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THE INFLUENCE OF PRE-SLAUGHTER STRESS ON MUSCLE SHORTENING, ISOMETRIC TENSION AND MEAT TENDERNESS OF BEEF.

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Background

Meat tenderness is considered to be one of the most important quality parameters of beef meat for the consumer. It is affected by a number of variables such as pre-slaughter stress, rigor temperature, ageing, electrical stimulation and the age of the animal. One of the most crucial of these variables is the rigor temperature, where Locker and Hagyard 1963 were the first to find a warm and cold shortening region. Using an apparatus designed by the Swedish Meat Research Institute (SMRI), where both the isometric tension and the shortening of the meat during the rigor process were continuously followed as a function of time in a cell of constant temperature, it was found that cold and warm shortening were induced below and above 10 and 18°C, respectively (Hertzman *et al.*, 1993; Olsson *et al.*, 1994). Moreover, it was shown in these investigations that the coefficients of correlation between shortening and sensorially determined tenderness (14 days aged) varied between 0.72*-0.94*** for the muscles *M. semitendinosus, M. semimembranosus* and *M. longissimus dorsi.*

The influence of long term stress, resulting in a lower glycogen level and thereby a higher ultimate pH, on tenderness has been the subject of controversy in the literature. Most researchers have observed a curve-linear relationship between tenderness and pH_u with a minimum around pH 5.8-6.0 (Bouton *et al.*, 1973; Fjelkner-Modig & Rudérus, 1983; Purchas, 1990). There have been different suggestions in the literature to explain the curve-linear behaviour, varying from pH-dependent proteolytic activities to pH-dependent shortening. According to Purchas (1990) only 50 % of the increase in shear force values could be explained by a shorter sarcomere length. In those more practical experiments, however, temperature control in the muscle was probably difficult to obtain and, as this variable strongly influences the shortening, the possibly pH-induced shortening cannot be differentiated from temperature-induced shortening. Therefore, the aim of this study was to determine the influence of pre-slaughter stress, as measured by an elevated pH_u (5.45-5.85), on rigor parameters such as muscle shortening and isometric tension, using the newly developed apparatus at the SMRI, at two controlled temperatures of 12 and 35°C. This type of investigation has already been carried out for pork (Fernandez & Tornberg, 1994) and this paper will present the results obtained for beef. Furthermore, the rigor parameters will be correlated with the sensory evaluated tenderness of meat aged for 14 days.

Material & Methods

M. longissimus dorsi from 16 young bulls of the Swedish Lowland breed with overnight lairage was selected for this experiment. The range of pH_u (5.45-5.85) was produced by selectively choosing the bulls whose behaviour showed a tendency for stress. The muscles were excised from the carcasses about 45 min after bleeding and the samples for the rigor measurements were cut out immediately. The 1.5 cm thick transverse slices of the muscle intended for sensory evaluation were vacuum-packed and incubated in a water bath at 35 or 12°C until pH_u was reached and thereafter aged at +4°C for 14 days.

Samples for pH, adenosine triphosphate (ATP) and creatine phosphate (CP) (Hertzman *et al.*, 1993) were taken regularly from a muscle piece kept at the two temperatures studied. Two muscle pieces for the isometric tension and shortening measurements were prepared as described elsewhere (Hertzman *et al.*, 1993). The isometric tension, expressed as force per unit area, and shortening, expressed as percentage decrease in muscle piece length, were registered every 15 min. All measurements were carried out in duplicate in a closed chamber with a temperature accuracy of ±0.5°C. The meat for sensory analysis was cooked in a water bath at 74°C for 60 min, reaching 74°C end point temperature, and served immediately to the assessors after cooking. This sensory analysis was performed by a trained expert panel of 12 men and women. Tenderness was judged on a nine-point scale (1=very tough, 9=very tender).

Results & Discussion

Figure 1 shows a typical appearance of the time course of rigor as measured by the shortening/isometric tension apparatus. It is clear that both the rigor temperature and pH_u have a major influence on the shortening and isometric tension of the muscle during the rigor process, Figures 1 and 2. At 12°C and a normal pH_u a minimum in muscle shortening (≈5 %) is obtained. However, the shortening increases strikingly with pH_u, a shortening of ≈30 % is obtained for the muscle at pH_u=5.85. This is comparable with a warm shortened muscle at normal pH_u. The correlation between pH_u and shortening is very good for both the temperatures studied, r=0.82* and r=0.88**, respectively. This is a much better correlation than that obtained for pork, where the shortening pH_u-dependencies at 12 and 35°C were $r=0.44^{ns}$ and $r=-0.26^{ns}$, respectively (Fernandez & Tornberg, 1994), but in that investigation pH_u ranged from 5.35 to 6.68.

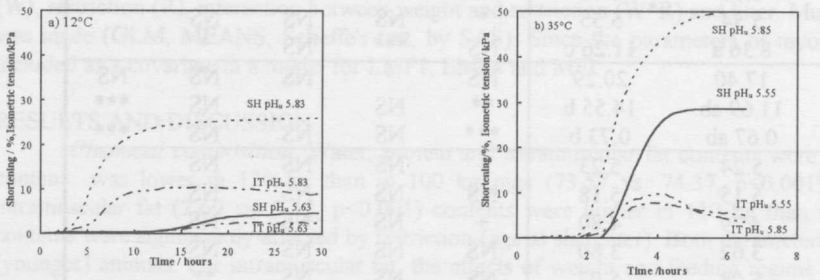

Figure 1. Shortening, SH (%), and isometric tension, IT (kPa) of LD as a function of post-mortem time. Two rigor temperatures and two different pH_u are shown, a; 12°C and b; 35°C.

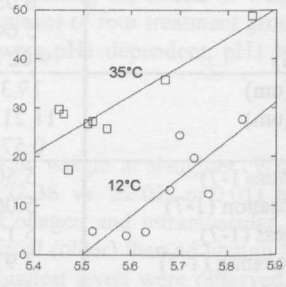

Figure 2. Maximum shortening as a function of pH_u at two rigor temperatures; O:12°C and □:35°C.

In Table 1 the influence of pH_u and temperature (T) on the course of rigor can be compared using the coefficients obtained from normalised multiple linear regression analysis, in accordance with the following model [1].

$$Y = k_0 + k_1 * pH_u + k_2 * T + k_3 * pH_u * T \qquad [1]$$

where Y is the variable studied.

Table 1. Coefficients from the regression analysis of the influence of pH_u and rigor temperature on time events during the course of rigor and other measured parameters, (n=16). R^2 = degree of explanation

Variables	k_0	Temperature k_0	pH_u k_2	Temp.*pH_u k_3	R^2
Time event (hours)					
Shortening onset	3.6***[a]	-2.7***	-4.1**	3.6**	0.74**
Isometric tension onset	1.6*	-1.3^{ns}	-1.4^{ns}	1.1^{ns}	0.30^{ns}
End of shortening.	17.1***	-11.5***	-3.5*	3.9*	0.96***
End of isometric tension	13.2***	-8.1***	-1.6^{ns}	1.4^{ns}	0.89***
End of ATP depletion	14.1***	-8.1***	0.4^{ns}	0.1^{ns}	0.90***
End of pH decrease	15.6***	-9.8***	-1.3^{ns}	0.6^{ns}	0.97***
ATP level at shortening onset (µmol/g)	4.2***	0.7*	0.9^{es}	-0.3^{es}	0.37^{es}
pH at shortening onset	6.5***	0.1^{es}	0.3*	-0.1^{es}	0.3^{es}
Maximum shortening (%)	23.7***[a]	11.9***	13.7***	-1.9^{ns}	0.85***
Maximum isometric tension (kPa)	8.9***	3.1***	2.6*	-1.6^{ns}	0.66**

a) Significance levels: *** p<0.001; ** p<0.01; * p<0.05; ns=not significant.

Only shortening onset and end of shortening pH_u have any significant influence on the time parameters, which is seen in Table 1 and illustrated in Figure 3. However, the pH dependence is only valid at 12°C , where the shortening starts and ends earlier at higher pH_u. The independence of pH_u at 35°C probably originates from the fact that warm-shortening is such a quick process that it dominates the kinetics in the pH-induced shortening. For all the time dependent rigor parameters studied, temperature had a significant influence in almost every case and had the largest impact compared to pH_u, except in the case of shortening onset, where the opposite was observed. ATP depletion seems to be mainly temperature controlled and does not give any clue to the reason for pH-induced shortening. According to Table 1, pH at the onset of shortening varies with pH_u, which indicates that the Ca^{2+}-release, initiating shortening, seems in these experiments to be controlled by pH itself and not by any lowered ATP-levels.

The sensory tests show a good correlation between pH_u and the measured meat tenderness at a rigor temperature of 12°C, Figure 4. However, at 35°C meat tenderness is more or less independent of pH_u, most probably due to a severe warm-shortening of the muscle, which seems to dominate the pH-induced shortening. An important observation is that pH_u has a large influence on the tenderness of meat at a rigor temperature of 12°C such that an increase in pH_u from 5.5 to 5.85 can lead to a decrease in meat tenderness from 7 to 4, even if the cooling procedure during post-mortem has been optimal. The correlation between meat tenderness measured after 14 days of ageing and the shortening and isometric tension at both temperatures was r=-0.60* and r=-0.82*** (Figure 5), respectively, which suggests that pH-induced shortening does exist and is important for sensorially evaluated tenderness. The correlations obtained in this investigation were also better than the relationship obtained by Purchas (1990) between tenderness and sarcomere length, which may be due to better temperature control in this study.

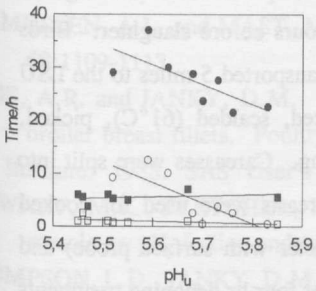

Figure 3. Shortening onset and end of shortening as a function of pH_u at two rigor temperatures; O:12° and □:35°C.

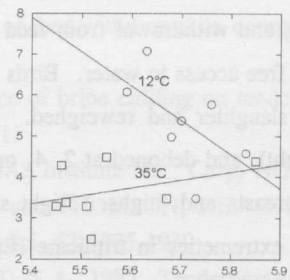

Figure 4. Sensorially determined meat tenderness as a function of pH_u measured at two rigor temperatures; O:12°C and □:35°C.

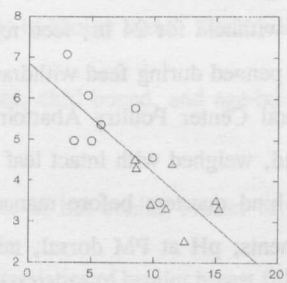

Figure 5. Sensorially determined meat tenderness as a function of maximum isometric tension(kPa) measured at the two rigor temperatures; O:12°C and □:35°C

Conclusions

The affects of pre-slaughter stress, measured as an elevated ultimate pH (pH_u 5.45-5.85), on muscle shortening, isometric tension and meat tenderness (14 days) were studied at two constant rigor temperatures, 12 and 35°C. Muscle shortening was shown to increase with pH at both temperatures. The meat tenderness decreased with increasing pH at 12°C but was more or less independent at 35°C. All samples at 35°C showed a low tenderness (2.5-4.5), most probably dominated by the warm shortening of the muscle. Significant relationships were found between sensorially determined meat tenderness and shortening (r=-0.60**) and isometric tension (r=-0.82***), respectively.

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