

Determinants of Ultimate pH of Meat and Poultry

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After slaughter, during conversion of muscle to meat, anaerobic glycolysis results in a pH decline. The rate and extent of pH decline are major determinants of meat quality. A higher ultimate pH (pHu) is associated with darker color, reduced drip loss (higher water-holding and water-binding capacity) and increased firmness (Warner, 1994; Pearson and Young, 1989). Pork from animals carrying the RN-gene has a lower pHu than from animals without the RN-gene. RN meat has a lower water-holding capacity and paler color than non-RN meat (Fernandez et al., 1992; LeRoy et al., 1990; Naveau, 1986). Pale broiler breast meat has lower water-holding capacity, resulting in 8-10% lower cooking yields (van Laack et al., 2000). The pale color and reduced water-holding capacity correlate with a lower pHu; pale broiler breast meat has a pHu of 5.70 vs 5.96 in normal-colored meat (van Laack et al., 2000). Pale, soft, exudative (PSE) pork is the result of a rapid post-mortem pH decline. The pHu of PSE pork is similar to that of normal pork. If the pHu is 5.7 or higher, a rapid post-mortem pH decline does not result in PSE pork (Fernandez et al., 1994). These results suggest that producing meat at a 'higher' pHu will result in acceptable quality by reducing the risk for PSE and high drip losses. Some packers already use pHu as quality-sorting criterion. To consistently produce meat with a specific pHu, we need to know what factors determine pHu.

Muscle glycogen level at death largely determines pHu. After slaughter, the muscle converts glycogen into lactate and energy. Lactate formation reduces pH (Greaser, 1986). Muscles with the same lactate concentration may have a different pHu (van Laack and Kauffman, 1999; van Laack et al., 2000). Why the same lactate concentration results in a different pHu is not clear. Possibly, different muscles have different buffering capacity and/or differ in the concentration of strong ions such as Mg^{+2} , Ca^{+2} , and Cl^- , two factors that influence the pH of a system (Stewart, 1981).

Measurement of glycogen concentration in the muscle is complicated. Cutting or touching the muscle activates the muscle metabolism, specifically glycogen breakdown. Thus, measured muscle-biopsy glycogen concentration is always lower than actual muscle glycogen concentration. Glycolytic potential (GP) provides a more accurate measure of glycogen level in the living muscle. GP includes all the components that can potentially be converted into lactate, representing the 'substrate' concentration of the muscle (Monin and Sellier, 1985).

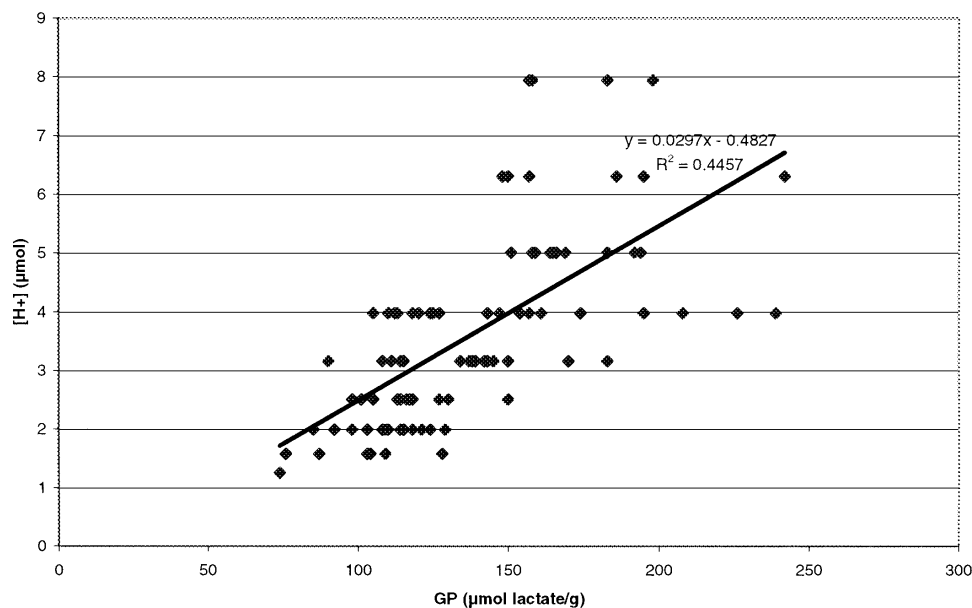
While a major determinant of pHu, GP differences cannot fully explain differences in pHu (van Laack and Kauffman, 1999). Figure 1 includes data from a study on the relationship between pHu and GP. Since pHu is the negative log of H^+ concentration, its relationship with GP (expressed in μmol lactate/g) is not linear. To analyze the relationship between the two factors, pHu was converted to H^+ concentration. As can be seen in Figure 1 (adapted from Van Laack and Kauffman, 1999), a higher GP tends to result in a higher H^+ concentration (lower pHu); variation in GP explains only 40% of the variation in H^+ concentration. Similar results have been reported by Maribo et al. (1999).

The pHu of horse meat and beef is similar, but glycogen levels in horse meat are higher than those in beef. The GP of pork from pigs that carry the RN-gene is more than 25% higher than the GP of pork from pigs without the RN-gene, whereas the difference in pHu is only about 0.1 units (Monin et al., 1987). Lactate production (pH decline) seems to stop before all glycogen is consumed (Monin et al., 1987; van Laack and Kauffman, 1999). Why does lactate production stop despite substrate availability?

Using a reconstituted glycolytic system containing all the enzymes and substrates found in muscle, Scopes (1974) studied the influence of variables such as substrate concentration and enzyme activity on the pHu. He concluded that if glycogen (GP) is not limiting, pHu is influenced by the activity of two glycolytic enzymes: glycogen phosphorylase and AMP-deaminase. Glycogen phosphorylase a, the active form of phosphorylase, influences the conversion of glycogen into glucose-1-phosphate and, thus, the substrate availability.

Glycolysis requires glucose, ADP, and phosphate to proceed (Greaser, 1986). Glycolysis stops if either glucose or ADP runs out. AMP-deaminase converts AMP into IMP. Thus, adenine nucleotides (ADP, AMP, and ATP) are irreversibly converted to IMP. As a result, ADP is no longer available for

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rephosphorylation and glycolysis stops. Scopes (1974) found that increasing amounts of AMP-deaminase resulted in higher pHu. The activity of phosphorylase and AMP-deaminase and their relationship with pHu in meat has not been studied.

Creatine phosphate (CP) levels also influence pHu (Scopes, 1974). A stimulated muscle immediately responds by regenerating ATP through conversion of ADP with CP to ATP and creatine. Creatine is an alkaline substance; its presence may limit pH decline. Different muscles contain different levels of CP (Pearson and Young, 1989). Also, ante-mortem stress reduces the level of CP in muscle at slaughter, possibly leading to lower pHu for the same level of lactate.

Muscle contains two different forms of glycogen: macroglycogen and proglycogen. These two types differ in protein content, size and solubility; proglycogen, with a MW of 400 kDa, contains about 10% protein and is acid insoluble, while macroglycogen has a MW of 10^7 Da, contains less than 1% protein and is acid soluble (Lomako et al., 1991). Results by Adamo et al. (1998; humans) and Lomako et al. (1991; rodents) indicate that increases in glycogen above a certain concentration mainly result from increases in macroglycogen levels. Adamo and Graham (1998) suggested that proglycogen is the precursor of macroglycogen. Glycogen stored as proglycogen is more readily available for energy production. Currently, we can only speculate about the presence of two glycogen forms in pork. Further research in this area may provide an explanation for the lack of correlation between pHu and glycogen levels.

Conclusions

Ultimate pH is a major determinant of meat quality. Knowledge about factors that determine ultimate pH is essential if we want to actively control ultimate pH of meat. Glycolytic potential, as measure of substrate concentration for post-mortem glycolysis, is a major determinant of pHu. However, the relationship between glycolytic potential and pHu is far from perfect. The contribution of other factors such as phos-

phorylase and AMP deaminase enzymes and the possible presence of two glycogen forms needs to be evaluated.

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