason, numerous studies have been conducted to evaluate the skin pigmenting properties of a variety of both natural and synthetic sources. Diseases, particularly coccidiosis, have been shown to have dramatic negative effects on pigmentation. Flock health is critical to uniform pigment absorption and deposition. Since the carotenoid pigments are deposited in the epidermis, care must also be exercised in processing not to remove this layer by over-scalding or damaging the skin during picking.

Table 1 Summary of factors affecting poultry skin pigmentation (Fletcher, 1989).

Factor	Examples
Feed sources	alfalfa, barley, corn gluten meal, grass meals, millet, milo, oats, wheat, yellow corn
Xanthophyll concentrates and exotic sources	algae, bacterial by products, beehive pollen, broccoli, citrus sludge, clover, cow manure, crawfish waste, kenaf, lake weed, lettuce, leucaena leaf meal, lobster shell, marigold extract, marigold meal, paprika extract, peanut leaf meal, seaweed, shrimp waste, soybean oil soapstock, sweet potato vine meal, tomato, yeast and synthetically produced xanthophylls such as beta-apo-8'-carotenal and canthaxanthin
Feed additives	anticoccidial drugs, antioxidants (BHT, vitamin E, etc.), fish oils and fish meals, growth promotants, meat scraps, trace mineral, vitamins (specially as antioxidants such a E, or negative effects of too much A)
Xanthophyll stability and biological availability	antioxidants, biological availability (absorption), biological deposition (genetic), chemical form (free or esterified), colouring capacity, storage time, temperature
Management and processing	breed and strain(genetic ability to deposit xanthophylls in skin), disease and health, environment, housing type, scalding, sex

With the increase in further processing of poultry and changing markets with increased cut up, deboned meat, and fully cooked products, the relative importance of skin colour has decreased in recent years, primarily in North America and Western Europe. The predominance of skinless raw products as well as further processing has reduced demand for whole birds and skin-on parts. The increased trend for further processing, which includes numerous breaded or coated products, has also resulted in a requirement by further processors to remove the epidermal layer of skin during scalding so as to increase coating adherence to the underlying dermal layer of the skin during further processing and cooking. The epidermal layer, also known as the cuticle, is loosened at scald water temperatures above 54°C and is removed during picking leaving only the underlying dermal layer of skin. Thus even in areas which may prefer a yellow skinned bird, further processing demands for removing the epidermis has resulted in decreased economic incentives to maintain high carotenoid levels in the feed.

MEAT COLOUR

Colour of raw poultry meat is critical for consumer selection while colour of the cooked meat is critical for final evaluation. Colours which differ from the expected pale tan to pink raw meat or from the tan to grey cooked meat will result in consumer rejection of the product. This is especially true with the appearance of pinkness in fully cooked meat; a major defect in poultry meat products. A recent survey indicated that approximately 7% of skinless-boneless breast fillets, packaged 4 fillets to a pack, had one or more fillets which were noticeably different from the other 3 fillets in the same package (Fletcher, 1999a). In a survey of five commercial broiler processing plants, breast meat colours were found to have a wide range with lightness values (lightness value ranges from 43.1 to 48.8 using the CIELAB colour description system) which had a strong negative correlation to muscle pH (Fletcher, 1999b). These results indicate that significant variations in breast meat colour exist and are present at the retail level. In a later study, Fletcher *et al.* (2000) showed that variations in raw breast meat colour are sufficient to cause variations in cooked product appearance.

Mugler and Cunningham (1972) reviewed many of the factors affecting poultry meat colour. Such factors as bird sex, age, strain, processing procedures, chemical exposure, cooking temperature, irradiation, and freezing conditions were all shown to affect poultry meat colour. In recent years additional factors have also been identified as affecting poultry meat colour. Maga (1994) reviewed the primary factors influencing pink discolouration in cooked white meat (pork and poultry). This review stressed the nature and reactions of the major meat pigment, myoglobin, as well as effects of nitrates and nitrites, ovens and environmental gasses (primarily carbon monoxide and nitric oxide), age, sex, and strain of animal, scalding temperature, irradiation, cooking temperature, storage, canning, processing additives, pre-slaughter conditions, haemachromes, and cytochrome C reactions on final meat colour. Froning (1995) presented the most recent review on many of these factors affecting poultry meat colour and those major factors are summarized in *Table 2*.

Table 2 Factors influencing poultry meat colour (from Froning, 1995).

Haem pigments	myoglobin, haemoglobin, cytochrome C and their derivatives, presence of ligands complexing with haem pigments
Pre-slaughter factors	genetics (new and fast growing strains), feed (e.g. mouldy feed), feed withdrawal, hauling and handling, stress, heat and cold stress, preslaughter gaseous environment of the bird
Slaughter Chilling Further processing	stunning techniques, presence of nitrates, additives and pH (e.g. salt, phosphates, etc.), end point cooking temperatures, reducing conditions, washing surimi-like processing, irradiation

Stress immediately prior to and during slaughter have been shown to affect meat colour. Antemortem temperature stress and excitement just prior to slaughter has been shown to affect turkey meat colour (Froning *et al.*, 1978; Babji *et al.*, 1982; Ngoka and Froning, 1982). Walker and Fletcher (1993) reported that epinephrine injections just prior to slaughter, to simulate severe antemortem stress, resulted in darker breast meat due in part to both a higher muscle pH and increased haemoglobin content of the meat. Northcutt *et al.* (1994) reported that thermal preconditioning and heat shock in chicken resulted in breast meat that appeared pale, soft, and exudative, similar to a condition found in pork.

Electrical stunning at high currents (greater than 100 mA) was shown to increase blood spots in broiler chicken breast meat by Veerkamp (1987). However, other than for haemorrhaging effects on meat appearance, comparisons of low and high current stunning appears to have little direct effect on broiler breast meat colour (Papinaho and Fletcher, 1995; Craig and Fletcher, 1997). Gas stunning or gas killing has been shown to affect breast meat colour. Mohan Raj *et al.* (1990) reported that broiler breast muscles from argon killed birds were less dark than those killed conventionally or killed with carbon dioxide. Fleming *et al.* (1991a) found that stunning with carbon dioxide resulted in significantly less red breast and thigh meat compared to electrically stunned turkeys. Maki and Froning (1987) showed that electrical stimulation resulted in redder raw breast meat but lighter cooked breast meat than non-stimulated controls. Froning and Uijttenboogaart (1988) reported that postmortem electrical stimulation resulted in darker broiler breast meat. However, Owens and Sams (1997) reported no effects of electrical stunning on turkey breast meat colour.

The effect of chilling and leaching of haem pigments on poultry meat colour is not clear. Fleming *et al.* (1991b) reported no effect of immersion versus air chilling on broiler breast or thigh muscle colour or haem content. However, Boulianne and King (1995) attributed pale boneless broiler breast fillets to loss of haem pigments during storage in ice slush tanks. Yang and Chen (1993) found that lightness and redness values of ground breast and thigh meat decrease with storage.

The major contributing factors to poultry meat colour are myoglobin content, chemical state of the haem structure, and meat pH. Myoglobin content has been shown to be primarily related to species, muscle, and age of the animal. Muscle pH has been shown to be primarily related to the biochemical state of the muscle at time of slaughter and following rigor mortis development. Both of these factors contribute to meat colour and the occurrence of meat colour defects.

The relationship of animal species, muscle type, and animal age on meat myoglobin content and visual colour was presented by Miller (1994). White meat from 8 week old poultry had the lowest myoglobin content (0.01 mg myoglobin/g meat) compared to 26 week male poultry white meat (0.10 mg/g), young turkey white meat (0.12 mg/g), 8 week poultry dark meat (0.40 mg/g), 26 week male poultry dark meat (1.50 mg/g), 24 week male turkey dark meat (1.50 mg/g) and compared to 5 month old pork (.30 mg/g), young lamb (2.50 mg/g), dark meat fish species (5.3 to 24.4 mg/g), white meat fish species (0.30 to 1.0 mg/g), 3 year old beef (4.60 mg/g), and old beef (16 to 20 mg/g).

Because of the importance of both fresh and processed meat colour, the biochemistry of the haem pigments and their reactions that affect meat colour are extremely well documented in the general meat science literature. Bodwell and McClain (1978) present a comprehensive coverage of the myoglobin reactions associated with fresh meat colour and cooking. The various ionic and covalent complexes of both the ferrous and ferric state of the haem with oxygen and other compounds to form the basic meat colour variations from the purplish red of deoxygenated myoglobin to the bright red of oxymyoglobin to the brown/gray of metmyglobin are well established. Bard and Townsend (1978) discuss numerous haem reactions involved in meat curing. The reactions with various nitrogen compounds and heat to form stable nitrosyl haemachrome complexes produce the desirable pink colour of cured red meats or the undesirable pinkness of some poultry products. A series of research reports by Ahn and Maurer (1990a, 1990b, and 1990c) presented a comprehensive coverage of the complex haem reactions that affect turkey breast meat colour. This series of papers clearly illustrates the complexity of the numerous potential compounds and their effects on turkey meat colour. Their work also illustrated the pronounced effect of muscle pH on the formation of these complexes.

PSE- AND DFD-LIKE CONDITIONS IN POULTRY MEAT

Muscle pH and meat colour have consistently been reported to be highly correlated, especially when wide ranges of meat colour are examined. This is especially true when referring to meat as being either PSE-like or DFD-like in which pH is strongly related to these extreme conditions. This is an important distinction since several scientists have not found consistent relationships between colour and pH in "normal" or unselected populations of breast meat. Since negative data is seldom published, the literature may have a bias toward publishing only positive data in regards to these relationships. Therefore, it may be important to emphasize that the breast meat colour and pH correlations may be more prevalent in studies where wide ranges of breast meat colour were purposely selected.

Higher muscle pH is associated with darker meat while lower muscle pH values are associated with lighter meat. In the extremes, high pH meat is often characterized as being dark, firm, and dry (DFD-like) and the lighter meat as being pale, soft, and exudative (PSE-like). Both DFD-like and PSE-like meat have been associated with poor functional properties, or at the very least, have been considered major contributing factors to product variation. Several researchers have demonstrated this significant relationship between raw breast meat colour and raw meat pH (Barbut, 1993; Boulianne and King, 1995 and 1998; Allen *et al.*, 1997; Fletcher, 1999b).

The effect of pH on meat colour is complex. One effect, as noted earlier, is that many of the haem-associated reactions are pH dependent. In addition, muscle pH affects the water binding nature of the proteins and therefore directly affects the physical structure of the meat and its light reflecting properties (Briskey, 1964). Also, pH affects enzymatic activity of the mitochondrial system thereby altering the oxygen availability for haem reactivity (Ashmore *et al.*, 1972 and Cornforth and Egbert, 1985).

Muscle pH has been associated with numerous other meat quality attributes including tenderness, water hold capacity, cook loss, juiciness, and microbial stability (shelf life). Allen *et al.* (1997 and 1998) showed that variations in breast meat colour, presumably due primarily to pH effects, significantly affect breast meat shelf life, odour development, moisture pick-up during marination, drip loss, water holding capacity, and cook loss.

Although the differences in poultry breast colour exist, and these differences are related to differences in muscle pH, there are some contradictions in the literatures as to what extent colour can be directly related to a loss of meat functionality based solely upon colour discrimination. Barbut (1997) reported that the occurrence of pale, soft, exudative (PSE) meat in broiler chickens ranged from 0% to 28% in 7 different flocks. Woelfel *et al.* (1998) examined the incidence of pale, soft and exudative chicken meat in a commercial plant and reported that approximately 37% of 1751 commercial broiler fillets examined could be classified as being pale and could be expected to exhibit poor water holding capacity. Mallia *et al.* (2000) reported that in Canada, broiler carcasses with dark breast fillets are often condemned for cyanosis although the dark, firm and dry (DFD-like) condition may be due to other causes such as ascites or emaciation. Qiao *et al.* (2001) reported that selected breast meat samples in the very light, normal, and very dark ranges were associated with significant differences in meat functionality.

Research has been conducted to better define factors contributing to DFD- and PSE-like conditions as well as methods to identify breed or strains that may be more prone to producing poor quality meat. Many of these projects, including stress, have been previously discussed. Qiao *et al.* (2002) reported that broiler breast meat with wide variations in lightness between very pale to very dark had significant differences in chemical composition. The authors concluded that although short term stress may contribute the most to breast meat colour variation, the compositional difference indicates that long term or genetic factors may create a predisposition to carcasses being either extremely light or dark. In an effort to determine if birds can be tested for a predisposition to colour variation, halothane has been used to detect turkeys prone to developing PSE meat (Wheeler *et al.*, 1999; Owens *et al.*, 2000b, Owens *et al.*, 2000c). These results indicated that halothane is only a limited predictor of PSE meat in turkey.

There appears to be little disagreement that DFD- and PSE-like conditions do occur in poultry breast meat and that these defects are related, at least in part, to difference that contributes to a colour difference, from extremes in darkness to lightness. However, from the articles reviewed, there appears to be a difference among researchers as to how much difference in absolute lightness values is necessary to describe meat that has reduced functional properties. Extreme differences in lightness values have been correlated with differences in functional properties, but arbitrary lightness cut-off values have yet to be established which can clearly differentiate meat functionality.

VISUAL DEFECTS

Visual defects are those factors that can dramatically affect the appearance of the carcass or meat but may not be only associated with the pigments, physical, or chemical property of the skin or meat. The most important visual defects are those associated with bruising and haemorrhages. The discolouration of muscle tissue due to bruising or due to the accumulation of blood in the tissue due to haemorrhages negatively affect product appearance. If severe enough, bruises and haemorrhages can result in product condemnation or product rejection by the consumer.

Bruising is due to physical trauma (without laceration) resulting in capillary rupture and haemorrhaging (escape of blood from the circulatory system) of blood into the surrounding tissue. Initially a bruise will impart a red discolouration to the damaged tissues but will begin to darken to a blue-black discolouration and finally to green and possibly yellow as the haem compounds degrade. Haemorrhaging refers directly to any capillary or blood vessel rupture resulting in blood pooling in the meat or below the skin. Therefore, bruises are due to aging of capillary haemorrhaging in the tissue due to physical trauma whereas haemorrhages refer simply to any blood accumulation.

Because bruises are a major source of condemnation and downgrading (Bilgili, 1990) efforts to reduce or control their incidence have been identified. Factors identified to affect bruising include breed/strain, sex, housing density, feathering, bird size and age, season, light intensity, litter conditions, housing ventilation, disease, mycotoxins, vitamins, stress, holding conditions, unloading, hanging, stunning, killing, and picking. Tung *et al.* (1971) reported that feed aflatoxins can result in capillary fragility and increased incidences of haemorrhages. Wu *et al.* (1994) found that corn containing *Fusarium moniliforme* resulted in significantly darker and more red turkey breast meat. As presented earlier, electrical stunning has been implicated in contributing to increased haemorrhaging and blood spotting in meat. However, it is often difficult to completely separate haemorrhaging from meat colour issues.

COLOUR CHANGES OVER TIME

A phenomenon associated with both broiler skin and meat colour is that the absolute colour has noted to change over time, especially during storage. Since early changes would not affect product appearance in the display case, little practical problems were associated with these gradual changes, except in rare cases of long term storage issues. However, with the increased concern with the relationship between breast meat colour and functional properties of the meat, interest in the use of machine vision and computer aided sorting devices have been receiving considerable interest in recent years.

Breast meat colour, measured both on the day of processing and following 24 hours holding have been shown by numerous authors to be different (Alvarado and Sams, 2000; Bihan-Duval *et al.*, 1999; Mallia *et al.*, 2000; Owens *et al.*, 2000a; Owens *et al.*, 2000b; Owens *et al.*, 2000c; Owens and Sams, 2000; Qiao *et al.*, 2001). In a series of studies, the effect of both short term (0 to 12 hours) and long term (1 to 7 days) on both soft and hard scalded broiler skin and on intact and packaged breast fillets, were studied. Results show that both skin and meat colour values change dramatically for the first several hours after processing, and continuously, but at a slower rate, through 7 days of storage (Petracci and Fletcher, 2002). Additional research has clearly shown that breast meat sample thickness and background colour can also dramatically affect instrumental colour readings (Bianchi and Fletcher, 2002). The results from these two studies clearly indicate that machine vision systems used in processing plants to sort carcasses or meat based on colour need to consider the post-mortem time, sample thickness, and background (belt) material effects on calibration of such systems.

COLOUR MEASUREMENT

The science of food colourimetry is well established and many resources are available describing various methods of colour measurement of a wide variety of foods using both subjective and objective measurement systems. Reflectance colourimetry is one the most widely used colour measurement systems used in food science. However, such methods were not designed to be optimal to measure the colour of opaque materials, such as meat where much of the light is either transmitted or absorbed as opposed to be reflected to the detector. However, systems to measure the colour or reflectivity of such materials are not readily available for meat colour determination. Unfortunately, the basis for much of the previous discussion of meat colour is based on the use of reflectance colour measurement. Although this may not invalidate these studies, some caution should be exercised in over interpreting the impact of the method of colour measurement in predicting biochemical properties of the meat.

Texture

Texture is probably the single most critical quality factor associated with the consumers' ultimate satisfaction with a poultry meat product. The two major contributors to poultry meat tenderness are the maturity of the connective tissues and contractile state of the myofibrillar proteins. The first, maturity of the connective tissue involves the chemical cross bonding of the collagen in the muscle. Since collagen cross-linking increases with age, meat is generally tougher from older animals. The second factor, the contractile state of the myofibrillar proteins, is primarily a function of the rate and severity of rigor mortis development.

As the modern broiler industry developed and began to dominate the chicken meat market, the issue of age related toughness (connective tissue cross-linking) has virtually disappeared. Except for spent hen and older bird utilization, or for specialty markets such as for capons, age related connective tissue toughness is not a major factor in broiler meat quality since the market age of broilers is less than 7 to 8 weeks of age.

The myofibrillar protein impacts on ultimate meat tenderness are primarily a function of the biochemical predisposition of the muscle at the time of slaughter, the rate and severity of rigor mortis development, and the physical handling of the carcass and muscle during rigor development. With traditional broiler industry production practices, processing, and the predominant marketing of whole carcasses the negative impact of the myofibrillar protein reactions were not thought to have a major impact on meat quality. Shrimpton (1960) concluded that,

"....if tough flesh is found on the carcasses of broilers, its presence is likely to be caused by adverse conditions during the life of the bird. The toughness may also be accentuated by bad practice in the packing station, but the changes associated with rigor seem likely to play only a small part in the development of toughness in the muscle of young chicken."

However, in recent years with the dramatic increase in cut up, deboned meat, and further processed products, the demands are placed on the slaughter plant to cut up and debone the carcasses as fast as possible. If the carcass is cut-up into parts, or more importantly, if the breast meat is removed from the carcass prior to the completion of rigor mortis, the muscles will contract unimpeded by the normal skeletal restraint, the muscle fibres will contract and shorten the muscle, and the resulting meat will be less tender.

Although the predominant marketing of young broilers minimizes age associated toughness, the economic incentive to cut-up and debone broilers earlier in the processing scheme has resulted in an increased incidence of tough broiler breast meat. During the past 20 years, intensive research efforts have been focused on determining the live bird and processing factors which affect breast meat tenderness. The ultimate goal has been to develop slaughter methods which would allow for acceleration of post-mortem rigor mortis such that carcasses could be cut-up and deboned as soon after slaughter as possible.

ACCELERATED PROCESSING

It has long been established that poultry must be allowed a postmortem aging period prior to cut-up and deboning, cooking, or freezing to avoid adverse toughening, especially in the breast meat (Koonz *et al.*, 1954). A plethora of recent data suggests that a minimum of 4 hours aging is required to allow the breast muscles sufficient time to complete rigor development and to allow subsequent removal from the carcass without excessive toughening.

The concept of accelerated processing is based on the rapid depletion of muscle glycogen and ATP stores as fast after slaughter as possible. Once the muscle loses the ability to generate ATP, rigor contractions cease and the muscle can be released from skeletal restraint with less adverse toughening. The major factors affecting rigor development and accelerated processing are antemortem handling, electrical stunning, gas stunning, and electrical stimulation.

LIVE BIRD HANDLING AND STRESS

Feed withdrawal, environment, and struggle prior to slaughter have been shown to affect muscle glycogen stores in the muscle at time of slaughter. Birds with higher muscle glycogen content at slaughter have lower final muscle pH and lower shear values than birds with lower muscle glycogen (Mellor *et al.*, 1958). Increasing feed withdrawal times have been shown to decrease breast muscle glycogen stores (Murray and Rosenberg, 1953; Kotula and Wang, 1994). The later authors also reported that increasing feed withdrawal also reduced initial breast muscle pH values, but had little effect on terminal muscle pH, and resulted in higher breast meat shear values.

Ante-mortem stress, including heat stress (Simpson and Goodwin, 1975; Lee *et al.*, 1976; Babji *et al.* 1982), epinephrine injections (Wood and Richards, 1975; Fletcher, 1991), as well as struggle (Ma and Addis, 1973; Lee *et al.*, 1979; Ngoka and Froning, 1982; Papinaho *et al.*, 1995), have been shown to accelerate glycogen depletion, increase the rate of pH decline, and possibly result in tougher meat. Although ante-mortem handling, feed withdrawal, and stress affect muscle glycogen content at time of slaughter and therefore the rate and severity of rigor as well as ultimate muscle pH, the effect on accelerated processing and final meat tenderness is still not well defined.

STUNNING AND SLAUGHTER

Electrical stunning has been shown to result in more tender breast meat and altered postmortem rigor development. Lee *et al.* (1979) showed that stunned birds had higher ATP, lower lactate, and higher pH values than non-stunned birds and concluded that stunning inhibited metabolism and delayed the onset of rigor. Kim *et al.* (1988) concluded that stunning indirectly delayed post-mortem glycolysis primarily through a suspension of ante-mortem struggle. Research directly comparing electrical stunning and ante-mortem struggle showed that the early delay in rigor attributed to electrical stunning was indeed due more to a suppression of ante-mortem struggle than to any direct effects of electrical stunning on muscle metabolism (Papinaho *et al.*, 1995). Comparisons between high current stunning, as recommended in Europe, and low voltage stunning, as commonly used in the North America, showed that high current stunning resulted in a more pronounced effect on early rigor delay than low voltage stunning (Papinaho and Fletcher, 1995; Papinaho and Fletcher, 1996; Craig and Fletcher, 1997). These differences in muscle glycogen stores and breast muscle pH during early rigor development, however, do not affect ultimate muscle pH, tenderness values, or meat quality.

In Europe, electrical stunning has been under intense scrutiny for both animal welfare and meat quality issues for the past 15 years. The use of high current stunning to insure humane slaughter is also associated with increased carcass damage and lower meat quality. Although gas stunning has been evaluated since the 1950's (Kotula *et al.*, 1957) possible application for humane slaughter and meat quality improvements have led to renewed interest in gas as a possible method for both stunning and killing of poultry. To this end, intensive research into the use of argon and carbon dioxide gas killing systems has been conducted in the United Kingdom. In addition to humane slaughter benefits, improvements in reduced carcass damage and improved meat quality were reported. Specifically, killing birds in a gas environment appeared to result in accelerated rigor such that the breast meat could be harvested earlier without adverse toughening (Mohan Raj *et al.*, 1990; Mohan Raj *et al.*, 1991). These authors reported that gas killing resulted in lower initial muscle pH, more tender meat, faster post-mortem rigor development, and early harvesting of tender breast meat compared to electrically stunned birds.

Evaluations and comparisons of conventional and gas killing in the United States have been less encouraging relative to accelerated processing. Poole and Fletcher (1998) compared gas killing to both high current and low voltage stunned and conventionally killed broilers. Their results indicated that gas killing only showed a meat quality advantage when compared to high current stunning. The authors concluded that at least part of the rigor accelerating influence of gas stunning previously reported by the UK researchers was made in comparison to high current stunning which is now known to delay early rigor development.

ELECTRICAL STIMULATION

Electrical stimulation has been used to accelerate rigor development and enhance red meat quality. Li *et al.* (1993) reviewed the use of electrical stimulation in poultry. Due to numerous variations in the electrical stimulation systems studied, results have been variable and inconclusive. Although most researchers agree that electrical stimulation accelerates early rigor development, the magnitude of such effects and its subsequent applicability for commercial utilization is still in question.

Researchers at Texas A&M University however have conducted numerous experimental trials as well as industry prototype systems and have concluded that electrical stimulation does indeed allow for earlier deboning of broiler breast meat (Birkhold *et al.*, 1992; Sams, 1994; Sams, 1995, Zocchi and Sams, 1996). A number of such systems are now in use in the commercial poultry industry in Brazil and North America.

It is interesting that electrical stunning delays rigor development while electrical stimulation accelerates rigor development. A comparison of both high and low current stunning followed by electrical stimulation shows that electrical stimulation is most effective following high current stunning and had little effect following low voltage stunning (Craig *et al.*, 1998). These results might explain some of the inconsistency in previous results evaluating electrical stimulation.

COMBINATION TREATMENTS

Clatfelter and Webb (1987) reported that a combination of high temperature conditioning and electrical stimulation could be used to produce tender early deboned breast meat. Sams (1990) reported that both high temperature conditioning and electrical stimulation had no individual effects on early deboned breast meat, but when used in combination, they resulted in more tender breast meat. Walker *et al.* (1994) compared various combinations of high and low voltage electrical stimulation, high temperature conditioning, and muscle tensioning on broiler breast meat tenderness and concluded that only high voltage electrical stimulation with muscle tensioning had a significant positive effect on muscle tenderness.

It appears that no one single rigor acceleration procedure works as well as combinations of treatments. Current evaluations of commercial electrical stimulation systems, extended chilling, and interactions with stunning and gas killing systems are making progress towards making accelerated processing a reality.

Conclusion

Traditionally, poultry quality issues have focused primarily on the appearance of both the carcass and meat and the tenderness of the meat. The dramatic changes in the market forms for poultry over the past 30 years, from a predominantly whole bird commodity to the modern highly diversified industry focused on cut up, deboned meat, and ready-to-eat further processed products has also resulted in a change of our quality expectations. Although the basic issues of appearance and texture are still critical quality issues, the specifics and relative degree of importance has evolved with the changes in market products. As the market continues to evolve, we can expect traditional quality issues to continue to evolve as well as the identification of new quality parameters. Also, during this time, we have seen a definite shift from a more traditional concept of market based quality, affecting price and preference, to a more production oriented definition of quality based on statistical control and product uniformity.

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