THE INFLUEN

URACE OF POSTMORTEM CHANGES IN BOVINE MUS	SCLE ON THE WATER-HOLDING	CAPACITY OF BEEF. II.POSTMORTEM
UF MUSCLE AT VARIOUS TEMPERATURES BETWEEN	I O 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 occurrence of Hamm et al. (1980) the influence of postmortem metabolism and development of rigor <sup>Nortis occurring in intact bovine neck muscles at 20°C on the water-holding capacity (WHC) of unsalted and salted <sup>Noscle</sup> home</sup> Muscle homogenates was reported. These studies had been carried out with special regard to the use of hot-deboned been for the storage of beef at various temperatures on WHC  $b_{eef}^{sole}$  for sausage production. However, the influence of postmortem storage of beef at various temperatures on WHC  $b_{eef}^{sole}$  for sausage production. However, the influence of storage at low temperature because under such condition for sausage production. However, the influence of postmortem storage of beef at various temperatures on the for sausage production. However, the influence of storage at low temperature because under such conditions of practical interest, particularly the effect of storage at low temperature because under such conditions only between the WHC of meat. 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) work it is known that lowering the temperature of ATP turnover and glycolysis; a further de $s_{aughter}^{VM}$  earlier work it is known that lowering the temperature of bovine muscle from about 3/0C (immediately arter  $c_{rease}$  of to 6-8°C results in a contineous decrease in the rates of ATP turnover and glycolysis; a further de-mortem metabolism (Honikel and Hamm,1978; Jeacocke,1977). This phenomenon is known as "cold-shortening" because the provide the term of to be a fall of the source and increasing shortening of bovine muscle which results in a remainder the term of the source and the source and the term of term of the term of term (Honikel and Hamm,1978; Jeacocke,1977). This phenomenon is known as "cold-shortening" because term of terms (Honikel and Hamm, 1978; Jeacocke, 1977). a fall of temperature from +10° to -1°C causes an increasing shortening of bovine muscle which results in a remar $k_{able}^{(a)}$  of temperature from +10° to -1°C causes an increase 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 bat the WHC of particular interest to know if there are differences on the WHC of beef is not yet available. It would be of particular interest to know if there are differences is not yet available. It would be of particular interest to the effect on WHC of mea between prerigor shortening, rigor-shortening and rigor mortis itself with regard to the effect on WHC of meat history of been prerigor shortening, rigor-shortening and rigor mortis itself with regard to the effect on WHC of meat history of the shortening of the shortening and rigor mortis itself with regard to the effect on WHC of meat and the shortening of the shortening of the shortening of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the shortening and rigor mortis itself with regard to the effect of the effect of the shortening and rigor mortis itself with regard to the effect of the effect of the effect of the shortening and rigor mortis itself with regard to the effect of the e terms of cooking loss of salted muscle homogenates, the latter presenting conditions which exist in sausage The prerigor shortening, rigor-shortening and rigor the latter presenting conditions which exist in success multiples of cooking loss of salted muscle homogenates, the latter presenting conditions where cold shortening occurs increases, Powell (1978) found that the drip loss of beef stored at temperatures where cold shortened muscle, Locker and Daines (1976) with beef kept at 10-15°C. Measuring the weight loss on cooking cold-shortened muscle, Locker (Louines (1976)) and the temperature of cold-shortening. The same authors reported in a following paper the store of rigor  $a_{nd}^{creased}$  compared with beef kept at 10-15°C. Measuring the weight loss on cooking cold-short concerning paper (Locker and Daines (1974) observed no influence of cold-shortening. The same authors reported in a following paper (Locker and Daines (1974) observed no influence of cold-shortening cold-shortened muscle after onset of rigo  $U_{\text{ocker}}^{\text{loganes}}$  (1974) observed no influence of cold-shortening. The same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors reported in a formula paper of the same authors are same authors reported in a formula paper of the same authors are authors reported in a formula paper of the same authors are authors and the same authors are a same authors are author Mortis Contrary to the latter result, Davey and Gilbert (1975) found a small increase in cooking loss as a result of Cold shortening.

his enigma needed clarification. To do this it was necessary to distinguish between shortening, measured by the second se decrease in sarcomere length, and rigor mortis, measured by decrease in extensibility of muscle.Rigor in neck muscle (Honikel et al., 1980) as well as at other temperatures between 0° and 30°C cond. et al., 1980) as well as at other temperatures between 0° and 30°C cond. et al.  $(H_{Onikel}^{urs} at a tissue pH of 5.9 at 20^{\circ}C$  (Hamm et al.,1980)as well as at other temperatures between 0 and 20  $C_{Onikel}^{urs} et a$  a tissue pH of 5.9 at 20  $C_{Onikel}^{on}$  (Hamm et al.,1980)as well as at other temperatures between 0 and 20  $C_{Onikel}^{on}$  et al. unpublished). It was the main purpose of this investigation to find the optimum conditions for the temperature of the length of time the hot-boned beef may be left at a given temperature of the length of time the hot-boned beef may be left at a given temperature of the length of time the hot-boned beef may be left at a given temperature of the length of time the hot-boned beef may be left at a given temperature temperature of the length of time the hot-boned beef may be left at a given temperature temperature of the length of time the hot-boned beef may be left at a given temperature temperatu Conditioning prerigor beef and to determine the length of time the hot-boned beef may be left at a given tempe-dature and straining prerigor beef and to determine the length with conventionally chilled rigor or postrigor meat

hature 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 Was min after of conditioning temperature samples of about 100-200 g and about 1 cm thickness. One of the strips Jo influence of conditioning temperature was studied in the lean bovine neck muscles, which were obtained attemption with a start was an after slaughter, and divided into samples of about 100-200 g and about 1 cm thickness. One of the strips bath analyzed to shape <sup>140</sup> min after slaughter, and divided into samples of about 100-200 g and about 1 cm thickness. One of the samples analyzed before incubation; the other strips were sealed in polypropylene pouches and placed in a cryostat the other 10-15 min incubation, the center of the samples had reached the bath ten bath The at the desired temperature. After 10-15 min incubation, the center of the samples had reached the bath temperature investigation. Muscles At selected periods of incubation and after 24 hours p.m. a sample was taken for further investigation. replicates from different animals had to be used to cover the temperature range between 0° and 30°C with several w. at the desired temperature. After 10-15 min incubation, the center of the samples had reached the bath tempe-re. At replicates for temperature, time of postmortem storage and tissue pH.

Methods for temperature, time of postmortem storage and tissue pH. the des for temperature, time of postmortem storage and tissue pH. the des for the preparation of unsalted and salted muscle homogenates at different times post mortem (p.m.),for originate erminant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the determinant of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the preparation of unsalted and salted muscle homogenates at different times post mortem (p.m.), for the preparation of unsalted muscle homogenates at different times post mortem (p.m.), for the preparation of unsalted muscle homogenates at different times post mortem (p.m.), for the preparation of unsalted muscle homogenates at different times post mortem (p.m.), for the preparation (p.m.) The determination of unsalted and salted muscle homogenates at different times post moreon (p.m.), and or bed in the preceding paper (Hamm et al., 1980). RESULTS AND DISCUSSION

 $I_n^{agreement}_{10}$  AND DISCUSSION  $I_n^{agreement}_{1967}$  than at 7° or 14°C (Fig.1) which is certainly due to an accelerated turnover of ATP (Newbold and Scopes,  $I_{267}^{ac}_{10}$  Honike) and Home 1079. Tolley et al. 1980). This phenomenon can be explained by an accelerated release of Which the arlier results, we found a much higher rate of philar at the second and Scopes, (act, Honikel and Hamm, 1978; Jolley et al., 1980). This phenomenon can be explained by an accelerated release of h ions from the sarcoplasmic reticulum (SR) or from the mitochondria into the myofibrillar space; these Ca<sup>2+</sup>ions (association with appropriate levels of ATP initiate muscular contraction before the onset of rigor mortis (add and Tume 1977, for further references see Hamm, 1979) as is demonstrated in Fig. 2. Proof for the role of (1979) (here as a from the sarcoplasmic reticulum (SR) or from the mitochold of the onset of rigor morting (here as a propriate levels of ATP initiate muscular contraction before the onset of rigor morting and Tume, 1977; for further references see Hamm, 1979) as is demonstrated in Fig. 2. Proof for the role of the cold the cold that was furnished by Honikel and Hamm (1978). in the cold-shortening effect was furnished by Honikel and Hamm (1978).

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 accompa-however an account of sarcomeres, caused by rising the tissue temperature above 16°C (Fig.2) was also accompa-however an account of sarcomeres, caused by rising the tissue temperature above 16°C (Fig.2) was also accompa-<sup>Alorea</sup> <sup>Alog</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alowever</sup> an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening effect, <sup>Alovever</sup> by a contrary to the cold-shorten metabolism did not result in precision shortening (Fig.2). however, an accelerated decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening critering the decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening critering the decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening critering the decrease of pH during the first hours p.m. (Fig.1). Contrary to the cold-shortening (Fig.2, upper curve), ted by because not enough free Ca<sup>2+</sup> was released from calcium accumulating organelles. This assumption is supported by the fact that enough free Ca<sup>2+</sup> was released from calcium accumulating organelles. This assumption is supported by the fact that enough free Ca<sup>2+</sup>, does not lower the rate of ATP turnover at tissue temperatures above about  $10^{6}$  obj/ this acceleration of postmortem metabolism did not result in pattern organelles. This assumption is supply because not enough free Ca<sup>2+</sup> was released from calcium accumulating organelles. This assumption is supply  $10^{6}$  (by the fact that addition of EGTA does not lower the rate of ATP turnover at tissue temperatures above about  $0^{6}$  (Monikel and H addition of EGTA does not lower the rate of ATP which results in a release of Ca<sup>2+</sup>, does rigor shorten at the procederated postmortem metabolism at The fact that addition of EGTA does not lower the rate of AIP turnover at the second  $(H_{Onlikel} and Hamm, 1978)$ . Just before depletion of ATP which results in a release of Ca  $(F_{Iq}, 2)$  and Hamm, 1978). Just before depletions (1975) also described. The accelerated pos Occur (Honike] and Hamm,1978). Just before depletion of ATP which results in a release of Ca<sup>-1</sup>, does rigor shorten low (Honike] and Hamm,1978). Just before depletion of ATP which results in a release of Ca<sup>-1</sup>, does rigor shorten the temperatures lower curve), as Locker and Daines (1975) also described. The accelerated postmortem metabolism at Or temperatures lasted for few hours p.m. only; then the further decrease of pH at O<sup>O</sup>C was much slower than at The temperature (Fig.1: Winger et al.,1979). <sup>Vicur</sup> (Fig.2, lower curve), as Locker and the solution of th

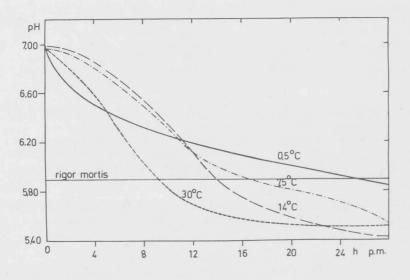
or higher temperatures lasted for few hours p.m. only; then one higher temperatures lasted for few hours p.m. only; then one of higher temperatures (Fig.1; Winger et al.,1979). With rime necessary for reaching pH 5.9 i.e. the onset of rigor mortis (Hamm et al.,1980), decreases considerably and we suggest, that after few hours at all temperatures studied similar temperatures (Fig.1) and we suggest, that after few hours at all temperatures by the normal With rising temperatures (Fig.1; Winger et al., 1990), decreases consideration with rising temperature (Fig.1 and 4) and we suggest, that after few hours at all temperatures studied similar influence of Ca<sup>+</sup> 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 unsalth muscle homogenates prepared prerigor is not influenced by the rate of postronter muscle as well as of the the muscle homogenates prepared prerigor is not influenced by the rate of postmortem metabolism (pH fall) or the degree of contraction in the prerigor is not influenced by the rate of postmortem metabolism (pH fall) or the cause some decrease of WHC (Tables 1 and 2; Fig.3). It is of particular importance that the development of rigor mortis

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

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

<sup>a</sup>Homogenates were prepared after reaching the required pH in intact muscles. The salted homogenates con<sup>taine</sup> 2 percent NaCl.



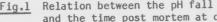


Fig.l Relation between the pH fall in bovine neck muscle and the time post mortem at different temperatures.

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

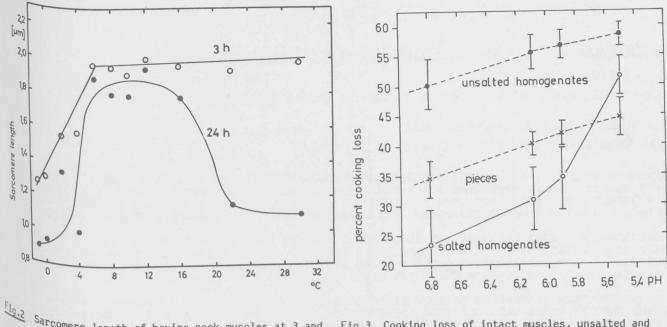
	percent cooking loss/pH unit				
	in t 6.8-6.1	the pH range 6.1-5.9	5.9-5.5		
Intact muscle Unsalted homogenate Salted homogenate	8.5 9.1 10.6	8.5 4.5 16.5	6.7 4.7 43.0		

(pH 5.9-5.5) did not have a significant inluence with on WHC. This observation is in agreement with the results obtained by 72.11 agreement (1980) the results observation is in agreement  $W^{10}_{\rm M}$  measured WHC of the upbect

muscle homogenates. The WHC of the salted muscle homogenates was higher that it is unsalted muscle homogenates was higher that is the unsalted muscle homogenates was higher that is the unsalted muscle homogenetics are the salted muscle homogenetics. homogenates was higher than that of the unsale of the the second terms of the terms of terms of the terms of ones, particularly in the prerigor state of the unsate of the as off would expect according to the state of t Before would expect according to the electrostatic theory of anothing to the electrostatic theory of swelling (Hamm, 1960, 1972, 1975). pH 5.9 was reached, i.e. during the prerigor phase, the influence of postmortem change les on the WHC was similar in the intact muscles of that in muscle homogeneto that in muscle homogenates either unsalted preserved to the preserved of the preserved to the the the the preserved to the pr salted (Tables 1 and 2, Fig.3). In this phase the WHC of the intact tissue or muscle independent nates, measured at the sampe pH, was independent of incubation temperature of PH, was independent of the sampe pH and the sampe of incubation temperature (Table 1). Consequently, cold-shortening (proci ly, cold-shortening (prerigor contraction) difference (ther an effect on William contraction) difference (ther an effect on William contraction) difference (the intact or homogenized with or without addition

It should be pointed out that in these experiments cooking loss more that in these experiments that is the second about 24 hours p.m. Preliminary results indicate results results indicate that cold-shortening in the results indicate resolt cated that cold-shortening does influence (dr) retention of intact unbested loss) after a longer period of ageing ( $Hon_{ke}^{(m)}$ ) et al., unpublished)

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



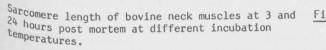
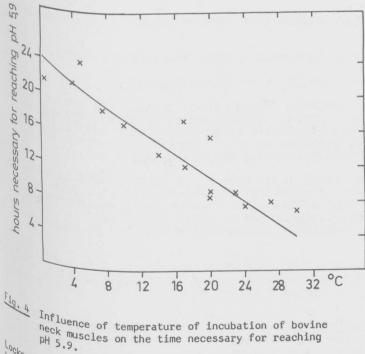


Fig.3 Cooking loss of intact muscles, unsalted and salted homogenates in relation to the post mortem pH fall in the intact muscle at temperatures between 0 and 30°C. The bars indicate the standard deviation.

<sup>stored</sup> at 20<sup>o</sup>C. The probable causes for the different behaviour of unsalted and salted muscle homogenates has  $b_{een}^{ored}$  at 20°C. The probable causes for the different behaviour (1980). We may discussed in the preceeding paper of Hamm et al. (1980).

We <sup>dire</sup>ady discussed in the preceeding paper of Hamm et al. (1700). infly conclude from our results that longitudinal changes of muscle occurring during contraction have much less and dence on which have a constant of the attraction between oppositely charged groups of adjacent molecules influence on WHC than alterations caused by attraction between oppositely charged groups of adjacent molecules particularly particularly that alterations caused by attraction between oppositely charged groups of adjacent molecules  $a_{nd}^{1}$  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



pH 5.9.

PH 5.9. Locker, R.H. and Daines, G.J. 1975: J. Sci. Food Agric. 26, 1721. Warsh, R.H. and Daines, G.J. 1976: J. Sci. Food Agric. 27, 193. <sup>wer</sup>, R.H. and Daines, G.J. 1975: J. Sci. Food Agric. <u>20</u>, <u>1976</u>; Marsh, B.H. and Daines, G.J. 1976: J. Sci. Food Agric. <u>27</u>, 193. Method. B. and Daines, G.J. 1976: J. Food Sci. <u>33</u>, 450. Devel Wold, R, P and Scopes, R.K. 1967: Biochem. 3. 102, Revel V.H. and Tume, R.K. 1977: Aust.J.Biol.Sci. 30, 519. Weil, V.H. 1978: Proceed.24th Meat Research Worker's Meeting, Kulmbach, paper D 1. Winger, W.D. 1976: Discussion of Topbool, 9, 501. Wie, R.W.D. 1978: Proceed.24th Meat Research. Winger, R.J. 1974: J. Food Technol. <u>9</u>, 501. S. Food Sci. <u>44</u>, 1681.

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).

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