Metabolic Factors Influencing Ultimate pH

Riëtte L.J.M. van Laack

Ultimate pH and Pork Quality

Ultimate pH (pHu) of pork is a major quality determinant. Higher pHu is associated with darker color (Kauffman et al., 1993). A lower pHu is associated with higher drip loss (Kauffman et al., 1993). Pale, soft, exudative (PSE) and red, soft, exudative (RSE) pork is undesirable because it has a low water-holding capacity. At pHu above 5.7, PSE and RSE pork quality problems do not occur (Fernandez et al., 1994). Production of pork with pHu above 5.7 would result in constant-quality meat with high water-holding capacity and reddish-pink color. The National Pork Producers Council recommends a pH above 5.7 for the production of "good" quality pork (NPPC, 1998).

How can we produce meat with a specific pHu? Only when we know what factors determine pHu. In the following, I briefly review factors that may influence pHu of pork.

Possible Determinants of Ultimate pH

Postmortem, glycogen is converted into lactate and energy. The lactate formation causes the postmortem pH decline (Greaser, 1986). Thus, pHu would be expected, at least in part, to be a function of muscle glycogen level at death.

Although glycogen concentration is related to pHu, it does not fully explain pHu variation. Studies by Warriss et al. (1989), Fernandez et al. (1992), Maribo et al. (1999), and van Laack and Kauffman (1999), demonstrate that glycolytic potential [a measure of glycogen concentration (Monin and Sellier, 1995)] accounts for a maximum of 40% of the difference in pHu of pork loin.

The glycogen concentration of muscle from pigs carrying the RN-gene is more than 25% higher than that of pork from pigs without the RN-gene. The difference in pHu of RN and non-RN pork 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). Clearly, factors in addition to glycogen concentration influence pHu.

Scopes (1974) evaluated factors that may influence pHu. Using a reconstituted muscle system, he found that creatine phosphate influenced pHu. Higher creatine phosphate levels were associated with higher pHu. Stress shortly before slaughter results in lower creatine phosphate levels immediately after slaughter. Possibly, variation in pHu results from differences in creatine phosphate levels at slaughter.

In the same study, Scopes (1974) evaluated the influence of enzyme concentration on pHu, finding that pHu was determined by the activity of two enzymes: glycogen phosphorylase and AMP deaminase. Higher levels of glycogen phosphorylase levels resulted in a lower pHu of the system.

Glycolysis requires glucose, ADP and phosphate (Greaser, 1986). Glycolysis stops if either glucose or ADP runs out. AMP-deaminase converts AMP to IMP. Scopes (1974) reported that higher amounts of AMP-deaminase resulted in higher pHu

R.L.J.M van Laack
Dept. Food Science and Technology
University of Tennessee
2509 River Road
Knoxville, TN 37996
rlaack@utk.edu or riette@att.net

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Determinants of Ultimate pH of Pork *Longissimus* Muscle

Until recently, the results by Scopes (1974) had not been tested *in vivo.* Van Laack et al. (2001) reported on their observations in pork muscle. They measured glycolytic potential, creatine-phosphate levels, phosphorylase activity, AMP-deaminase activity and pHu in 53 pork loins. (Table 1).

Glycolytic potential explained 37% of the differences in pHu (higher glycolytic potential– lower pHu). A higher phosphorylase a activity correlated with a lower pHu (r=-0.47). AMP deaminase activity explained about 10% of the differences in pHu. When combining several factors, phosphorylase a and glycolytic potential explained 50% of the variation in pHu. What explains the remaining 50%?

Pro and Macro Glycogen and Ultimate pH

In the 1950's researchers recognized two forms of glycogen: free and bound (Bloom et al., 1950). More recently the terms macroglycogen and proglycogen have been introduced. Proglycogen has a MW of 400 kDa, contains 10% protein and is acid insoluble. Macroglycogen has a much larger MW

TABLE 1. Pearson correlation coefficients (r) among biochemical characteristics of pork *longissimus* muscle (n=53).

	GP	CP	Pa	AMPD
pHu	–0.61	NSa	–0.47	0.32
Glycolytic potential (GP)b	1.00	0.29	0.47	–0.47
Creatine phosphate (CP)b		1.00	0.69	–0.27
Phosphorylase a (Pa)c			1.00	–0.42
AMP-deaminase (AMPD)c				1.00

a NS=not significant (p<0.05)
b µmol lactate/g
c Units = 1 µmol per min at 30°C

(10^7), contains less than 1% protein and is acid soluble (Lomako et al., 1991). Adamo and Graham (1998) suggested that proglycogen is the precursor of macroglycogen. Glycogen stored as proglycogen is readily available for energy production. Macroglycogen must be converted to proglycogen before it can be used (Lomako et al., 1991; Adamo et al., 1998). We speculated that pHu might be related to proglycogen rather than to macroglycogen. In the same samples as mentioned above, we analyzed the concentration of macro- and proglycogen and calculated the relationship with pHu. As reported by others (Bloom et al., 1950; Charpentier et al. 1966) pork muscle contains the two forms of glycogen. However, we did not find a relationship between proglycogen and pHu.

Further research on how postmortem conditions influence the conversion of macroglycogen to proglycogen is needed.

Rate of Glycolysis (ATP-ase activity) and Ultimate pH

ATP-ase converts ATP into ADP, Pi and energy. Rigor onset occurs when no ATP is left for contraction and relaxation (Greaser, 1986). As long ADP and glycogen are present, ATP can be produced and glycolysis proceeds. Rigor onset occurs if either glycogen or ADP is depleted. Consequently, if at pHu some glycogen remains, glycolysis must have stopped because of ADP depletion.

A higher ATP-ase activity will result in a faster depletion of ATP, and a faster onset of rigor. Some researchers have suggested that higher ATP-ase activity results in lower pHu and vice versa. White fibers have lower pHu and higher ATP-ase activity; is this a causal relationship? In a model system, ATP-ase levels did not affect pHu (Scopes, 1974).

How might ATP-ase be related to pHu? The lower pHu in fast-glycolyzing conditions and higher pHu under rapid chilling (slower glycolysis) suggest that ADP depletion is influenced by rate of glycolysis. We may need to look at the balance between ADP production (via ATP-ase) and ADP depletion. At high ATP-ase activity ADP production is rapid. ADP will be reconverted to ATP via glycolysis and some will be lost via AMP deaminase. The ratio of what will be converted to ATP and what will be converted to AMP and then to IMP depends on the activity of the enzymes involved.

Conclusion

We have some understanding of possible determinants of meat pHu.. Substrate concentration (glycogen level) explains 40-50% of the variation in pHu. We do not know the importance of the glycogen availability. A detailed analysis of various metabolites of glycolysis (glucose-1-phosphate, glucose-6-phosphate etc) and ATP, ADP, IMP and other products may give information about additional factors that influence meat pHu. Since ADP depletion determines when glycolysis stops, a detailed analysis of factors that influence this depletion seems warranted. We hypothesize that when ATP-ase activity is lower, the depletion of ADP via AMP, IMP route will be faster than the regeneration of ATP. In other words, at slower ATP-ase activity adenosine depletion is relatively faster and, thus, ultimate pH will be higher.

Ultimate pH of meat is a main quality determinant. A better understanding of the determinants of meat pHu will allow better prediction and possibly allow control of meat quality. Once we know which mechanisms control pHu, we may be able to more effectively select animals that consistently produce meat with the desired pHu.

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