Onderstepoort Journal of Veterinary Science and Animal Industry, Volume 21, Number 2, March, 1947.

Printed in the Union of South Africa by the Government Printer, Pretoria.

Meat Studies No. 2.—Toughness of Meat.

By P. J. MEARA, Section of Zootechny and Meat Research.

CONTENTS.

SECTION 1.—INTRODUCTION.

QUALITIES such as flavour, texture, juiciness, colour, and aroma contribute to the appreciation of meat. However, most people agree that tender meat is good meat. Toughness makes for unpalatability, or even inedibility for a section of the population.

Agreement has not been reached regarding the nature of toughness, although the three constituents of meat—muscle fibres, connective tissue, and fat—must each play a rôle. Evidence is still inconclusive as to the exact relationship of the various factors contributing to toughness. These factors are as follows (Sweetman, 1937):—

1. *The quality of muscle fibres.*

Toughness of the muscle fibre depends upon the development and density of the fibre, possibly due to changes occurring with age, activity, etc.. In the past, attention has been directed mainly to the connective tissue content of meat, and quality of fibre has received scant attention. While the quality of any foodstuff is difficult to define, the work of Bate-Smith (1934, 1935), determining the proteins of muscle is a big step towards a precise definition of quality in the case of meat. Unfortunately this lead has not yet been followed up.

2. *The kind and amount of connective tissue.*

Toughness due to connective tissue depends upon the proportion of collagen and elastin present in the meat. In general, elastin constitutes only an insignificant fraction of the connective tissue. As heat has little action on elastin it is unchanged during cooking. On the other hand, heat changes collagen to gelatin which is water-soluble and tender. Furthermore, collagen softens and swells under the action of very dilute acid, thereby facilitating the process of heat change. As the lactic acid normally produced in flesh reaches a concentration of 0·9 per cent. two to three days after slaughter, this is an important consideration.

3. *The amount and distribution of the fat.*

Toughness tends to be diminished by fat deposition within a muscle. Presumably the infiltration of fat between the collagen fibres separates these fibres, which can then be broken down more easily by the preparation of the meat and by chewing.

4. *The texture or " grain " of the meat (size of muscle bundle).*

A coarse texture is usually associated with poor eating qualities (stringy or tough meat). Hammond (1940) is of opinion that the size of the muscle bundles is the main factor affecting tenderness in meat.

5. *The degree of ripeness of the meat.*

During rigor mortis the previously soft and flabby muscle fibres become firm and taut. Meat eaten in this condition is rubbery, but after the resolution of rigor the muscles are soft and more tender. A further noticeable improvement is brought about by an additional period of ripening. Almost certainly the increasing tenderness during ripening must be partly due to a decrease in collagen, but an investigation of the physical consistence of the proteins in the muscle fibre during these changes is also highly desirable.

SECTION 2.—MEASUREMENT OF TOUGHNESS.

A tasting panel may be formed to determine the final quality of the meat. Here selected persons taste a number of meat samples, and grade each sample on a scale of points for each of its properties (tenderness, texture, flavour, etc.). According to the score averaged for specific properties the samples can be rated, in order from best to poorest.

In addition, various mechanical penetrating or cutting devices may be used to grade meat. Owing to the difficulty of establishing an efficient tasting panel these objective methods of measuring tenderness have many advantages. On the other hand, it is almost impossible to imitate the complex cutting and grinding action performed by the teeth, so that these instruments are not entirely reliable in interpreting human taste preferences.

Among the instruments devised for testing meat toughness are the following:—

1. *Tressler and Murray's penetrometer.*

By subjecting the meat to the action of a penetrometer a measurement is obtained of the pressure necessary to force the point of the instrument into the meat. A high reading indicates that great force is required, i.e., toughness.

2. *Warner-Bratzler shear.*

A shearing device has been developed by the United States Bureau of Animal Industry for measuring tenderness. The instrument measures in pounds the shearing resistance of a one-inch sample core, cut with the grain of the meat by means of a sharpened steel cylinder similar to a cork-borer.

3. *Volodkevich's chewing apparatus.*

This apparatus, mainly in use in Germany, records the force required to crush meat between two wedges. The assumption is that the value obtained reproduces the chewing resistance of the meat, and serves as a measure of its tenderness.

4. *Winkler's apparatus.*

Winkler (1939) constructed an apparatus somewhat similar to that of Volodkevich, of simple design, with the advantage of a recording device.

Chemical methods have also been used for comparing meat quality. Unfortunately attention has largely been focussed on connective tissue to the exclusion of muscle proteins. By the chemical determination of the collagen and elastin content it becomes possible to compare different types of muscle, as well as different classes of animals. Lately, workers have determined the amount of collagen changed to gelatin during cooking, to indicate the probable tenderizing effect of different types of cooking. With this method of approach only one phase of the toughness problem is examined, that of connective tissue. The other equally important phase, that of physical consistence of muscle protein, is not considered.

Section 3.—Factors influencing Toughness of Meat.

1. *Muscle Fibres.*

Meat in rigor mortis is generally believed to be less tender than meat taken from the carcass immediately after slaughter and cooked at once. (Brewster, 1944. pages 140-141, 143, 144.) This is due to a hardening and stiffening of muscles during rigor, as a result of the post-mortal coagulation of muscle proteins. The magnitude of this toughening effect can probably be deduced from measurements of the increased hardness of muscle in rigor. Thus, Mangold, cited by Paul *et al* (1944), observed a relative increase in stiffness of muscle during rigor of approximately 67 per cent., as compared with muscle immediately after death. Bate-Smith (1939) showed that " in the Psoas of the rabbit, the onset of rigor is marked by a change in the modulus of elasticity from a value between 700 and 3,000 to one in the neighbourhood of 10,000 ".

After the resolution of rigor, when the muscles again become flabby, the meat is more tender. For instance, chickens killed and stored overnight are more tender than chickens cooked and eaten on the day of killing (Lowe, 1937). Hanson *et al* (1942) too, find that meat from chickens cooked shortly after killing is rubbery and difficult to chew. Paul *et al* (1944) state that beef roasts were " extremely difficult to cut when rigor was at its peak, as they were hard and rigid and the procedure was similar to cutting a rubber cork ".

Toughness of the muscle fibre is regarded as being dependent upon the development and density of the fibre, due to activity and to changes occurring with age. Inherent differences are known to exist in the density of the muscle fibres in different types of muscle and animal. Thus Beard's (1924) histological study showed that, in the toughest muscles the fibres contain the densest sarcoplasm, whereas in the tenderest muscles the fibres contain the lightest sarcoplasm.

Volodkevich (1938) established age differences in the density of muscle fibres. After a force of eleven kilograms had been attained in his apparatus, the resistance across the grain of beef decreased slightly, subsequently increasing markedly when the wedges were close together. With veal this second increase in resistance was absent. His explanation is that the more tender fibres are torn early in the squeezing process, while the stronger, tougher fibres which remain resist this force towards the end of the process.

When meat is subjected to mechanical tests for toughness the direction of the grain of the sample is of importance. If the squeezing or cutting force is applied transverse to the line of the fibres, resistance is offered mainly by the fibres. However, when this action is parallel to the fibres the resistance is derived mainly from connective tissue. Steiner (1939) showed that this latter force is not reduced by an increased period of holding the meat nor by an increased temperature, whereas a marked reduction occurs in the force required to cut through the muscle fibres. He holds that connective tissue plays a negligible rôle in the great reduction of toughness brought about in this way. Rather, there is a change in the muscle fibres which become less dense and are softened.

In addition to the naturally occurring changes, the effect of cooking must also be considered. Moran and Smith (1929), Steiner (1939), Ramsbottom *et al* (1945) hold that raw meat is more tender than cooked meat. A contrary finding is presented by Black *et al* (1931), who obtained results showing that the shearing strength of cooked meat is less than of uncooked meat. Presumably the initial effect of heating is to increase toughness by coagulating the muscle protein, but Steiner observes that the longer cooking is continued the more tender is the final product.

Gottschall and Kies (1942) consider that in the absence of adequate criteria of what constitutes tenderness it is difficult to determine quantitative tenderization of meat. Proteolytic enzymes induce tenderness by virtue of their action in breaking down protein in ripening meat, but Hoagland *et al* (1917) found that the changes in the protein constituents are almost negligible in the case of meat stored for three weeks.

2. *The Connective Tissue Content.*

Differences in connective tissue content have been shown for different species of animals. Pork, for instance, contains little connective tissue. For the different cuts of pork, the percentage of connective tissue is moreover nearly similar, as compared with a wide variation in the different cuts of beef (Mitchell *et al*, 1927). In beef, Mitchell *et al* (1928) found that the less tender cuts (shoulder) contain more collagen than the more tender ones (rib, tenderloin).

This observation is confirmed by Ramsbottom *et al* (1945), who show that muscles containing little connective tissue are more tender than muscles containing large amounts of connective tissue.

It is well known that coarse cuts with large amounts of connective tissue become relatively more tender after hanging than tender cuts containing less connective tissue (Moran and Smith, 1929; Steiner 1939). Observations by Hall and Mackintosh (1930-35) indicate that when beef cuts are ripened the collagen content may change very little when this is originally less than four per cent. When originally eight to ten per cent. of collagen is present this may be reduced one-half and correspondingly less between four and eight per cent.

Contradictory results are found regarding the amount of connective tissue present in animals of increasing age. Observations by Hammond (Moran and Smith, 1929, p. 42) show that the proportion of connective tissue to muscle substance is considerably higher in the tender meat of foetal lamb than in the tougher meat of adult sheep. This finding is corroborated for the rate by Hines and Knowlton (1939). These authors calculate that the connective tissue decreases from forty per cent. of the total muscle mass at fifteen days of age to fifteen per cent. at ninety days. On the other hand, Mackintosh *et al* (1936) obtained a higher collagen value in mature steers than in yearling steers. This was associated also with an increase in shear value. Mitchell *et al* (1932-33) too, report that the connective tissue content of lean meat from choice steer calves may be less than that from carcasses of choice yearling steers.

3. *The Amount and Distribution of Fat.*

Fattening beef animals brings about a relative increase in tenderness of the Longissimus dorsi muscle of about thirty per cent. (Helser *et al*, 1930), so it is to be expected that tenderness increases with increase in the grade of carcass in most animals (Stanley and Cline, 1929). Mackintosh *et al* (1931-35, 1936) show that changes in tenderness are associated with the degree of marbling of the meat, so that an increased finish tends to render meat more tender. In general, tenderness of rib roasts shows a tendency to increase with increasing finish (U.S. Conf. Co-op. Meat Investigations, 1937). Mutton chops from fattened ewes, old and young alike, graded higher in tenderness than cuts from old thin animals (Eckblad and Cline, 1936). More fat was present in the meat of cattle fed a supplement of corn in addition to Lespedeza hay, than in cattle receiving Lespedeza hay alone, and the shearing test showed an increased tenderness of more than thirty per cent. in the meat of the supplemented animals (Report B.A.I., 1941).

In the face of these studies there would seem to be little reason for doubting that fatness increases tenderness. Nevertheless, careful work by Cover *et al* (1944) indicates that it is doubtful whether fatness influences tenderness in lamb to any marked extent. Working with beef, Ramsbottom *et al* (1945) too, find no relationship between the amount of fat within a muscle and the toughness of that muscle.

4. *The Texture or " Grain " (size of muscle bundles).*

Texture and consistence of meat have long been used by the trade as indications of quality. A fine grain, associated with a firm meat and a velvety moist surface, is preferred. In general, coarse texture is associated with diminished tenderness (Hammond, 1940, 1942; Rambottom *et al* 1945). That toughness of meat is associated with texture, is indicated by the improvement effected by hammering meat with a rolling-pin. This has the effect of breaking down the larger muscle bundles into small ones, and decreasing the toughness.

However, the thickness of the muscle fibres comprising the bundle, considered as a separate factor from size of bundle as such, may also exert an influence. Thus, Satorius and Child (1938) found that large bundles of fine fibres are more tender than smaller bundles of thick fibres. Hammond and Appleton (1932) too, showed a tendency for the tenderest muscle to have the thinnest fibres.

In young animals, where the muscle bundles are small in size, the meat is tender. With age the muscle bundles increase in size, due to the increasing size of the component fibres, and the meat becomes tougher. Females have flesh of finer texture than males, with castrated animals occupying an intermediate position. Size of the animal too, has an effect. In small animals (rabbit, sheep) the muscle bundles are smaller and the meat is tender, whereas the meat from large animals (cattle) in which the bundles are larger is tougher. In some muscles the fibres grow much larger than others, hence bringing about an increased coarseness of their texture. For instance, M. Gracilis in the leg of mutton is fine-grained and tender as compared with the coarse-grained M. Vastus lateralis which is tough (Hammond and Appleton, 1932).

Apart from size of fibre or bundle, the distribution of the connective tissue is another factor to be considered in relation to texture. In general, the connective tissue in a fine-grained muscle is finely and evenly distributed throughout the muscle. Presumably such muscles break down easily on mastication, whereas the connective tissue may be distributed in bands and patches in coarsely grained muscle and mastication will probably be more difficult.

Methods of tenderizing meat (beating with a hammer, ripening, prolonged cooking) may all act in an incidental manner by tending to break up the grain. Either the large bundles break down into smaller ones in a mechanical fashion, or by a softening of the connective tissue holding the bundles together a similar effect may be achieved.

The difficulty is to distinguish between connective tissue content and meat texture as separate factors inducing tenderness. In the absence of measurement of texture controlled by parallel determination of connective tissue in the different muscles the relative importance of these factors is not easily decided. For instance, a higher or lower connective tissue content in a muscle may contribute to a lesser or greater degree of tenderness, quite apart from the effect of the texture characteristic of that particular muscle. In the sheep, Hammond and Appleton (1932) have shown that the extensors and flexors of the leg and foot are more finely grained than the thigh muscles. Yet the former class are in general sinewy and tendinous, and do not constitute the meaty muscles of the leg of mutton.

5. *Changes due to Ripening of Meat.*

After death there is a chemical change in the proteins of muscle whereby the muscles become firm, but when rigor mortis passes off the coagulated muscle proteins become converted into soluble forms. Subsequently there is a swelling and softening of collagen fibres due to the lactic acid produced in the muscle after death (Moran and Smith, 1929). As may be expected, the pH of muscle in rigor is roughly proportional to its lactic acid content (Bate-Smith, 1936). According to Moran (1935) the pH of muscle falls from approximately 7·2 to 5·8. As a result of this acidification of the meat the collagen is more easily converted into soluble gelatin by the cooking process. This action is reinforced by a hydrolytic action of the ferments present in muscle, when meat is hung a long while. The latter process apparently does not play an appreciable rôle during the first thirty days (Hoagland *et al*, 1917).

Still other possibilities are suggested by the experiment of Winkler (1939). Samples of raw pork and beef were adjusted to different pH values by injecting appropriate concentrations of lactic acid *or* ammonia. After storing the meat for four days at 0° C. the samples were tested for tenderness and, in general, it was found that the addition of sufficient lactic acid *or* ammonia makes the meat more tender. Winkler thinks it unlikely that hydrolysis of connective tissue around the muscle bundles is responsible for these observed changes in tenderness. He mentions as possible factors changes in the protein water relations, or an increased activity in protein-splitting enzymes.

Histological changes occurring in the muscle fibres of poultry during the onset and resolution of rigor mortis have been described by Hanson *et al* (1942). First characteristic contracture nodes and internodes appear with the onset of rigor mortis. With the resolution of rigor the cell contents become thinner. Later definite breaks appear in the fibres, and finally the striated structure of the fibres changes to a granular type of structure. The authors conclude that these changes within the muscle fibres appear to be correlated with the increasing tenderness of the flesh. Similar changes were observed by Paul *et al* (1944) in their study of beef muscles.

6. *General.*

Apart from the factors already considered it is of interest to mention certain other characters, concerning rather the individual animal.

As regards feeding, a number of investigators have shown that maintenance and sub-maintenance rations produce a peculiar rubbery consistency of the meat (Hunt, 1935; Barbella *et al*, 1936).

As regards heredity, it is likely that breeding may play an important part in producing differences in quality of meat. For instance, the progeny of one sire were shown to have meat of considerably greater toughness than that of another sire (Report B.A.I. 1941). Thus a superior breeding value is established as having material influence on meat quality, apart from factors such as age of animals, their feeding and management, the handling and storing of carcasses (Report B.A.I., 1937, 1939). This fact, that some animals possess a natural tendency to tender meat which is lacking in others, is also brought out by Warner and Alexander (1932).

SECTION 4.—METHODS TO INCREASE THE TENDERNESS OF MEAT.

1. *Hanging.*

It is accepted that hanging meat for a period after slaughter increases its palatability. This is mainly due to the marked increase in tenderness but, in addition, the meat is also more juicy and richer in flavour. Moran and Smith (1929) pointed out that the British public did not appreciate this improved palatability, and mentioned the inertia of the trade to introduce this reform. Consequently, in Britain, carcasses were generally allowed to hang for only twenty-four hours after slaughter to cool and set, before removal to the shops for sale. Moran and Smith report an increase in tenderness of beef of ten per cent. after hanging seven days at 41° F., increasing to thirty-one per cent. after seventeen days. They recommend hanging sides or quarters for ten to twelve days at 36 to 38° F., after an initial cooling of the carcass for one to two days at 31 to 33° F.

In the United States ripening of meat is widely practised. Consumers appreciate the fact that hanging meat increases its tenderness and improves its flavour. As a result a considerable amount of beef is held in cold storage for two to six weeks before delivery to the retail trade. However, it will be noted that the process of ageing can be satisfactorily applied only to carcasses with a good covering of fat. With poorly finished beef the ripening period must be short, due to the increased susceptibility to microbial spoilage, greater shrinkage, etc. Mainly ribs, loins, and hindquarters of high-grade well-fattened cattle are kept at about 36° F. in an atmosphere of fairly low relative humidity. Pork consumers prefer unripened meat. While there is no definite choice in the lamb trade, some customers ask for ripening of hindquarters. In general, however, lamb is moved into the retail trade as quickly as possible to reduce shrinkage losses during storage.

In beef, Hiner and Hankins (1941) found that in order to keep deterioration down to a minimum and yet obtain a large tenderizing effect it is advisable to hang cuts from Low to Good grade beef carcasses for not more than fifteen days at 34° F. The total tenderizing effect between the fifth and thirty-fifth day was 28·2 per cent., of which twenty per cent. occurred from five to fifteen days, and only eight per cent, from fifteen to thirty-five days.

Warner and Alexander (1932) investigated the changes in ripened legs of lamb. Tenderness increased during the first ten days of storage, but during the next ten days only a slight increase was apparent.

Although prolonged ripening is an expensive process, consumers in the United States consider it is justified by the increased palatability, especially tenderness. The disadvantages associated with ripening are mentioned by Ewell (1940). They are, the cost of refrigeration (average five per cent.); the interest on capital invested in meat; the loss of weight (two to ten per cent.); an impaired colour or bloom; and the necessity for trimming as a result of spoilage due to bacteria and moulds.

2. *The Tenderay Process.*

In order to overcome the disadvantages associated with hanging meat a higher temperature may be used to increase the speed of ripening. Steiner (1939), Ewell (1940) showed that the ripening effect is increased as the temperature is raised from 32 to 60° F. As the temperature is increased the rate of tenderizing rises, so that the time required for a given degree of tendering is greatly reduced, e.g., one to three days at 60° F. is equivalent to twenty-one days or longer at 34 to 37° F. However, as the temperature is raised spoilage (bacterial, mould, rancidity) increases even more rapidly than the speed of tendering. Furthermore at high temperatures the bloom is badly spoilt, unless the relative humidity is high, which again favours bacterial and mould spoilage.

An advance became possible when Harvey Rentschler showed that ultra-violet radiation can be used to retard spoilage and reduce shrinkage, when ripening is carried out at a high temperature and high relative humidity. Due to retarded bacterial and mould development the meat can be held at warmer temperatures, and the ripening process is accelerated. Although the cost of installing and operating " Sterilamps " is slight, considerable economic benefit results from the shortened period of storage and a quicker turnover.

Ewell (1939) describes the advantages of this system of ripening. A very slight coagulation occurs on the meat surface, too slight to affect appreciably its appearance or taste. At the same time this coagulation is sufficient to reduce shrinkage materially (several per cent.), this being in addition to the reduction in evaporation loss made possible by the maintenance of a relative humidity of about ninety per cent. Without the " Sterilamp " such humidities result in serious loss after only a few days, due to a surface growth of bacteria and the consequent necessity for trimming.

Ewell (1941) enquired into the factors making possible these desirable effects. Apart from the direct radiation inhibiting or killing air-borne organisms and, to a lesser extent, micro-organisms on the meat surface, a minute concentration of ozone ($\frac{1}{1000}$ p.p.m.) is produced in the radiated air. With a properly controlled air circulation this ozone reaches meat surfaces shaded from the direct radiation and limits development of organisms on surfaces not directly exposed to " Sterilamps ". Apparently these two agents acting in conjunction bring about the favourable effect.

Moulton (1939) describes how beef is aged, at 55 to 58° F. and ninety per cent. relative humidity, in three to four days by the Sterilamp process as compared with several weeks under the methods previously employed. Griswold and Wharton (1941) found that meat held for forty-eight hours at 60° F. under continuous irradiation is slightly more tender than that held at 36° F. for the same length of time. Ensminger *et al* (1942) report that the use of ultra-violet light reduced the surface microflora of beef, but at the same time a greasy appearance was imparted to the tallow during ageing periods of seven to fourteen days.

Deane (1942) mentions the possible ill-effects to personnel of exposure to the Sterilamps, e.g., the radiation arousing latent tuberculosis, conjunctivitis resulting from direct exposure of the eyes to ultra-violet lighting. People are warned not to look directly at the lamps even momentarily, and protection for the eyes is provided by means of a cap with a visor.

The relation of ultra-violet radiation, and temperature during ageing, to quality in beef is reviewed by McIntosh *et al* (1942). They found that ultra-violet radiation reduces the surface microflora of beef. They could detect no difference in texture and tenderness of good quality beef shortloins aged for seven and fourteen days, with and without ultra-violet light at 34° and 50° F. However, they state that the meat was of such good quality initially that it would be difficult to effect improvement. They cite research at the Mellon Institute which showed that the general effect of using high humidity, higher temperature, and Sterilamps was to advance beef at least one government grade.

Porter (1940) quotes results at one market producing a large quantity of tenderay beef. The trimming losses were reduced from approximately six per cent. to less than half of one per cent., and shrinkage to an equally negligible figure, as compared with the older method of hanging beef.

3. *The Birdseye Process of Quick-freezing.*

Before considering the effect of freezing on the tenderness of meat it is desirable to consider the phenomenal development of the Birdseye process. By this process cuts of meat are prepared, wrapped, and placed in a carton for freezing upon a moving belt. At the entrance to the freezing tunnel an overhead belt is kept gently and uniformly pressed against the package to ensure a very rapid heat transfer. As both belts are cooled to very low temperatures, by sprays of calcium chloride brine cooled to about 50° F. below freezing point, the material is frozen rapidly at an extremely low temperature. By virtue of the speed of freezing a great improvement is effected over other freezing processes, as the original structure of the meat is retained.

The possibilities of this method aroused the interest of packers in the United States. As a result quick-freezing was applied in the meat-packing industry in connection with cuts of meat (fillet, steak, roasts), and the commercial distribution of quick-frozen meat to retail trades started about 1930. The advantage of the handy package may be judged from the fact that Kolbe (1930) estimates that in the retail trade economies of 2·5 cents per pound are made through handling the packed products. Another advantage is that the packer retains all waste fractions (fat, bone, trimmings), which can be usefully employed.

In addition to quick-freezing, another development is the freezer locker branch of the industry. Originally started in the middle 1920's this has made enormous progress all over the United States since 1937. In 1941 about 4,000 freezer locker plants were in operation, increasing at the rate of about 100 per month (Carlton, 1941). Assuming an average of 200 rented lockers per plant, the 4,000 lockers were serving upwards of 800,000 families, or a turnover of about 480,000,000 pounds per year of which meats comprised about seventy-five per cent. of the locker output.

Space for the proper storage of quick-frozen foods is provided by these freezing lockers, and commercial distributors are also enabled to serve remote districts. Included in the service provided by the locker plant is also the purchase of carcasses wholesale from the packers for patrons, and the deboning, cutting, wrapping and labelling of the separate cuts of meat. At wholesale prices meats are generally ten to twelve cents per pound cheaper than over the counter retail prices. Thus it is estimated that the average family using 800 pounds of meat per year saves about $60 annually, after deducting the cost of processing and the locker rental.

Little was known of the effect of freezing on tenderness of meat, until the use of temperatures far below freezing point became customary. Then

Tressler and Murray (1932) compared chilled and quick-frozen beef and reported the process of quick-freezing had made the beef more tender. In one experiment a quick-frozen grade C steak became as tender as a non-frozen grade A steak (Tressler *et al*, 1932). Hankins and Hiner (1938, 1940) showed that all freezing temperatures studied (20°, – 10°, – 40° F.) made meat more tender than the unfrozen controls. As there was no real difference in tenderizing steaks between – 10° F. and – 40° F. they recommend the former temperature as being economical and practical for this purpose. In poultry too, the process of quick-freezing renders the thigh muscles consistently more tender than the corresponding muscles from unfrozen control birds (Stewart *et al*, 1945).

Studies were also undertaken to determine the period of time beef should age before it is frozen, in order to achieve a maximum tenderizing effect (Hankins and Hiner, 1941; Hiner and Hankins, 1941). These workers confirmed their previous finding that quick-freezing increases tenderness of beef. By comparison with beef aged thirty-five days at 34°F., beef was of similar tenderness when frozen at – 10° F. after ageing it for only five days at 34° F. The authors recommend that cuts from low good grade beef carcasses should be aged not more than fifteen days at 34° F., then frozen at – 10° F. Bray *et al* (1942), who also studied the effect of freezing aged beef, conclude that after beef has been ripened freezing does not increase its tenderness still further.

All workers do not agree regarding the tenderizing effect produced by freezing meat. Thus, Bull *et al* (1937) reported that the flavour and quality of quick-frozen meats and those not frozen are similar, except that frozen pork is consistently more tender and juicy than the fresh. Paul and Child (1937) too, found no significant difference in tenderness of unfrozen beef and beef frozen at 0·6° F. However, Brady *et al* (1942) point out that under the conditions of this experiment it took twenty-five hours for the interior of the meat to reach this temperature, whereas in their own experiment an average of only seven hours was required for the interior of the quick-frozen meat to reach a temperature of 0° F. Thus, not only room temperature at which freezing takes place, but also the actual freezing rate plays an important part in the tenderizing process. Owing to differences in the mechanical set-up cuts of meat may be frozen in markedly different lengths of time, even under the same temperature conditions.

Recent work by Hiner, Madsen and Hankins (1945) throws light on the nature of the histological changes occurring during the quick-freezing of meat. As these authors review the literature dealing with the histology of ice-formation in frozen meat, no mention is made here of the earlier work in this field. In their study, beef shearing tests showed a consistent increase in tenderness as the freezing temperature is progressively lowered from 18° F. to – 114°. Histological sections of the frozen beef showed that *inter*-fibrillar ice is formed at relatively high freezing temperatures (18° F.) As the freezing temperature is lowered (0°, – 10°, – 40°, – 114°),*intra*fibrillar freezing becomes progressively more extensive. The expansion occurring when the cell moisture is frozen *intra*cellularly tends to rupture the muscle fibre itself, and at – 114° F. nearly every fibre is ruptured. Hiner and his co-workers believe that the tenderizing effect of low freezing temperatures is largely due to disintegration of fibres, resulting from *intra*fibrillar ice formation, but partly also by stretching and rupture of the interstitial connective tissue.

With the impetus afforded by war conditions another major development has been brought about. Quick-freezing can now be applied to whole quarters of beef. Previously only small cuts could be treated, but by the Brewster process whole quarters of beef are boned out and frozen in the same number of hours as it formerly took days (Brewster, 1944). Stated briefly, warm meat is deboned immediately after killing and the deboned beef is compressed into moulds, for freezing by brine sprays at $-14 \cdot 8°$ F., for six hours. After freezing, the moulds are thawed in approximately forty seconds sufficiently for the block of frozen meat to be removed from the mould, for bagging and shipment in freezers at $-18°$ F. The chief merit of the new process is the saving of roughly thirty-five per cent. of storage and transport space as compared with *ordinary type boneless beef.* The possibilities of this new development are enhanced by the fact that this quick-frozen beef is claimed to be perhaps even better in palatability than pre-war *chilled beef.* Brewster suggests this is because freezing is carried out before rigor mortis sets in. His observations show that meat which is " quickly frozen immediately after killing retains during its frozen state, and on thawing out, the characteristics of freshly-killed meat ". Bate-Smith (1944) discusses the theoretical basis making possible this desirable state of affairs.

4. *The use of Enzymes for Tenderizing Meat.*

Yet another development has been the utilization of enzymes in tenderizing meat. For instance, 223,000 pounds of crude papain were imported into the United States in 1938 in comparison with 54,000 pounds in 1932, its greatest use being in the manufacture of meat tenderisers (Ramsbottom and Rinehart, 1940).

These authors also mention the first industrial use of bromelin (the proteolytic enzyme in pineapple juice) in the meat-packing industry. Here the casing containing the sausage meat is treated by spraying bromelin as a fine mist onto the casing of large " frankfurters " and sausages. By virtue of the action of the bromelin the complex natural proteins of the animal casings are broken down into proteins of simpler composition less resistant to mastication and digestion. Thus penetrometer test readings, of treated as compared with untreated " Frankfurters," yielded average readings of 75·7 and 122·2 units.

5. *Cookery.*

In the preceding pages an attempt has been made to discuss briefly the general problem of toughness of meat, and the methods whereby a degree of tenderizing may be effected. Cookery has not been mentioned. Obviously, this final stage is extremely important, as indifferent preparation may offset the benefits of skilled animal husbandry and meat processing up to this point. It is clear that cooking should be such that the quality and flavour of good meat are in no way impaired. Furthermore, skill must also be exercised to improve the palatability of inferior quality meat. That workers are alive to the importance of the cookery process is evidenced by the vast amount of information available regarding this aspect of the problem. American workers, mainly, have pioneered the investigation of scientific cookery. Enormous progress has been reported in the United States since 1925, when co-operative meat investigations were first undertaken (U.S. Conf. Co-op. Meat Investigations, 1937, 1942).

Acknowledgments.

My thanks are due to Professor J. H. R. Bisschop, Section of Zootechny and Meat Research, Onderstepoort, and to Mr. R. Hirzel, Chief Meat Grader, Division of Animal and Crop Production, for reading the manuscript and making suggestions.

REFERENCES.

BARBELLA, N. G., HANKINS, O. G., AND ALEXANDER, L. M. (1936). The influence of retarded growth in lambs on flavour and other characteristics of the meat. *Proc. Amer. Soc. Animal Prod.*, 1936, pp. 289-294.

BATE-SMITH, E. C. (1934). A scheme for the approximate determination of the proteins of muscle. *J. Soc. Chem. Ind.*, Vol. 53, pp. 351T—354T.

BATE-SMITH, E. C. (1935). The proteins of meat. *J. Soc. Chem. Ind.*, Vol. 54, pp. 152T-154T.

BATE-SMITH, E. C. (1936). The effect of fatigue on post-mortem changes in muscle. *Rept. Food Investigation Board* (Great Britain), pp. 21-25.

BATE-SMITH, E. C. (1939). Changes in elasticity of mammalian muscle undergoing rigor mortis. *J. Physiol.*, Vol. 96 ,pp. 176-193.

BATE-SMITH, E. C. (1944). The quick freezing of meat. *Modern Refrig.*, Vol. 47, pp. 267-269.

BEARD, F. J. (1924). A study of tough and tender meat. Master's Thesis, Iowa State College. *Cit.* Lowe, B. (1937).

BLACK, W. H., WARNER, K. F., AND WILSON, C. V. (1931). Beef production and quality as affected by grade of steer and feeding grain supplement on grass. *U.S. Dept. Agric. Tech. Bull.*, No. 217.

BRADY, D. E., FREI, P., AND HICKMAN, C. W. (1942). Effect of freezing rate on quality of broiled steaks. *Food Res.*, Vol. 7, pp. 388-393.

BRAY, R. W., VAIL, G. E., AND MACKINTOSH, D. L. (1942). Influence of freezing on tenderness in " aged " beef. *J. Animal Sc.*, Vol. 1, p. 81.

BREWSTER, J. A. (1944). The quick freezing of beef in quarters: commercial, engineering and biological aspects. *Proc. Inst. Refrig.*, Vol. 40, pp. 133-148.

BULL, S., WOODRUFF, S., AND ROGOSHESKI, E. (1937). A preliminary study of the use of frozen meats. *U.S. Conf. Coop. Meat Investigations, Rept. Rev. Comm.* 1937, Vol. 2, Pork, Ref. No. 157.

CARLTON, H. (1941). Quick-frozen foods and refrigeration. *Refrig. Eng.*, Vol. 41, pp. 328.

COVER, S., MACKEY, A. K., MURPHEY, C. E., MILLER, J. C., BASS, H. T., BELL, C. L., AND HAMALAINEN, C. (1944). Effects of fatness on tenderness of lamb. *Texas Agric. Exp. Sta. Bull.* No. 661.

DEANE, D. L. (1942). Ultra-violet radiation in meat storage. *Army Vet. Bull.*, Vol. 36, pp. 210-219.

ECKBLAD, I., AND CLINE, J. A. (1936). Cooking losses, cooking time, palatability, serving value of mutton chops. *U.S. Conf. Coop. Meat Investigations, Rept. Rev. Comm.*, 1937, Vol. 2, Cookery, Ref. No. 55.

ENSMINGER, W. E., SOTOLA, J., McINTOSH, J. A., PROUTY, C. C., AND ROBERTS, J. (1942). The relation of ultra-violet light and temperature during ageing on quality of beef. *J. Animal Sci.* Vol. 1, p. 351.

EWELL, A. W. (1939). New developments in the use of ultra-violet light in food storage. *Refrig. Eng.*, Vol. 37, pp. 27-28.

EWELL, A. W. (1940). The tenderizing of beef. *Refrig. Eng.*, Vol. 39, pp. 237-240.

EWELL, A. W. (1941). Researches on ultra-violet light and ozone, and their relations as germicidal agents. *Refrig. Eng.*, Vol. 41, pp. 331-334.

GOTTSCHALL, G. Y., AND KIES, M. W. (1942). Digestion of beef by papain. *Food Res.*, Vol. 7, pp. 373-381.

GRISWOLD, R. M., AND WHARTON, M. A. (1941). Effect of storage conditions on palatability of beef. *Food Res.*, Vol. 6, pp. 517-528.

HALL, J. L., AND MACKINTOSH, D. L. (1930-35). Physical and chemical indices of ripening performance. *U.S. Conf. Coop. Meat Investigations, Rept. Rev. Comm.* 1937, Vol. 1, Methods, Ref. No. 31.

HAMMOND, J. (1940). Some factors affecting the quality and composition of meat. *Chem. and Ind.*, Vol. 59, pp. 521-525.

HAMMOND, J. (1942). Factors influencing the composition and the properties of meat. *Chem. and Ind.*, Vol. 61, p. 334.

HAMMOND, J., AND APPLETON, A. B. (1932). Growth and development of mutton qualities in the sheep. Part 5. Oliver & Boyd, Edinburgh and London.

HANKINS, O. G., AND HINER, R. L. (1938). Tenderness of beef as affected by different freezing temperatures. *Proc. Amer. Soc. Animal Prod.*, 1938, pp. 260-261.

HANKINS, O. G., AND HINER, R. L. (1940). Freezing makes beef tenderer. *Food Industries*, Vol. 12, Part 1, pp. 49-51.

HANKINS, O. G., AND HINER, R. L. (1941). Quality of meat as affected by freezing temperatures. *Refrig. Eng.*, Vol. 41, pp. 185-188.

HANSON, H. L., STEWART, G. F., AND LOWE, B. (1942). Palatability and histological changes occurring in New York dressed broilers held at 1·7° C. (35° F.), *Food Res.*, Vol. 7, pp. 148-160.

HELSER, M. D., NELSON, P. M., AND LOWE, B. (1930). Influence of the animal's age upon the quality and palatability of beef. *Iowa Agric. Expt. Sta. Bull.*, No. 272.

HINER, R. L., AND HANKINS, O. G. (1941). Tenderness of beef as affected by aging with and without subsequent freezing. *Refrig. Eng.*, Vol. 42, pp. 172-174.

HINER, R. L., MADSEN, L. L., AND HANKINS, O. G. (1945). Histological characteristics, tenderness and drip losses of beef in relation to temperature of freezing. *Food Res.*, Vol. 10, pp. 312-324.

HINES, H. M., AND KNOWLTON, G. G. (1939). Effect of age upon the cellular phases of skeletal muscle. *Proc. Soc. Exp. Biol. and Med.*, Vol. 42, pp. 133-135.

HOAGLAND, R., McBRIDE, C. N., AND POWICK, W. C. (1917). Changes in fresh beef during cold storage above freezing. *U.S. Dept. Agric. Bull.*, No. 433.

HUNT, W. E. (1935). Fattening thin native lambs. *Maryland Agric. Expt. Sta. Bull.*, No. 379, pp. 115-117.

KOLBE (1930). Why quick-freeze? *Food Industries*, Vol. 2.

LOWE, B. (1937). Experimental cookery. John Wiley & Sons, Inc., New York.

MACKINTOSH, D. L., HALL, J. L., AND VAIL, G. (1931-35). Relation of ether-extract of beef ribeye to mechanically separable fat and to tenderness as judged by committee. *U.S. Conf. Coop. Meat Investigations, Rept. Rev. Comm.*, 1937, Vol. 1, Methods, Ref. No. 3.

MACKINTOSH, D. L., HALL, J. L., AND VAIL, G. (1936). Some observations pertaining to tenderness of meat. *Proc. Amer. Soc. Animal Prod.*, 1936, pp. 285-289.

MANGOLD, E. (1921, 1922). Cit, Paul, P., Lowe, B., and McClurg, B. R. (1944).

McINTOSH, J. A., SOTOLA, J., BOGGS, M., ROBERTS, J., PROUTY, C. C., AND ENSMINGER, M. E. (1942). The relation of ultra-violet light and temperature during aging to quality of beef. *Washington Agric. Expt. Sta. Bull.*, No. 422.

MITCHELL, H. H., BEADLES, J. R., AND KRUGER, J. H. (1927). The relation of the connective tissue content of meat to its protein value of nutrition. *J. Biol. Chem.*, Vol. 73, pp. 767-774.

MITCHELL, H. H., HAMILTON, T. S., AND BULL, S. (1932-33). Quality of yearling and baby beef compared in tests. *Illinois Agric. Expt. Sta., 46th Ann. Rept.*, 1933, pp. 77-78.

MITCHELL, H. H., HAMILTON, T. S., AND HAINES, T. W. (1928). Some factors affecting the connective tissue content of beef muscle. *J. Nutrition*, Vol. 1, pp. 165-178.

MORAN, T. (1935). Post-mortem and refrigeration changes in meat. *J. Soc. Chem. Ind.*, Vol. 54, pp. 149T-151T.

MORAN, T., AND SMITH, E. C. (1929). Post-mortem changes in animal tissues—the conditioning or ripening of beef. *Food Investigation Board Spec. Rept.*, No. 36.

MOULTON, C. R. (1939). Ultra-violet radiation in the meat-packing industry. *Food Manufacturer*, Vol. 14, pp. 232-235.

PAUL, P., AND CHILD, A. (1937). Effect of freezing and thawing beef muscle upon press fluid, losses, and tenderness. *Food Res.*, Vol. 2, pp. 425-431.

PAUL, P., LOWE, B., AND McCLURG, B. R. (1944). Changes in histological structure and palatability of beef during storage. *Food Res.*, Vol. 9, pp. 221-233.

PORTER, T. R. (1940). Ultra-violet finds new applications. *Food Industries*, Vol. 12, Part 7, pp. 51-53.

RAMSBOTTOM, J. M., AND RINEHART, C. A. (1940). Meat-packer puts fruit enzyme to work. *Food Industries*, Vol. 12, Part 6, pp. 45-47.

RAMSBOTTOM, J. M., STRANDINE, E. J., AND KOONZ, C. H. (1945). Comparative tenderness of representative beef muscles. *Food Res.*, Vol. 10, pp. 497-509.

REPORT B.A.I. (1937). Animal breeding and meat research. *Rept. Chief B.A.I.*, 1937, U.S. Dept. Agric., p.3.

REPORT B.A.I. (1939). Meat investigations. *Rept. Chief B.A.I.*, 1939, U.S. Dept. Agric., p. 10.

REPORT B.A.I. (1941). Meat investigations. *Rept. Chief B.A.I.*, 1941, U.S. Dept. Agric., p. 14-15.

SATORIUS, M., AND CHILD, A. M. (1938). Effect of cut, grade and class upon palatability and composition of beef roast. *Minnesota Agric. Expt. Sta. Tech. Bull.*, No. 131.

STANLEY, L., AND CLINE, J. A. (1929). Tenderness of steaks as affected by carcass grade. *U.S. Conf. Coop. Meat Investigations, Rept. Rev. Comm.*, 1937, Vol. 2, Cookery, Ref. No. 51.

STEINER, G. (1939). Die postmortalen Veränderungen des Rindermuskels bei verschiedenen Temperaturen, gemessen an seinem mechanischen Verhalten. *Arch. f. Hyg.*, Vol. 121, pp. 193-208.

STEWART, G. F., HANSON, H. L., LOWE, B., AND AUSTIN, J. J. (1945). Effects of aging, freezing rate and storage period on palatability of broilers. *Food Res.*, Vol. 10, pp. 16-27.

SWEETMAN, M. D. (1937). Food preparation. John Wiley & Sons, Inc., New York.

TRESSLER, D. K., BIRDSEYE, C., AND MURRAY, W. T. (1932). Tenderness of meat. I. Determination of relative tenderness of chilled and quick-frozen beef. *Indus. and Engin. Chem.*, Vol. 24, pp. 242-245.

TRESSLER, D. K., AND MURRAY, W. T. (1932). Tenderness of meat. II. Determination of period of aging grade A beef required to produce a tender quick-frozen product. *Indus. and Engin. Chem.*, Vol. 24, pp. 890-892.

U.S. CONF. COOP. MEAT INVESTIGATIONS (1937). Beef, degree of finish. *U.S. Conf. Coop. Meat Investigations, Rept. Rev. Comm.*, 1937, Vol. 1, Ref. No. 30-37.

U.S. CONF. COOP. MEAT INVESTIGATIONS (1937). Cookery. *U.S. Conf. Coop. Meat Investigations, Rept. Rev. Comm.*, 1937, Vol. 2, Ref. No. 1-34.

U.S. CONF. COOP. MEAT INVESTIGATIONS (1942). Cookery, *U.S. Con. Coop. Meat Investigations, Rept. Rev. Comm.*, 1942, Vol. 4, Ref. No. 72-92.

VOLODKEVICH, N. N. (1938). Apparatus for measurements of chewing resistance or tenderness of foodstuffs. *Food Res.*, Vol. 3, pp. 221-225.

WARNER, K. F., AND ALEXANDER, L. M. (1932). Lamb becomes more tender when ripened by period of storage. *Yearbook of Agric.*, 1932, *U.S. Dept. Agric.*, pp. 260-263.

WINKLER, C. A. (1939). Tenderness of meat. 1. A recording apparatus for its estimation, and relation between pH and tenderness. *Canad. J. Res., D, Zool. Sci.*, Vol. 17, pp. 8-14.