

CHANGES IN MEAT DURING COOKING*

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The changes that occur in meat during cookery are complex in that, at different temperatures, different meat components undergo changes that affect tenderness and water loss (shrink). Hamm (1965) notes that chemical and physical changes in meat occur in more or less discrete steps. Machlik and Draudt (1963) showed that, by heating 1/2-inch beef semitendinosus muscle cores as a model, it was possible to make some separation of changes that are reflected in terms of mechanical shear. They noted relatively little change in shear in one hour up to 50°C and a sharp decrease in shear to a minimum around 60°C with behavior corresponding to the collagen shrinkage reaction. They noted a hardening that reached a maximum in 30-60 minutes in the 70-75°C range and at higher temperatures noted a gradual decrease in shear believed to correspond to the breakdown of collagen to gelatin. Many workers have shown that the major changes in the sarcoplasmic and myofibrillar protein undergo heat denaturation at relatively low temperatures; thus in the range of collagen shrinkage (58-62°C) the major portion of the sarcoplasmic and myofibrillar protein are already denatured.

Hamm and Deatherage (1960), using 30 minute heating times, found that there was some change of solubility of the globular and structural proteins in the 20-40°C range but that, in the 40-60°C range, solubility decreased rapidly. At 60°C, 23% of the proteins remained soluble compared to the unheated control. Solubility continued to decrease slowly up to 80°C.

Using rabbit muscle Paul *et al.* (1966) found a decrease in sarcoplasmic proteins (extractable with KCl-Borate I=0.05 pH 7.5), myofibrillar proteins (extractable with KI borate I=0.6 pH 7.5) and an increase in denatured protein (extractable with 0.1 N NaOH) with increasing time and temperature of heating. Observing Paul's data for samples heated at 30 minutes, it appears that the most important effect of heat on solubility of the sarcoplasmic proteins occurred below 55-60°C.

Locker (1956) found that, on heating purified rabbit myosin at 53°C, pH 6.2, flocculation occurred within two to three minutes and a leathery gel formed within five minutes.

Samejima *et al.* (1969) studied the heat gelling properties of myosin, actin and actomyosin in model systems (30 minutes at 60°C), using the heat gelling test of Trautmann (1966). After 15 minutes myosin A, myosin B, and heavy meromyosin formed gels that remained in the test tube when inverted. Other proteins became turbid or flocculated upon heating 30 minutes at 60°C.

* Presented at the 25th Annual Reciprocal Meat Conference of the American Meat Science Association, 1972.

They noted that myosin A precipitation, which was essentially complete at 65°C, was not decreased by sulphhydryl reducing or oxidizing agents and interpreted these results to indicate that heat precipitation of myofibrillar proteins is not due to disulfide formation.

Cohen (1966) heated ground ham to 120, 130, 140, 150, 160 and 165°F internal temperature at different heating rates. Protein soluble in 0.9% NaCl was generally reduced to a very small fraction at 150°F (65.6°C). Temperature was the major factor in solubility of the 0.9% NaCl, extractable protein but heating time also played a part.

Machlik and Draudt (1963), in a study of time and temperature of heating of 1/2-inch diameter beef semitendinosus muscle plugs, found that below 50°C little change in shear occurred during heating up to 300 minutes. In the 55 to 58°C range there was a slow decrease in shear. This change became very large and very rapid in the 60°C range. This change was considered to be a manifestation of the collagen shrinkage reaction. The rate of the change in shear values, expressed in terms of the temperature that produced 1/2 of the change in one minute, was from 61-66°C.

Draudt et al. (1964) presented evidence that this, indeed, was the collagen shrinkage reaction by virtue of the fact that susceptibility to attack by proteolytic enzymes in low concentration occurred exactly at the occurrence of the sharp decrease in shear. The temperature range for the marked shear change as well as the variability noted is consistent with more recent differential thermal analysis (DTA) studies on epimesial collagen (Field et al., 1970).

In the range of 60 to 65°C, once the initial collagen shrinkage reaction is complete, the shear values remain constant up to three-hour heating.

In the range of 66-70°C, a marked rise in shear values occurs. The change is time dependent and is somewhat more variable with respect to temperature than is the collagen shrinkage change. This hardening, which manifests itself as a substantial increase in shear, reaches a maximum in 15 to 30 minutes at about 74°F. At about 70°F a general downward trend in shear with heating time begins to become apparent which is interpreted to be due to the solubilization of collagen. The effect of the hardening reaction, however, apparently persists even at 90°C. The slow decrease in shear is believed to be due to solubilization of collagen increases with increasing temperature.

Ritchey et al. (1963) found some decrease in beef longissimus dorsi and biceps femoris muscle insoluble collagen nitrogen after heating to 61°C. A considerably further decrease in insoluble collagen nitrogen in the muscle was noted after heating to 80°C. These authors presented an extensive review of the literature. Many workers, including Herring et al. (1967), have studied this change which will not be reviewed further here.

With some important exceptions, a major portion of the beef and beef-containing products processed in one form or another in industry, in the

home, or in institutional cookery are heated to a temperature that will invoke the hardening reaction. This hardening of beef becomes apparent upon heating 30 minutes at temperatures of 66-70°C (150.8-158°F). Draudt et al. (1964) found this reaction occurs in the normally tender cuts, such as the longissimus dorsi (LD), as well as in the less tender cuts such as the semitendinosus. Tuomy et al. (1963) noted that there was little tenderness change, if any, in the 140-160°F range. They noted that the initial change on heating beef was a toughening which occurred very rapidly and noted that, if the temperature was below 180°, little tenderization occurred with extended heating time. Ramsbottom et al. (1945) recognized that most meat cuts toughened upon cooking.

Bouton and Harris (1972) in a paper which has recently brought several physical methods to bear on the question of the effect of heating at 37, 40, 50, 60 and 70°C on the physical properties of meat, found significant increases in compression values for one-year-old steers and veal on heating at 75°C as compared to 60°C for one hour but did not see a significant change for older animals.

In industrial cookery, the lower limit for meat product processing is often a pasteurization temperature. The minimum practical temperature to achieve reliable kill or heat inactivation of spoilage organisms corresponds to approximately 150°F (65.6°C). This is the temperature at which the hardening reaction begins to be apparent in shear data. The upper temperature level is generally restricted in industrial heat processing (exclusive of canning) and institutional cookery by uneconomic shrink losses and product quality damage that often occurs at high temperatures. By necessity, much meat processing occurs in the range in which the hardening reaction occurs but at temperatures and heating times too low to obtain effective tenderization by solubilization of collagen to gelatin.

Relatively little research has been carried out with the specific objective of gaining a better understanding of the important hardening, toughening change. Papers by Bouton and Harris (1972), Dube et al. (1972), and Paul et al. (1966) provide techniques and insights that will help meat research workers understand the hardening (toughening) action of heat.

Giles (1969) reported progressive sarcomere shortening up to 20% that occurred at 70°C but not at 60°C when muscle strips were heated.

Dube et al. (1972) found that increasing the temperature of cooking myofibrillar extract resulted in gradual shortening of sarcomeres with a maximum change taking place in the 70-80°C range. Bouton and Harris (1972) suggest the possibility that some of the effect on shear and compression in this temperature range might be due to bunching up of connective tissue due to shortening of the sarcomeres reported by Giles (1969).

In the present author's work low levels of papain caused a sharp decrease in the shear value of longissimus dorsi muscles precisely corresponding to the shear change associated with collagen shrinkage (Draudt et al., 1964). The shear increased in papain treated samples in a manner parallel to hardening in samples without papain added. A similar result is noted in figure 1 (Rimstidt, 1965).

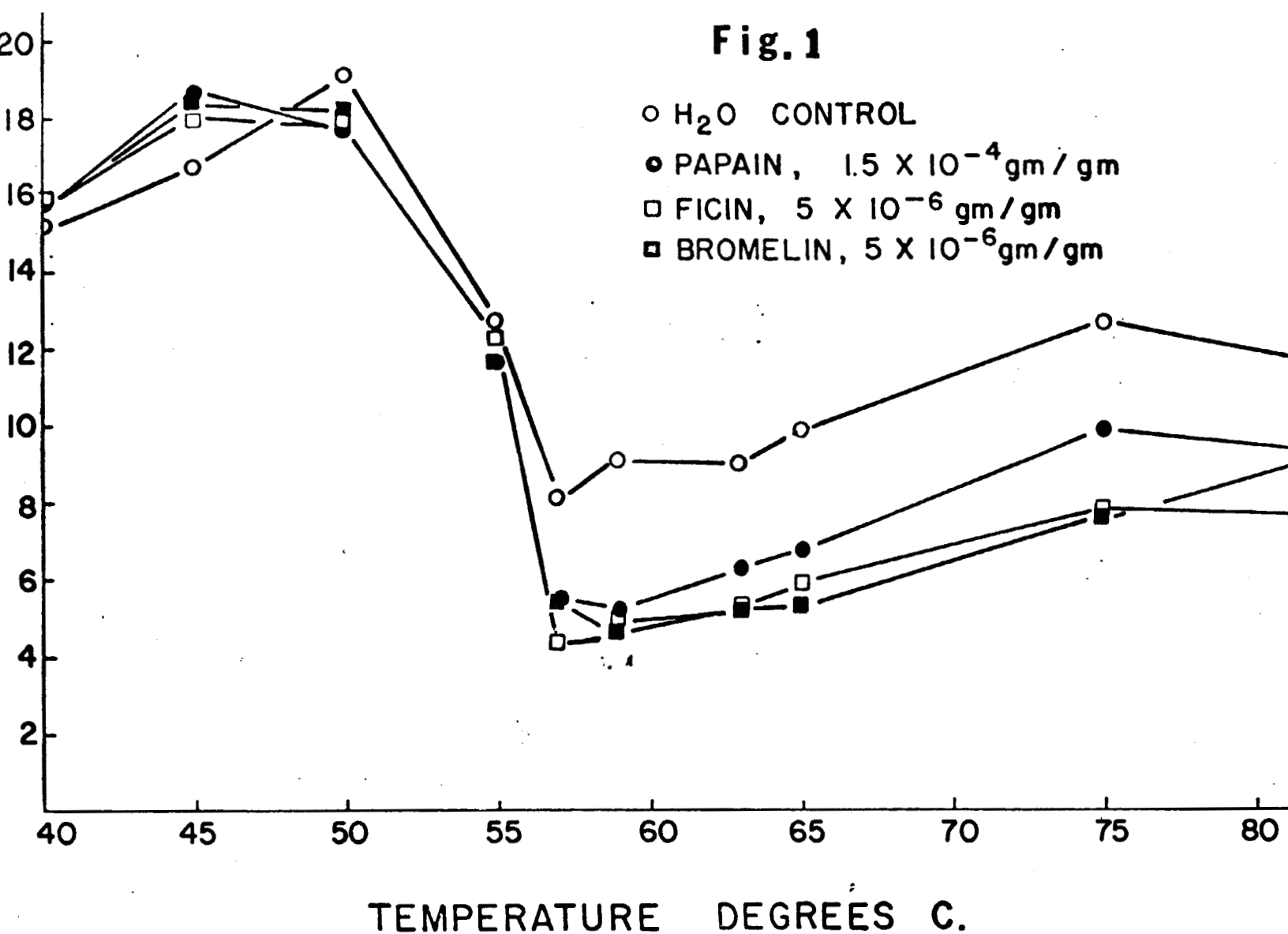


Figure 1. Average Shear Force in Pounds Versus Temperature of Heating for 60 minutes for 1/2-inch Diameter Choice Grade Beef Semitendinosus Muscle Plug Treated with 10% Water, 10% Papain Solution, 10% Ficin Solution, and 10% Bromelin Solution.

Figure 1 shows the shear values for 1/2-inch diameter semitendinosus muscle plugs from the same muscle soaked overnight with 10% water alone, 10% water containing papain, 1.5×10^{-4} g/g meat; ficin 5×10^{-4} g/g meat bromelin; 5×10^{-4} g/g meat. All three of the enzymes decreased the shear by about 1.5 pounds force at the temperature corresponding to collagen shrinkage. The papain-treated sample exhibited the same increase upon heating to the hardening reaction temperature, approximately 5 pounds force, as the untreated samples. The ficin and bromelin treated samples increased by about 3 pounds force.

It is suggested that, if the bunching of collagen were involved in the hardening reaction, a greater effect of shear could be expected in the hardening zone upon treatment with these proteolytic enzymes which readily attack heat shrunk collagen.

Hamm and Hofmann (1965) investigated the effect of heat on the availability and disappearance of sulphhydryl groups upon heating myofibrils. The sulphhydryl groups reacting with N-ethyl-maleimide (NEM) increased upon heating from 30°C to a maximum at 70°C for 30 minutes. The number of sulphhydryl groups reacting with AgNO_3 was not affected by heating to 70°C and only a relatively small loss occurred at 90°C. This indicated that sulphhydryls become more readily available but do not form appreciable disulphide bonds below 70°C. Hamm and Hoffman's work (1965) thus strongly suggests that formation of disulfide bonds may not be a major factor involved in the hardening reaction.

Dube et al. (1972) found that the maximum rate of sulphhydryl loss was between 70-80°C. More than 50% of the initial sulphhydryl groups were lost at 90°C. Results varied between breeds and between the psoas major and the longissimus dorsi.

Infusion of a beef carcass with salt curing solution produced very tender meat in experiments at Ohio State University (Weiser et al., 1953). Wierbicki et al. (1957) studied factors that affect the water holding capacity of meat. He showed a distinct inflection in the percent juice loss around 60°C. While the general trend is increasing juice loss for samples heated at increasing temperatures, in the 60°C range there is a distinct reversal of juice loss. The present writer has seen this effect many times.

Hamm (1965) has discussed many heat induced changes occurring in meat. Mahon (1961) clearly pointed out the dominant effect of salt in decreasing cooking shrink in the presence of tripolyphosphates.

Since the technique of Machlik and Draudt (1963) makes it possible to "see" the hardening reaction as well as several other heat induced changes in beef in terms of mechanical shear values, tests were carried out to find out more about how sodium chloride treatment affects tenderness.

METHODS

The method of Machlik and Draudt (1963) was employed which is briefly as follows.

Choice grade beef semitendinosus muscle was frozen and partially thawed overnight. Approximately 140 plugs 1/2-inch in diameter and 1 1/2-inches long were cut from the partially frozen (tempered) meat. The plugs were individually weighed, placed in 16 mm x 150 mm test tubes and 10% vol/wt treatment solution was added. The tubes were held overnight in a 4°C cold room. Plugs were removed from the test tubes to conical 15 ml centrifuge tubes containing a small button and were heated in temperature-controlled water baths. The tubes were immediately chilled in an ice water bath 5 minutes. The plugs were weighed as a group of four.

In all tests each treatment was replicated with four plugs and three Warner-Bratzler shear measurements were made on each plug. Each data point is an average of 12 shear readings. In this work sodium bicarbonate was used to obtain small increases in pH without damage to the meat that might occur if a strong alkali such as sodium hydroxide were used.

In part one the treatment solutions were: water; 12.5% sodium chloride solution; 2.5% sodium bicarbonate solution; and a solution of 12.5% sodium chloride and 2.5% sodium bicarbonate.

In part two solutions containing a combination of 12.5% sodium chloride and eleven levels of sodium bicarbonate from 0 to 5% were used.

In part one, test tube samples were heated one hour in water baths at 50, 55, 60, 63, 70, 74 and 77°C $\pm$ 0.2°C. The internal temperatures reached to within 1°C in 7 minutes.

In part two, all samples were heated one hour at 74°C $\pm$ 0.2°C, in a water bath.

RESULTS AND DISCUSSION

In figures 2 and 3, showing results of treatment of plugs from a single semitendinosus muscle, it is noted that sodium chloride (1.25%) had a profound effect on the percent water loss (shrink) but had no significant effect on shear values below 63°C. Salt thus greatly decreased the hardening effect. In this case lowering the pH slightly, by approximately 0.3 units, by the addition of 0.25% sodium bicarbonate substantially decreased water loss but did not decrease the shear value beyond the effect obtained with sodium chloride alone. The breaks in the water loss curves at 60°C, similar to those reported by Wierbicki *et al.* (1957), is somewhat more pronounced than is often seen.

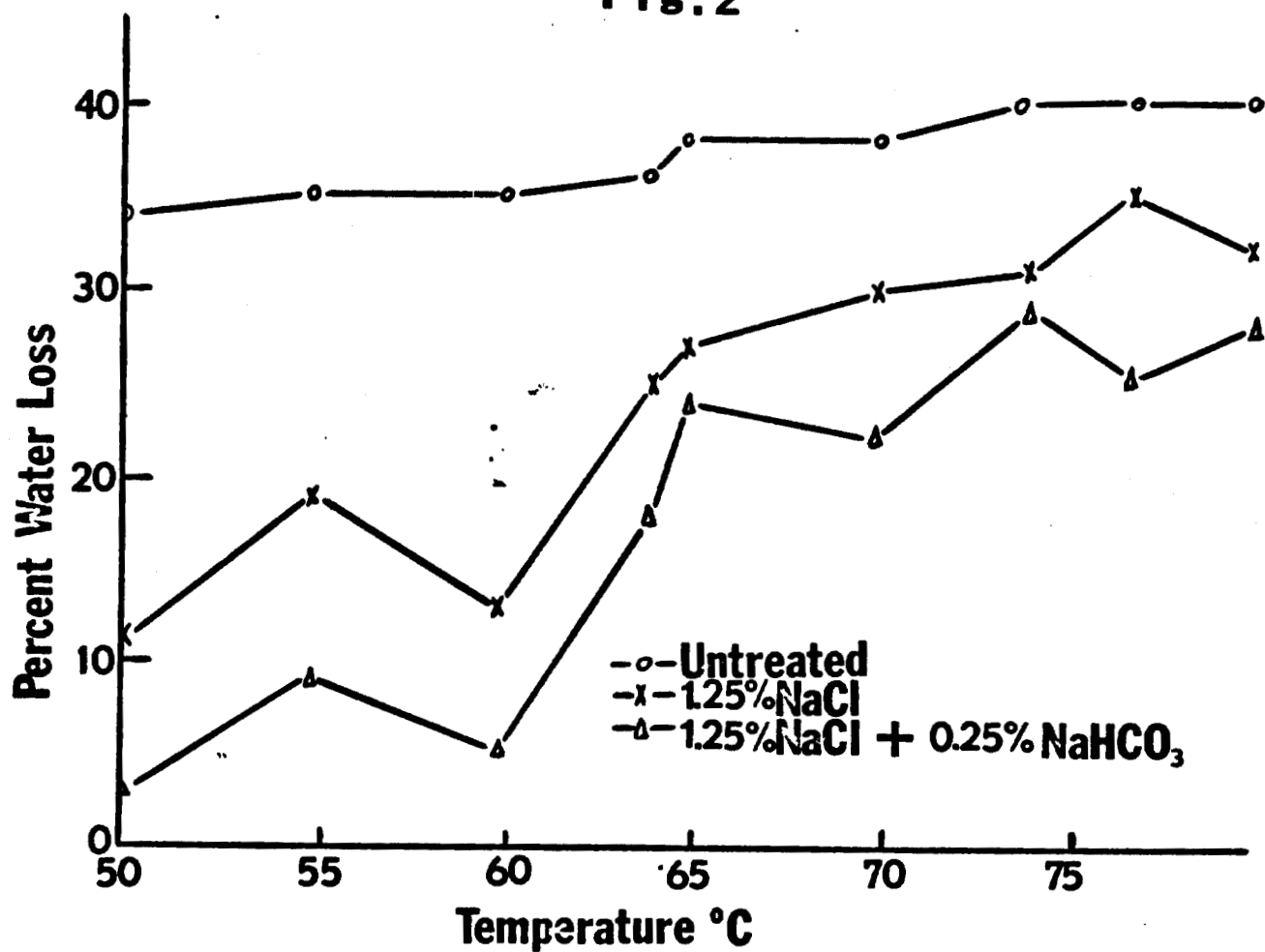
Fig. 2

Figure 2. Average water loss (shrink) in percent versus temperature of heating for 60 minutes for 1/2-inch diameter choice grade beef semitendinosus muscle plugs treated overnight as follows: o-o 10% water only; x-x 10% 12.5% NaCl solution; Δ-Δ 10% of solution containing 12.5% NaCl and 2.5% NaHCO₃.

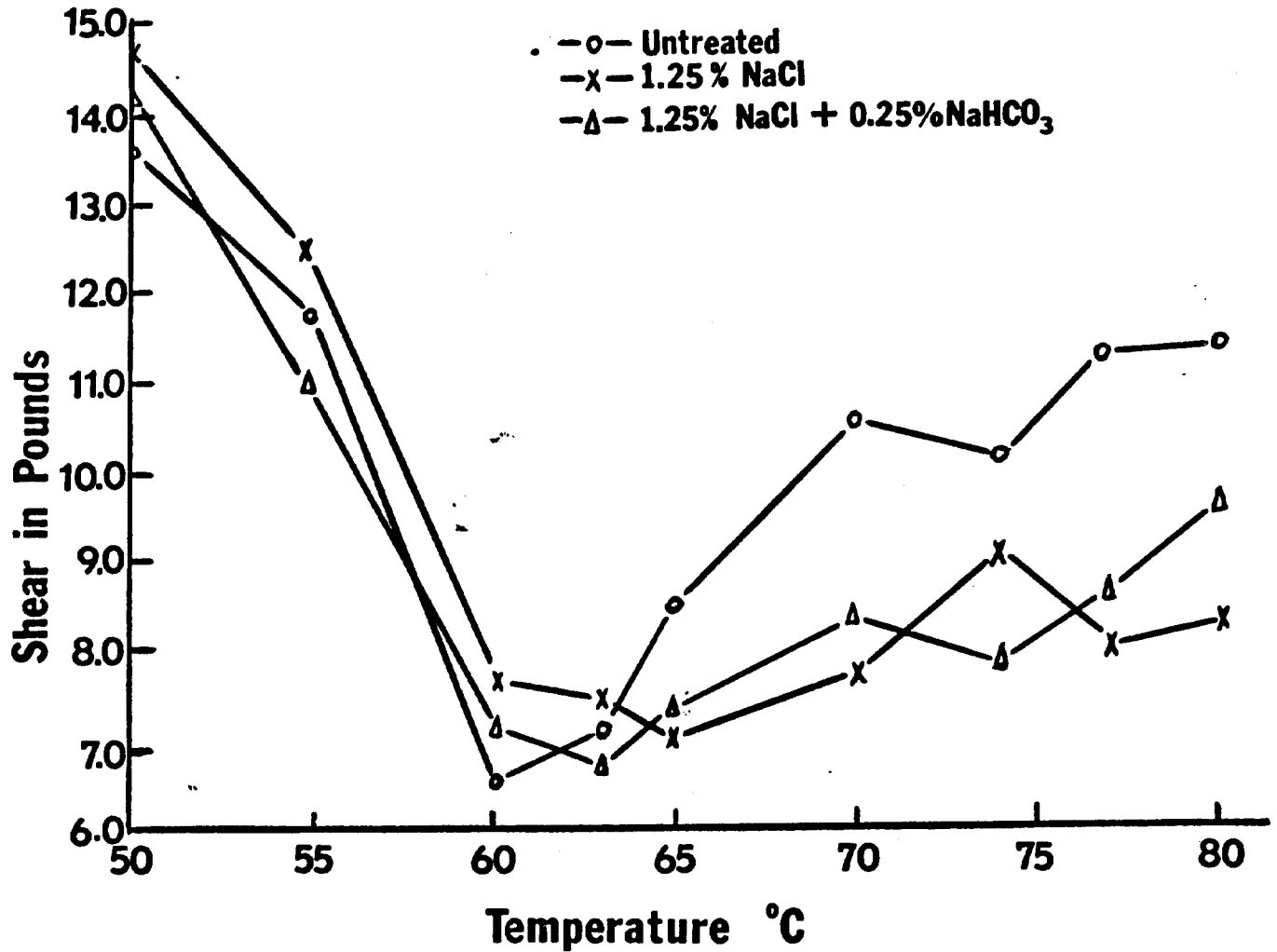
Fig.3

Figure 3. Average shear force in pounds versus temperature of heating for 60 minutes for 1/2-inch diameter choice grade beef semitendinosus muscle plugs treated overnight as follows: o-o 10% water only; x-x 10% of 12.5% NaCl; Δ-Δ 10% of solution containing 12.5% NaCl and 2.5% NaHCO₃.

In a similar experiment, figures 4 and 5, plugs from a single good grade semitendinosus muscle were heated at different temperatures with 10% water alone, 1.25% sodium chloride alone, 0.25% sodium bicarbonate alone, and with a combination of the two. The average pH values for the cooked samples were 5.85 for the water treatment; 5.94 with 1.25% salt only; 6.10 with .25% sodium bicarbonate only; and 6.15 for the combination of 1.25% salt and 0.25% sodium bicarbonate.

Figure 4 shows the typical shrink (water loss) and shear curves seen with the beef semitendinosus muscle that has not been treated. As seen in figure 5, adding 1.25% salt substantially decreased the shrink. Sodium bicarbonate (0.25%) alone also reduced shrink somewhat. The combination gave an additive effect in this case. The effect of bicarbonate alone was most important in the 60-65°C range. The effect with respect to shear is quite different. Salt treatment and bicarbonate treatment had little effect on shear values (figure 6) below the temperature of the hardening range. The combination gave an additive effect to substantially decrease the shear in the hardening range.

The effect of raising the pH with various levels of bicarbonate up to 0.5% for choice beef semitendinosus plugs cooked to a temperature to accentuate the hardening reaction, 74°C for 60 minutes, is given in figures 7 and 8. The results in figure 8 are representative of three similar experiments.

In the absence of sodium chloride increasing pH decreased the shrink loss and the shear values as pH of the cooked meat increased up to approximately pH 6.8 with little change in either between 6.8 and 7.0.

Adding salt (1.25%) alone profoundly decreased the shear for samples heated one hour at 74°C. Adding bicarbonate to the sample containing salt had virtually no effect on shear and a relatively low effect on percent shrink.

These results demonstrate that salt has a much more profound effect on tenderness than does pH. This is in line with the view of Mahon (1961) with respect to the relative importance of sodium chloride and pH in changing meat volume.

The results of these tests indicate that the effect of sodium chloride and sodium bicarbonate is to improve tenderness through decreasing the severity of the hardening reaction. The hardening reaction due to heat must involve primarily bonds that are affected by sodium chloride.

This is in agreement with the work of Hamm and Hofmann (1965) who showed that little disulfide formation occurred in meat extracts heated below 70°F. Dube *et al.* (1972) found evidence of some disulfide formation in the hardening range. Our results do not rule out the occurrence of disulfide cross link formation but they do suggest that disulfide bonds probably do not play an important role in the physical hardening effect.

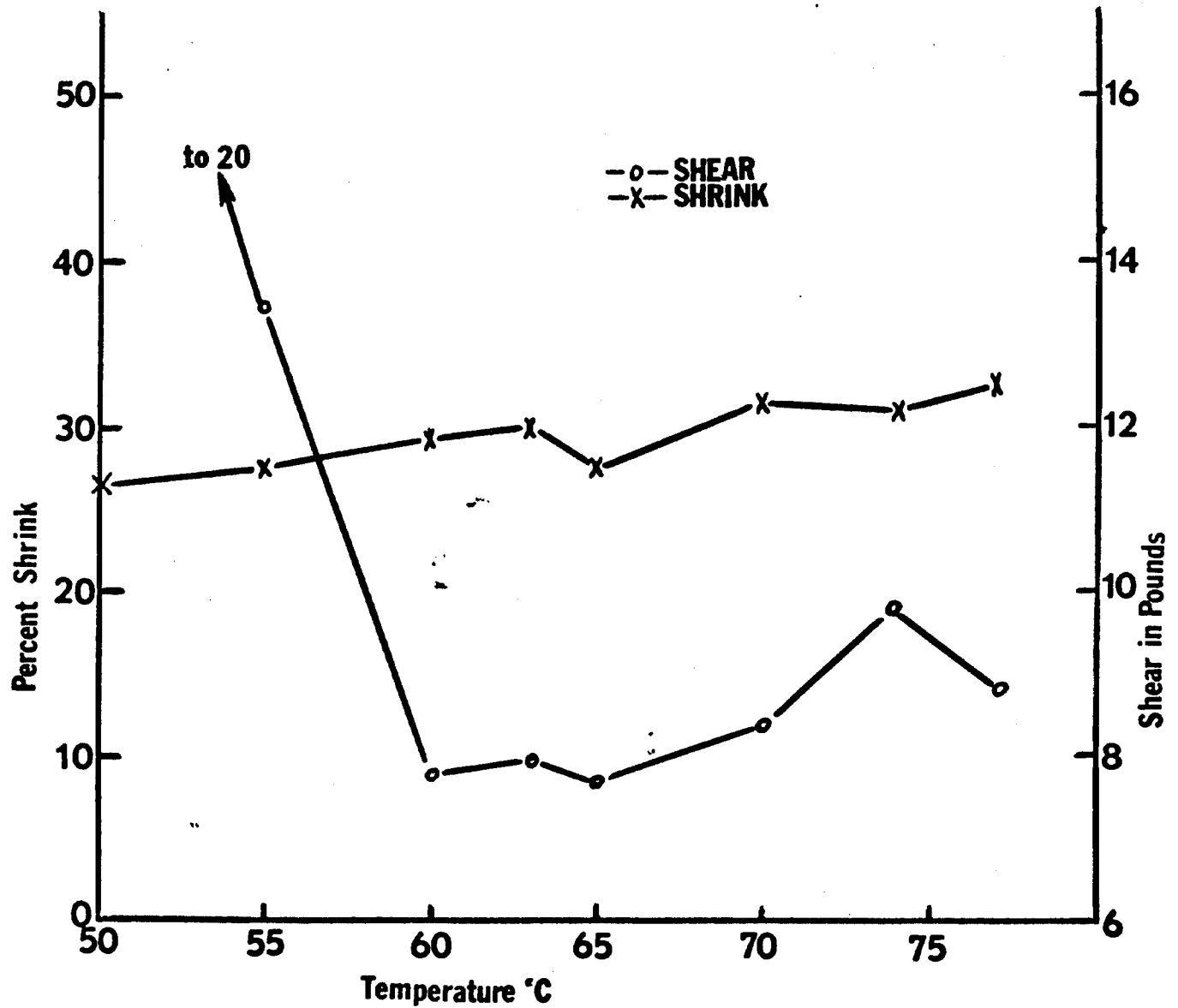
Fig. 4

Figure 4 Average shear force in pounds and shrink in percent versus temperature of heating for 60 minutes for 1/2-inch diameter choice grade beef semitendinosus muscle plugs treated with 10% water only.

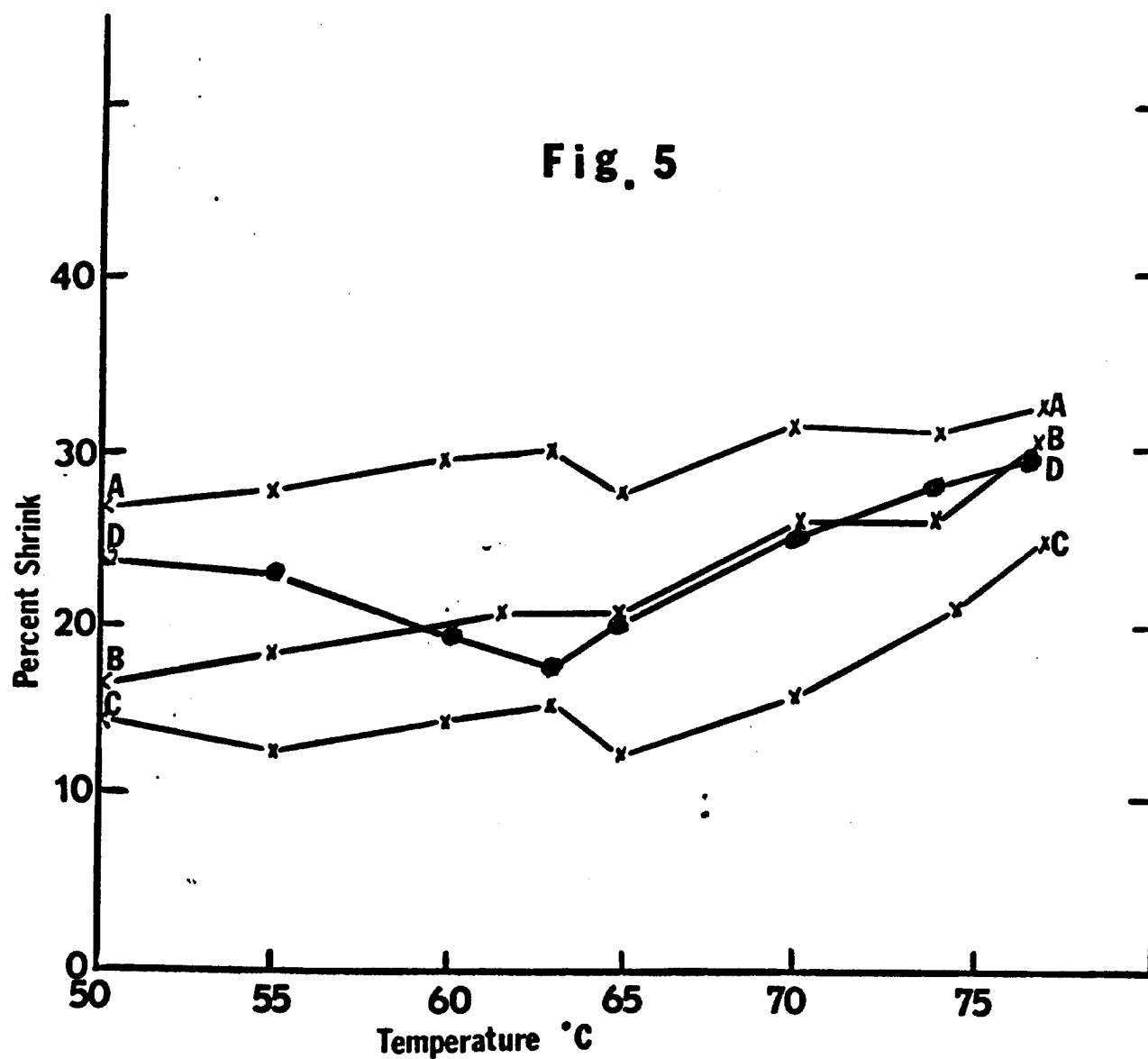


Figure 5. Average shrink in percent versus temperature of heating for 60 minutes for 1/2-inch diameter choice grade beef semitendinosus muscle plugs treated as follows. A. 10% water; B. 10% of 12.5% NaCl solution; C. 10% of solution containing 12.5% NaCl and 2.5% NaHCO₃; D. 10% of 2.5% NaHCO₃ solution.

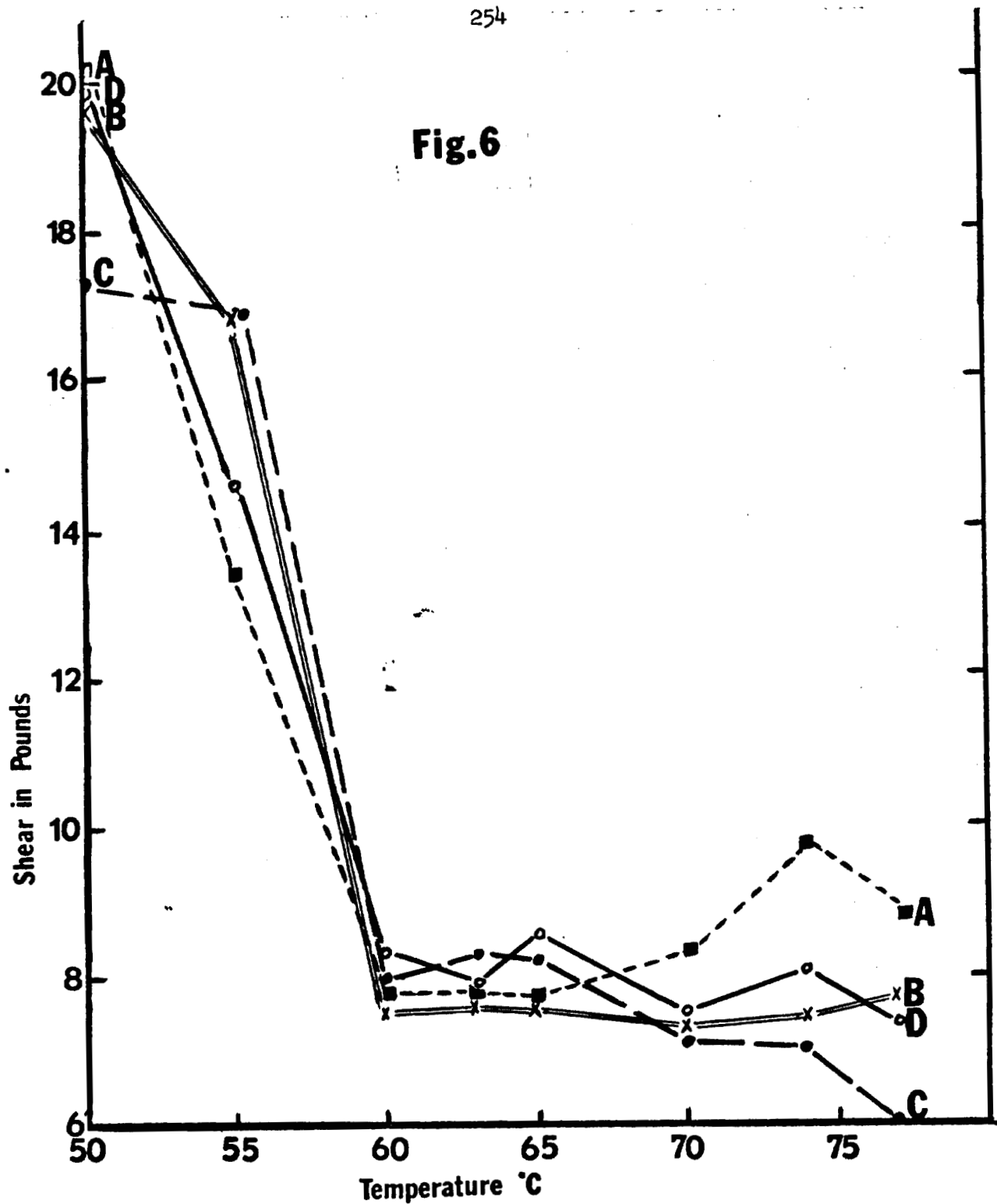


Figure 6. Average shear force in pounds versus temperature of heating for 60 minutes for 1/2-inch diameter choice grade beef semitendinosus muscle plugs treated as follows. A. 10% water only; B. 10% of 1.25% NaCl solution; C. 10% of solution containing 12.5% NaCl and 2.5% NaHCO₃ solution; D. 10% of 2.5% NaHCO₃ solution.

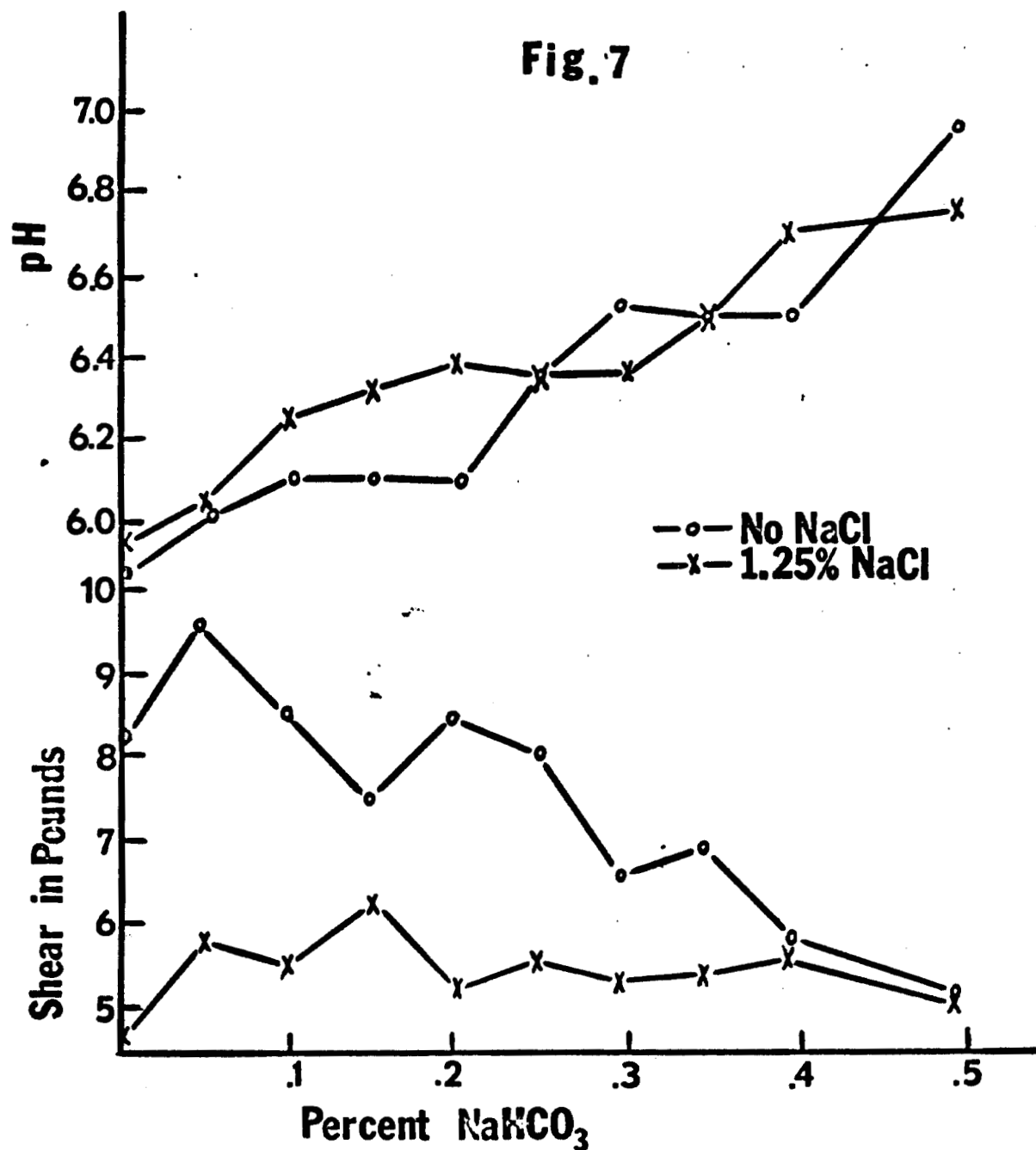


Figure 7. Average shear in pounds and pH versus percent NaHCO_3 (gm NaHCO_3 /gm meat $\times 100$ added as 10% solution) for 1/2-inch diameter choice grade beef semitendinosus muscle plugs heated for 60 minutes at 74°C .

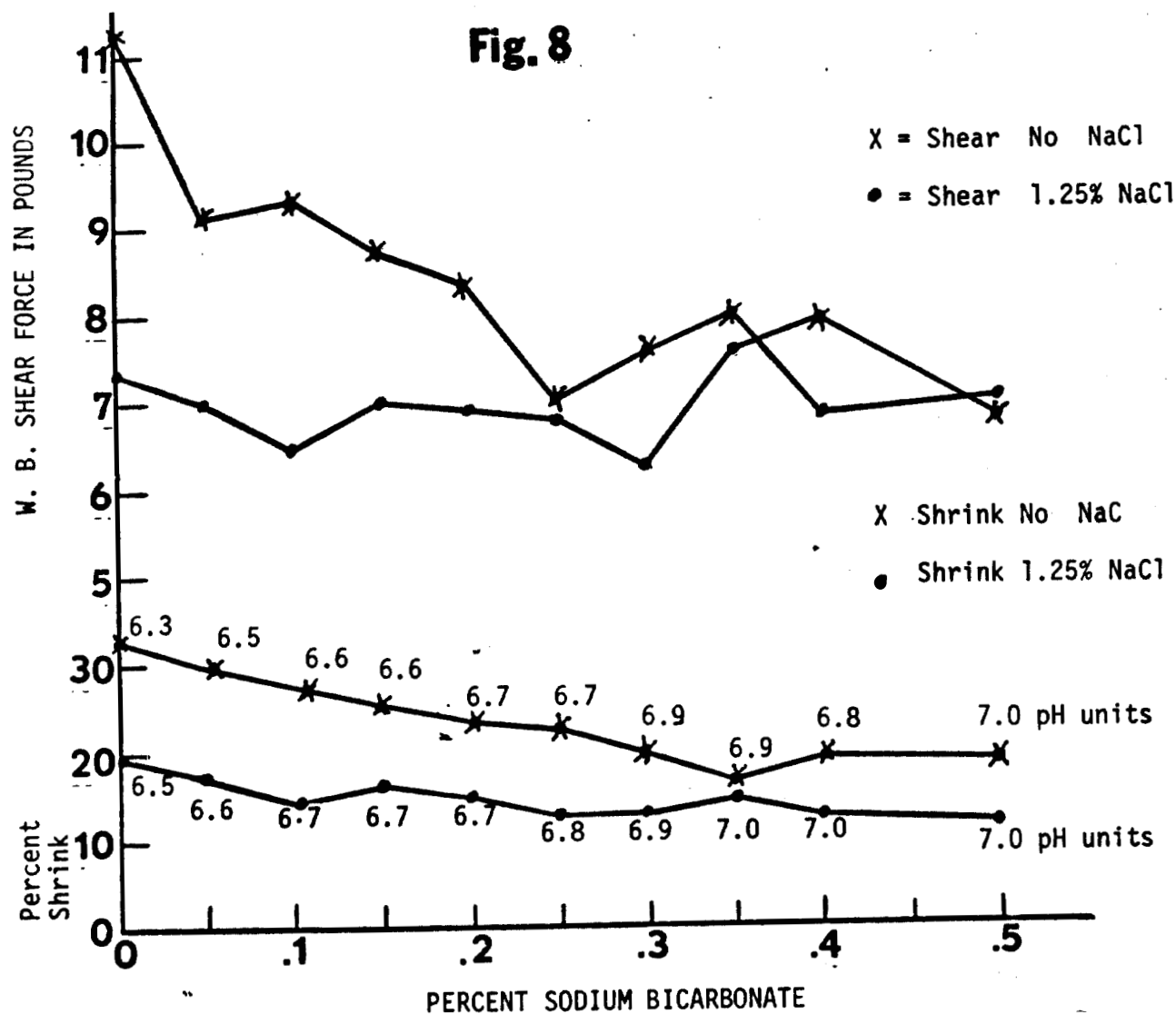


Figure 8. W. B. Shear Force in Pounds and Percent Shrink of 1/2 inch Diameter Beef Semitendinosus Muscle Plugs Heated One Hour at 74°C. Versus Percent Sodium Bicarbonate

These results demonstrate the application of physical shear measurement to gaining some understanding of the effect of treatments affecting tenderness. It is projected that this technique might have application in evaluating such factors as the effect of the kind and the amount of connective tissue in meat as well as other biological factors.

Considering the data presented here as well as data presented by Machlik and Draudt (1963) and Draudt *et al.* (1964), it is apparent that a minimum number of heating temperatures for 60 minutes could be selected that would give a good overall indication of the contribution of the various factors that can be seen in shear versus temperature plots. Heating small samples at the following temperatures for 60 minutes is suggested: 40°, 50°, 60°, 74° and 90°C.

40°C will provide an indication of initial tenderness before much heat change has affected the mechanical properties.

50°C will indicate the area of maximum shear value before collagen shrinkage occurs. The meat has undergone denaturation of most of the contractable proteins but the collagen shrinkage reaction, the hardening reaction, and collagen solubilization has not entered the picture.

60°C will show the effect of the collagen shrinkage reaction without appreciable hardening reaction and collagen solubilization as well as the effect of enzyme treatment if this is a variable.

74°C will indicate the magnitude of the hardening reaction with only limited effect due to collagen solubilization.

90°C will show some effect of solubilization of collagen though time is a factor of substantial importance in "seeing" this effect.

From the standpoint of simplicity of experimentation, it would be desirable to find out if the changes in the shear pattern "seen" with the above technique can also be distinguished by slowly programming the temperature of a water bath upward from room temperature to about 90°C.

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