THE INFLUENCE OF POSTMORTEM CHANGES IN BOVINE MUSCLE ON THE WATER-HOLDING CAPACITY OF BEEF. II.POSTMORTEM STORAGE OF MUSCLE AT VARIOUS TEMPERATURES BETWEEN 0 AND 30°C

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INTRODUCTION

In the preceeding paper of Hamm et al. (1980) the influence of postmortem metabolism and development of rigor mortis occuring in intact bovine neck muscles at 20°C on the water-holding capacity (WHC) of unsalted and salted muscle homogenates was reported. These studies had been carried out with special regard to the use of hot-deboned beef for sausage production. However, the influence of postmortem storage of beef at various temperatures on WHC is also of practical interest, particularly the effect of storage at low temperature because under such conditions not only rigor mortis but also cold-shortening could influence the WHC of meat.

From earlier work it is known that lowering the temperature of bovine muscle from about 37°C (immediately after slaughter) to 6-8°C results in a contineous decrease in the rates of ATP turnover and glycolysis; a further decrease of tissue temperature down to the freezing point (about -1°C) causes an increasing acceleration of postmortem metabolism (Honikel and Hamm,1978; Jeacocke,1977). This phenomenon is known as "cold-shortening" because a fall of temperature from +10° to -1°C causes an increasing shortening of bovine muscle which results in a remarkable decrease of tenderness (Marsh and Lee,1966; Rowe,1974).

Cold shortening occurs before the onset of rigor mortis. Clear information on the influence of cold-shortening on the WHC of beef is not yet available. It would be of particular interest to know if there are differences between prerigor shortening, rigor-shortening and rigor mortis itself with regard to the effect on WHC of meat in terms of cooking loss of salted muscle homogenates, the latter presenting conditions which exist in sausage mixtures. Powell (1978) found that the drip loss of beef stored at temperatures where cold shortening occurs increased compared with beef kept at 10-15°C. Measuring the weight loss on cooking cold-shortened muscle, Locker and Daines (1974) observed no influence of cold-shortening. The same authors reported in a following paper (Locker and Daines, 1976) even a small increase in WHC on cooking cold-shortened muscle after onset of rigor mortis. Contrary to the latter result, Davey and Gilbert (1975) found a small increase in cooking loss as a result of cold shortening.

This enigma needed clarification. To do this it was necessary to distinguish between shortening, measured by decrease in sarcomere length, and rigor mortis, measured by decrease in extensibility of muscle.Rigor in neck muscle occurs at a tissue pH of 5.9 at 20°C (Hamm et al.,1980)as well as at other temperatures between 0° and 30°C (Honikel et al. unpublished). It was the main purpose of this investigation to find the optimum conditions for conditioning prerigor beef and to determine the length of time the hot-boned beef may be left at a given temperature and still obtain the benefit of a high WHC compared with conventionally chilled rigor or postrigor meat.

MATERIALS AND METHODS

The influence of conditioning temperature was studied in the lean bovine neck muscles, which were obtained within 30-40 min after slaughter, and divided into samples of about 100-200 g and about 1 cm thickness. One of the strips was analyzed before incubation; the other strips were sealed in polypropylene pouches and placed in a cryostat bath at the desired temperature. After 10-15 min incubation, the center of the samples had reached the bath temperature. At selected periods of incubation and after 24 hours p.m. a sample was taken for further investigation. Muscles from different animals had to be used to cover the temperature range between 0° and 30°C with several replicates for temperature, time of postmortem storage and tissue pH.

Methods for the preparation of unsalted and salted muscle homogenates at different times post mortem (p.m.),for the determination of pH value, sarcomere length and cooking loss (as a measure for WHC) were carried out as described in the preceeding paper (Hamm et al.,1980).

RESULTS AND DISCUSSION

In agreement with earlier results, we found a much higher rate of pH fall at 0.5°C during the first four hours p.m. than at 7° or 14°C (Fig.1) which is certainly due to an accelerated turnover of ATP (Newbold and Scopes, 1967; Honikel and Hamm,1978; Jolley et al.,1980). This phenomenon can be explained by an accelerated release of Ca^{2+}ions from the sarcoplasmic reticulum (SR) or from the mitochondria into the myofibrillar space; these Ca^{2+}ions in association with appropriate levels ot ATP initiate muscular contraction before the onset of rigor mortis (Newbold and Tume,1977; for further references see Hamm,1979) as is demonstrated in Fig. 2. Proof for the role of Ca^{2+} in the cold-shortening effect was furnished by Honikel and Hamm (1978).

Increased shortening of sarcomeres, caused by rising the tissue temperature above 16°C (Fig.2) was also accompanied by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, however, this acceleration of postmortem metabolism did not result in prerigor shortening (Fig.2, upper curve), probably because not enough free Ca^{2+} was released from calcium accumulating organelles. This assumption is supported by the fact that addition of EGTA does not lower the rate of ATP turnover at tissue temperatures above about 10°C (Honikel and Hamm,1978). Just before depletion of ATP which results in a release of Ca^{2+}, does rigor shortening occur (Fig.2, lower curve), as Locker and Daines (1975) also described. The accelerated postmortem metabolism at low temperatures lasted for few hours p.m. only; then the further decrease of pH at 0°C was much slower than at 7°C or higher temperatures (Fig.1; Winger et al.,1979).

The time necessary for reaching pH 5.9 i.e. the onset of rigor mortis (Hamm et al.,1980), decreases considerably with rising temperature (Fig.1 and 4) and we suggest, that after few hours at all temperatures studied similar amounts of Ca^{2+} are released. Apparently then the rate of postmortem metabolism is determined by the normal influence of temperature on biochemical reactions.

Another interesting finding is the fact that the WHC (cooking loss) of the intact muscle as well as of the unsalted muscle homogenates prepared prerigor is not influenced by the rate of postmortem metabolism (pH fall) or the degree of contraction in the prerigor or early rigor period but depends only on the pH itself; falling pH causes some decrease of WHC (Tables 1 and 2; Fig.3). It is of particular importance that the development of rigor mortis

Table 1 Percent cooking loss of intact muscle, unsalted and salted muscle homogenates at different incubation temperatures and different pH values of the intact tissues

Incub. temp. °C	pH 6.8			pH 6.1			pH 5.9			pH 5.5		
	intact muscle	homogenate[a] unsalted	salted	intact muscle	homogenate[a] unsalted	salted	intact muscle	homogenate[a] unsalted	salted	intact muscle	homogenate[a] unsalted	salted
0.5	34	52	24	42	58	36	44	59	40	-	-	55
4	34	50	16	40	53	31	41	55	34	44	60	51
5	36	53	20	41	56	32	42	56	37	45	57	50
7.5	37	51	28	40	56	29	42	57	35	45	60	49
10	27	49	22	38	55	28	40	55	35	45	55	51
14	33	53	22	39	54	22	41	55	22	44	58	53
17	32	49	21	40	57	36	43	57	41	44	58	54
20	37	48	27	42	58	36	43	58	40	44	60	51
20	35	42	16	39	50	24	41	52	27	43	57	48
23	33	55	31	40	57	32	42	59	33	44	59	54
24	37	47	26	44	58	33	46	59	34	53	59	50
27	37	53	28	39	57	32	40	58	34	42	60	47
30	35	52	26	41	56	32	42	57	34	45	60	56
$\bar{x}$	34.4	50.3	23.6	40.4	55.8	31.0	42.1	56.7	34.3	44.8	58.6	51.5
SD	2.8	3.4	4.6	1.6	2.3	4.3	1.7	2.0	5.2	2.7	1.6	2.7

[a]Homogenates were prepared after reaching the required pH in intact muscles. The salted homogenates contained 2 percent NaCl.

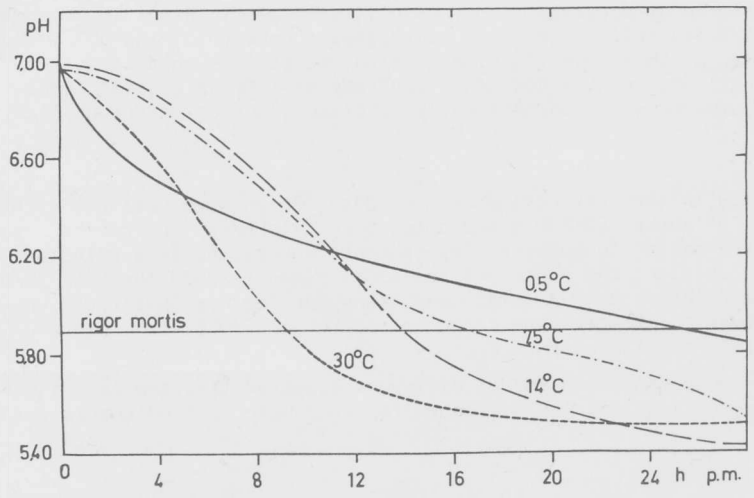

Fig.1 Relation between the pH fall in bovine neck muscle and the time post mortem at different temperatures.

Table 2 pH-dependent postmortem changes in cooking loss in intact muscle, unsalted and salted homogenates (from table 1).

	percent cooking loss/pH unit in the pH range		
	6.8-6.1	6.1-5.9	5.9-5.5
Intact muscle	8.5	8.5	6.7
Unsalted homogenate	9.1	4.5	4.7
Salted homogenate	10.6	16.5	43.0

(pH 5.9-5.5) did not have a significant influence on WHC. This observation is in agreement with the results obtained by Jolley et al.(1980) who measured WHC of the unheated tissue.

Striking results were obtained with salted muscle homogenates. The WHC of the salted muscle homogenates was higher than that of the unsalted ones, particularly in the prerigor state as one would expect according to the electrostatic theory of swelling (Hamm,1960,1972,1975). Before pH 5.9 was reached, i.e. during the prerigor phase, the influence of postmortem change of pH on the WHC was similar in the intact muscles to that in muscle homogenates either unsalted or salted (Tables 1 and 2, Fig.3). In this phase, the WHC of the intact tissue or muscle homogenates, measured at the sampe pH, was independent of incubation temperature (Table 1). Consequently, cold-shortening (prerigor contraction) did not exert an effect on WHC of muscle either intact or homogenized with or without addition of salt.

It should be pointed out that in these experiments cooking loss was measured not later than about 24 hours p.m. Preliminary results indicated that cold-shortening does influence water retention of intact unheated neck muscles (drip loss) after a longer period of ageing (Honikel et al., unpublished).

Contrary to the finding for unsalted muscle homogenates, the development of rigor mortis (pH 5.9-5.6) in the intact muscle resulted in a remarkable decrease of WHC of salted muscle homogenates, no matter at which temperature the muscle had gone in to the state of rigor (Table 1 and 2, Fig. 3). Similar results were obtained by Hamm et al. (1980) with muscles

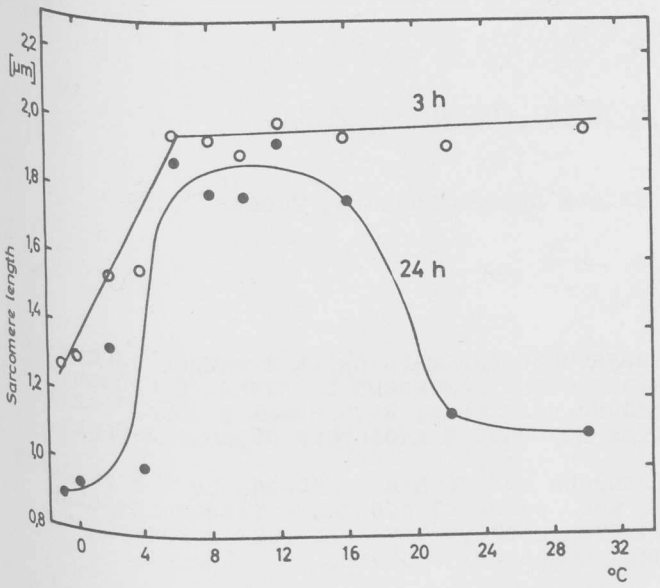

Fig.2 Sarcomere length of bovine neck muscles at 3 and 24 hours post mortem at different incubation temperatures.

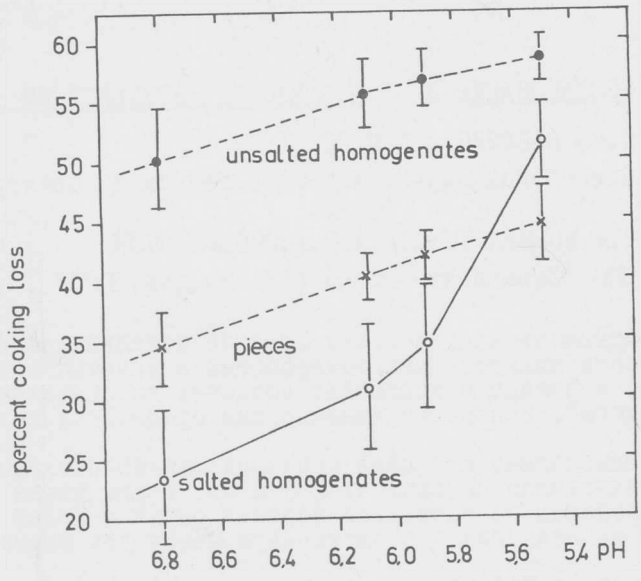

Fig.3 Cooking loss of intact muscles, unsalted and salted homogenates in relation to the post mortem pH fall in the intact muscle at temperatures between 0 and 30°C. The bars indicate the standard deviation.

stored at 20°C. The probable causes for the different behaviour of unsalted and salted muscle homogenates has been already discussed in the preceeding paper of Hamm et al. (1980).

We may conclude from our results that longitudinal changes of muscle occurring during contraction have much less influence on WHC than alterations caused by attraction between oppositely charged groups of adjacent molecules and particularly by cross-linking between myofilaments during development of rigor.

To preserve the high WHC of freshly slaughtered beef it is crucial that the meat is minced and salted before the onset of rigor mortis (Hamm et al., 1980). Therefore, it is of practical importance to know the time of postmortem storage after which rigor occurs at a given temperature. The length of this period depends on the temperature of muscle because the time necessary to reach pH 5.9 (onset of rigor in neck muscles) increases linearly with falling temperature (Fig. 4).

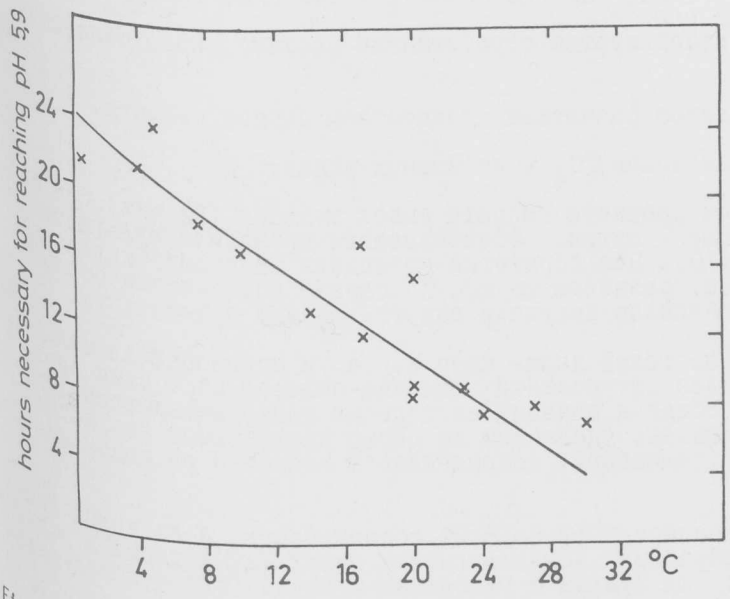

Fig. 4 Influence of temperature of incubation of bovine neck muscles on the time necessary for reaching pH 5.9.

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