Optimised feeding systems for improving meat quality

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Poultry is regarded as a high quality meat, which is healthy and safe to the consumer. It is well-known that there are many parameters: genetics, management, processing and nutrition that can influence the measurable quality attributes. This paper will review how feeds and feeding systems can influence, both positively and negatively, a variety of quality attributes in poultry meat.

Keywords: meat quality; texture; flavour; appearance; nutritional quality; safety; feeding systems

Introduction

If the European industry is to compete successfully with product imported from areas of the world where production costs are cheaper it must ensure that the quality of the product that it produces is of a high level.

Quality is traditionally a difficult parameter to define and when applied to a natural product such as food can mean many different things to different people.

For the purposes of this paper the definition of quality has been limited to the following attributes: texture, flavour, appearance, nutritional quality and product safety.

There are many factors which can influence the quality parameters mentioned: genetics, management, nutrition, stress, post mortem processing, storage and cooking.

It is therefore evident that, due to the high number of factors which are involved, the number of potential interactions is very large and to demonstrate a clear relationship between any single parameter and another is very difficult. However, there is published data and practical experiences which clearly show that through the optimization of feeding systems we can have a significant positive effect on meat quality.

Texture

Meat texture can be said to be primarily influenced by the degree of fibre contraction at the time of rigor, however it will also be influenced by the maturity of the fibre present. Meat is composed of many different structural components and therefore texture will be influenced by these as well as the individual muscle fibre. As the connective tissues mature, the level of collagen cross bonding increases and the meat will be tougher (Fletcher 2002). However due to the fact that the majority of poultry are slaughtered at a relatively immature state it is unlikely that this particular aspect will become a problem.

If texture is to be influenced it is therefore via the control of muscle contraction at rigor.

The onset of rigor in the muscle is primarily influenced by the reduction in effective energy reserves (ATP) and once the ATP is fully depleted, rigor contraction will cease. It therefore follows that if we are to minimize the degree of fibre contraction we need to minimize the level of ATP and the muscle’s ability to produce ATP, at the time of slaughter.

Post mortem, glycogen reserves in the muscle will be converted via anaerobic glycolysis to lactic acid, with the subsequent generation of ATP. If this occurs rapidly, at high temperature, a rapid pH
fall occurs and due to the rapid utilization of ATP, an early onset of rigor. This combination has been shown to result in a greater degree of rigor shortening and poorer meat texture (Khan, 1974).

Workers have therefore tried to find ways of preventing the rapid pH reduction and trials have centred primarily on ways of reducing the rate of glycolysis.

Feed withdrawal prior to slaughter has been shown to be an effective way of reducing both liver and muscle glycogen. Warris et al (1988) demonstrated that liver glycogen was reduced to a negligible concentration after six hours of feed withdrawal with a corresponding elevated initial pH (Table 1).

It was also shown that the glycogen level in the thigh muscle could be significantly reduced, with a related elevation in pH via feed restriction. However, feed restriction did not influence either the glycogen store or pH of the breast muscle (Table 2).

Table 1 Liver Glycogen concentration (mg/g) and initial pH in full fed (C) and fasted birds (F) (Warris et al 1988)

<table>
<thead>
<tr>
<th>Time after feed withdrawal from fasted birds (hrs)</th>
<th>Liver Glycogen (mg/g)</th>
<th>Initial pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>20.7</td>
<td>6.33</td>
</tr>
<tr>
<td>3</td>
<td>22.9</td>
<td>6.38</td>
</tr>
<tr>
<td>6</td>
<td>25.7</td>
<td>6.33</td>
</tr>
<tr>
<td>9</td>
<td>28.5</td>
<td>6.34</td>
</tr>
<tr>
<td>12</td>
<td>22.3</td>
<td>6.33</td>
</tr>
<tr>
<td>18</td>
<td>22.0</td>
<td>6.32</td>
</tr>
<tr>
<td>24</td>
<td>23.6</td>
<td>6.32</td>
</tr>
<tr>
<td>36</td>
<td>26.6</td>
<td>6.32</td>
</tr>
</tbody>
</table>

Table 2 Glycogen concentration (mg/g) and ultimate pH in breast and thigh muscle for full fed (C) and fasted (F) birds (after Warris et al 1988)

<table>
<thead>
<tr>
<th>Time after food withdrawal from fasted birds (hrs)</th>
<th>Breast muscle</th>
<th>Thigh muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glycogen</td>
<td>pH</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>F</td>
</tr>
<tr>
<td>0</td>
<td>4.8</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>3.1</td>
<td>3.4</td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>4.2</td>
<td>5.3</td>
</tr>
<tr>
<td>18</td>
<td>3.9</td>
<td>3.5</td>
</tr>
<tr>
<td>24</td>
<td>4.7</td>
<td>4.1</td>
</tr>
<tr>
<td>36</td>
<td>5.4</td>
<td>4.6</td>
</tr>
</tbody>
</table>

The breast muscle has higher glycogen stores as it is classed as glycolytic muscle designed for anaerobic activity over short bursts, such as rapid wing flapping.

However, it has been demonstrated that the level of glycogen can be depleted in the breast muscle under certain conditions (Kotula and Wang 1994).

It is therefore proposed that a feed withdrawal period of around six hours should be optimum for achieving satisfactory glycogen depletion.

The rate of glycolysis can also be reduced through the use of specific feed additives which will inhibit the glycolytic enzymes. Quercetin, a natural component of many fruits and vegetables is an inhibitor of lactate dehydrogenase, a key enzyme in the glycolytic pathway. Kremer et al (2000) investigated the use of Quercetin in improving pork quality and showed a higher pH and increased water holding capacity following its use. As previously mentioned, the rate of pH fall is temperature dependant and it has been shown that fillets from birds held at high temperature (29ºC) had lower pH, higher cooking loss and greater shear force, than those from birds held at lower temperature (7ºC) (Holm and Fletcher 1997).

McCurdy et al (1996) demonstrated that meat from young turkey toms (18 weeks) was significantly paler for birds reared during the summer months compared to birds reared during the winter. This may be due to metabolic heat stress occurring in the birds, due to a high environmental temperature. The effect of heat stress can be reduced through the use of optimised feeding regimes, where dietary energy is switched away from carbohydrate sources into fat sources. Dietary fats have a higher net
efficiency of energy utilisation and will therefore result in less metabolic heat generation, which will contribute to the impact of heat stress.

Finally the impact of proteolytic enzymes should be considered. The calpain-calpastatin enzyme system is active in bringing about post mortem proteolysis which will have a positive impact on meat texture. The enzymes are most active at neutral pH and therefore rapid pH falls will minimise their effect. Proteolysis will continue at low pH via the catheptic proteases and they will complete the tenderisation process providing that the calpain system has had sufficient time to be active.

Flavour

The development of poultry meat flavour is a complex process and a good review has been given by Farmer (1999). Flavour is made up of two key components, the aroma or volatile component and the taste from non volatile, water soluble components.

The volatile components are generally only produced and released after cooking, which explains why cooked meat has a more striking flavour.

Many of the precursors of the volatile compounds present in the muscle are supplied via the diet. Thiamine (Vitamin B₁) which when degraded by heating will release active sulphur and nitrogen containing compounds, which are active in the production of the “meaty” aroma in cooked chicken. An adequate dietary supply of this vitamin will help maximise this effect.

The majority of the work conducted on the effect of dietary regime on meat taste, has centred around the impact of specific raw materials.

Salmon et al (1981) showed that high levels of canola meal increased the frequency of the off-flavours in chicken meat. However subsequent work by Hawrysh et al (1980) found that the feeding of a guaranteed low glucosinolate variety did not affect the eating quality of the poultry meat.

Poste (1990) reviewed the inclusion of fishmeal in the diet and demonstrated that 12% fishmeal inclusion significantly reduced the chicken flavour and increased the fish off flavour in cooked chicken meat stored overnight at 4ºC.

It is well known that birds stored for a period of time prior to evisceration will gain a stronger, meaty flavour, compared to birds eviscerated prior to storage.

Mead et al (1983) showed that modification of the intestinal microflora affected poultry meat flavour thus demonstrating a link between diet, the internal microbial population and meat flavour.

Since the loss of the in feed antibiotic growth promoters much work is being done on the impact of diet and specific raw materials, on intestinal microflora and in the light of this connection the impact on meat flavour should also be measured.

Specific fatty acids can significantly influence meat flavour both through a positive route and a negative one. Alpha linolenic acid is associated with the production of strong flavours whereas linoleic acid is associated with milder flavours. However, both acids are susceptible to oxidation, the by-products of which, will have a significant negative impact on meat flavour. The level of vitamin E, a natural antioxidant, in the diet has been shown to significantly reduce the negative impact of such oxidation.

Chae et al (2006) demonstrated that increasing dietary vitamin E from 0mg/kg to 200mg/kg had a significant effect on muscle tocopherol content and TBARS level (Table 3).

Table 3 Effect of alpha tocopherol acetate level on muscle tocopherol level and thio-barbituric acid reactive substances (TBARS) in breast meat (from Chae et al 2006)

<table>
<thead>
<tr>
<th>Added alpha tocopherol acetate (mg/kg)</th>
<th>0</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle tocopherol (mg/kg)</td>
<td>0.17</td>
<td>0.24</td>
<td>0.26</td>
<td>0.27</td>
<td>0.28</td>
</tr>
<tr>
<td>TBARS (mg/kg)</td>
<td>0.32</td>
<td>0.31</td>
<td>0.30</td>
<td>0.27</td>
<td>0.25</td>
</tr>
<tr>
<td>10 days storage</td>
<td>2.72</td>
<td>2.64</td>
<td>2.61</td>
<td>1.62</td>
<td>1.44</td>
</tr>
</tbody>
</table>
Appearance

In many respects the appearance of the poultry meat may be regarded as the most important of all the quality parameters since it is very often the first impression which determines whether or not the produce will be selected for purchase.

Appearance will be influenced by colour and the absence of any abnormal physical imperfections.

In most cases, poultry meat will be sold with the skin on, either as a whole carcass or skin on portions, and therefore skin colour will be a prime quality parameter.

Geographical differences exist regarding the preference for different skin colours, which are largely determined by the historical availability of different feed ingredients. Countries which are traditional corn users, have a preference for yellow skinned birds whereas countries feeding predominantly wheat have a preference for white skinned birds.

The colouration of the skin is achieved via the supply of xanthophylls via the feed, however the bird also requires the genetic ability to absorb and deposit the pigments in the skin.

With increasing specialisation in the poultry industry, niche markets have opened up for differentiated products. Therefore, in the UK there is a small demand for premium “corn fed” product with yellow skin colouration. Due to the fact that these products are perceived to be different, they are regarded as high quality and command a premium price. Correct feeding of a specific diet is required to achieve the desired colouration.

The colour of the meat itself is less directly influenced by the diet or feeding system, and an excellent review by Fletcher (2002) covers the main influencers. Muscle pH and meat colour are highly correlated, with low pH generally producing a pale meat colour and high pH resulting in a much darker colouration. It is thought that pH has its effect through its influencing the various haem reactions in the muscle which are pH dependant.

The level of myoglobin in the meat will influence the “redness” colouration and specifically the balance between the various myoglobin complexes, ie oxymyoglobin will produce a characteristic bright red colour whereas metmyoglobin will impart a browner colour.

With the clear involvement of pH in muscle colouration it is apparent that any of the feeding practices previously described, i.e. feed withdrawal prior to slaughter, that are designed to prevent rapid pH fall post mortem, will also affect meat colour.

During growing there is the opportunity for unwanted physical damage to occur to the carcass. Some of them may be indirectly influenced by the diet and therefore they may be controlled through optimised feeding.

Breast blisters and hock burn are probably the most common reasons for carcass downgrade and have a significant negative effect on meat quality.

Tucker and Walker (1999) produced a good review of the main contributory factors to hock burn in broilers and highlighted stocking density, environment, drinker design and nutrition as all playing a part.

Skin lesions are generally caused by excessive contact between the skin and wet, corrosive litter. It is well known that diet can directly influence litter moisture content through high mineral level, excessive or poor quality protein and poor fact quality.

In a trial by Bray (1985) it was shown that the effect of these can often be additive (Table 4).

Poor fat quality with low digestibility has been shown to produce dark, sticky litter and a higher incidence of hock burn (Table 5).

Enzyme use has also been shown to improve litter quality via the breakdown of non starch polysaccharides.

Table 4 The effect of protein quality and sodium level (%) on litter nitrogen content (%) (Bray 1985)

<table>
<thead>
<tr>
<th>Sodium Level (%)</th>
<th>Good (pH)</th>
<th>Protein Quality Mixed (pH)</th>
<th>Poor (pH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.129</td>
<td>5.72</td>
<td>6.43</td>
<td>7.53</td>
</tr>
<tr>
<td>0.267</td>
<td>6.08</td>
<td>6.60</td>
<td>7.55</td>
</tr>
</tbody>
</table>
Bone porosity can influence meat appearance through leakage into the muscle causing “black bone”. Dietary programmes designed at optimising bone structure (calcium, phosphorous, vitamin D₃, 25-hydroxycholecalciferol) have shown improvements in meat appearance and customer acceptance (Korver and Saunders-Blades 2005).

### Nutritional Quality

Poultry meat has rightly gained significant market popularity due to it being a lean meat with a favourable (unsaturated) fatty acid profile.

Feeding regimes have focused heavily on optimising growth rate and cost of production and therefore high energy diets are generally used to maximise weight gain and minimise feed conversion ratio. One of the consequences of this approach is that with increasing growth rate there is a parallel increase in carcass fat content.

Saleh et al (1997) showed that through increasing the calorie to protein ratio of the diets fed, by feeding different levels of starter and finisher, they could increase the abdominal fat percentage from 3.84% to 4.41%. Although the fat pad is discarded during evisceration there is likely to be a parallel increase in subcutaneous fat and this may have a negative impact on the healthy image of poultry meat. Work by Bartov (1998) has shown that the fat content of the chicken thigh can be increased by alterations to the energy, protein ratio.

High energy diets can be used advantageously, providing that the amino acid content is increased pro rata in order to ensure an optimum calorie to protein ratio. Hess (2004) demonstrated that carcass fat content can be reduced through the use of higher amino acid densities.

A better understanding of the true utilisation of energy and the true digestibility of amino acids will help in our ability to formulate diets for optimum carcass composition and therefore the on-going development of net energy and ileal digestible amino acid data is to be welcomed.

Fatty acids in the feeds of poultry are absorbed unchanged and therefore the fat make up of the poultry meat can be directly influenced by the dietary fat type fed.

Table 6 shows data from Chanmugam et al (1992) where different dietary oils clearly influenced the fatty acid composition of the carcass fat.

<table>
<thead>
<tr>
<th>Corn Oil</th>
<th>Linseed Oil</th>
<th>Menhaden Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>C18:2 u-6</td>
<td>37.5</td>
<td>21.4</td>
</tr>
<tr>
<td>C18:3 u-3</td>
<td>1.3</td>
<td>21.9</td>
</tr>
<tr>
<td>C22:5 u-3</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>C22:6 u-3</td>
<td>0.16</td>
<td>0.28</td>
</tr>
</tbody>
</table>

It is therefore evident that dietary manipulation of carcass fat composition is possible and this is already being exploited commercially with the production of high omega 3 chicken meat.

As mentioned elsewhere in the paper, the fatty acid composition will also impact on meat flavour both positively and negatively if oxidation occurs, and therefore the adequate supply of biological antioxidants such as Vitamin E must be emphasized.

There is growing interest in the production of functional foods where nutrient composition is adjusted to provide a benefit to the consumer. Omega 3 fatty acid enrichment has already been mentioned and another area gaining interest is selenium supplementation (Yarozhenko et al 2004).
Selenium levels can be increased in poultry meat via the diet and already selenium enriched chicken is commercially available in many Asian countries.

Safety

The consumer expects that any food products available for sale in the shops is safe for the purpose intended i.e. consumption. It is therefore hard to turn the issue of safety into a positive attribute, however, if things go wrong the potential negative impact is considerable. It is therefore sensible to ensure that everything is done to ensure that the product is as safe as possible.

The feeding system used for poultry production can have a significant effect on product safety as the feed is a potential vector for residues and can also influence the potential for bacterial contamination of the processed carcass.

Salmonella and campylobacter are perceived as being the two most important zoonotic bacteria. Lister (2002) reported that on average, 50% of poultry carcasses are contaminated with campylobacter and it is considered that spoilage from the gastrointestinal tract during processing is the primary route of infection.

Feed withdrawal prior to slaughter has already been discussed as a potential way of improving poultry meat texture and flavour, however, the initial reason for implementing feed withdrawal was to ensure that the gastrointestinal tract was empty at slaughter and therefore the risk of bacterial contamination of the carcass was reduced.

The length of the feed withdrawal period is significant in achieving low levels of carcass contamination.

If the withdrawal period is too short (<6 hours, feed withdrawal to slaughter) then the GIT may still be full of feed and water and susceptible to damage by the evisceration equipment due to its physical size (Northcutt, 2001). However Bilgili and Hess (1997) showed that if the feed withdrawal period extended over 14 hours then the tensile strength of the GIT decreased to the point where breakage may easily occur. They also demonstrated that the gall bladder increased in size with time leading to an increased chance of bile spoilage.

Dietary regimes have also been investigated to try to reduce the level of bacteria within the gastrointestinal tract. Jin and Hruby (2003) demonstrated that the use of exogenous enzymes reduced the level of both salmonella and campylobacter in the caecum of broilers, fed both corn and wheat based diets. Khaksefidi and Rahimi (2005) examined the salmonella and campylobacter levels on carcasses of broilers fed either a control diet or the control supplemented with a mixed bacterial probiotic. Birds fed the probiotic showed a significant reduction in the level of carcass campylobacter and a reduction from 100% contamination for salmonella to 40% contamination.

Food contamination scares in the past have had significant negative effects on consumer confidence and Grashorn (2005) summarises many of the key issues in this area.

Legislation is in place to regulate the level of contaminants in animal feed and animal products will be regularly screened for the presence of both contaminants and residues.

Data generated within the UK by the Medicines Act Veterinary Information Service (MAVIS) shows the coccidiostat group of compounds to be the area of most concern (Table 7).

<table>
<thead>
<tr>
<th></th>
<th>% of samples in excess of action limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1999</td>
</tr>
<tr>
<td>Pesticides</td>
<td>0 (434)</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>3.6 (249)</td>
</tr>
<tr>
<td>Anti-microbials</td>
<td>0 (1102)</td>
</tr>
<tr>
<td>Mycotoxins</td>
<td>0 (31)</td>
</tr>
<tr>
<td>Coccidiostats</td>
<td>6.1 (774)</td>
</tr>
</tbody>
</table>

In 2005 data shows a reduction in residues compared to 1999 however at 4.2% there is still work to be done.
Withdrawal diets are commercially available for use prior to slaughter. These diets are non-medicated and must be used for the required period of time, determined by the legal withdrawal period of any compound previously used.

Feeding systems should always allow for the use of such diets and it is the responsibility of the farmer to ensure that all medicated feed is clear of the feed tract and that the feeding system is drawing from the correct feed bin, in advance of the required withdrawal period.

The withdrawal period is set to ensure that any residue is below the MRL (maximum residue limit) however, low levels in excess of the detection limit, but below the MRL may still be found.

Work by Mortier et al (2005) clearly showed the presence of the anticoccidial diclazuril in both breast and thigh at levels well below the MRL, nine days after feed withdrawal (legal withdrawal period – 5 days).

Reference


