4:4 Mechanical properties of pork fatty tissue

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1. Introduction

The quantity and physical properties of fatty tissue are important attributes of carcass quality. In recent years in the UK pig carcasses have become leaner and, by 1983, average P_2 for fat thicknesses in carcasses weighing 60-80 kg had declined to 15mm and entire males as a percentage of all pigs classified had risen to 22%. (Meat and Livestock Commission 1984). There is increasing anecdotal evidence of tissue quality problems associated with the leaner and lighter carcasses, although its incidence has not been quantified. The main defects are wet, soft muscle and soft, oily and floppy subcutaneous fatty tissue which has a tendency to separate from the underlying muscles. The meat is unattractive and difficult to handle, slice and pack.

Subcutaneous adipose tissue is an irregular connective tissue in which fat cells mature and become the principal component. In transverse section the cells have a polyhedral appearance with four to six faces and are surrounded by connective tissue fibres (Hausman, 1978; Stanley and Voisey, 1979). Pork subcutaneous backfat has two principal layers. The outer, in which the supporting connective tissue appears to be a continuous three dimensional network with ramifications to the dermis, is separated from the inner by a thin layer of connective tissue. In immature animals, that part of the inner layer adjacent to M. longissimus consists of sub-layers each bounded by a lattice of connective tissue. As the tissue develops the sub-layers fill with lipid and become less distinct. With increasing maturity a third layer may develop over the LD (Moody and Zobrisky, 1966). The growth from presumptive to mature adipose tissue will therefore alter cellular and supporting tissues, and mechanical properties.

In previous studies attention has concentrated on the lipid component; texture of backfat being discussed in terms of fatty acid composition (Wood et al. 1978). Dransfield and Jones (1984) investigated texture and mechanical properties of pork backfat in relation to hardness and described methods for its assessment. Tschizhikova et al. (1971a,b) described a method for measuring breaking stress in backfat and measured the ultimate shear stress of pork backfat with a conical plastometer; Stanley and Voisey (1979) presented texture-structure relationships in cooked Canadian bacon. This paper rationalises published data on mechanical properties of pork backfat with recent measurements made at the Meat Research Institute to relate mechanical properties to composition of backfat from boar, gilt and castrate pigs.

2. Materials and Methods

2.1 Cohesiveness of fat and muscle

The structural integrity of pork tissue was determined by tensile loading along the dorsal-ventral axis (Wood et al. 1984a). Cores of tissue, 36 mm diameter, with centres 65 mm from the dorsal mid-line and 30 mm caudal to the last rib (Figure 1,A), were taken from boars and castrates at 90 kg live weight. The skin surface was bonded with cyanoacrylate to an aluminium disc attached via a flexible coupling to the load cell of a materials testing machine (Instron TM-SM). The lower surface (M. longissimus) was similarly attached through a rigid coupling to the movable crosshead. At 20 ± 1°C the cores were extended at 50 mm/min. - nominal strain rate 0.035 s^{-1}. A continuous record of force and extension was obtained in relation to the observed yielding, separation and rupture of the component tissues.

2.2 Viscoelasticity of fatty tissue

The time-dependent relaxation modulus was determined on cylinders of subcutaneous fatty-tissue 30 mm diameter. They were cut along the dorsal-ventral axis with a cork borer from frozen and tempered (1°C) blocks of backfat from commercial pigs of liveweight 80-110 kg. The cylinders contained skin, outer and inner layers of fatty tissue (Figure 1,B) and were compressed between parallel plates by 10% (about 2 mm) of original height in 0.5s at 3°C in water (Dransfield and Jones, 1984). Force was recorded for 1 hour. The relaxation modulus, at time t sec after compression (Et), was the ratio of nominal stress and strain measured at right angles to the plates. Isochronal load-strain curves were derived from relaxation data on cylinders compressed between 2-8%

2.3 Tensile strength of fat layers

The strength of isolated inner and outer layers of subcutaneous fatty tissue was measured under tension in 'normal' and collagen-rich tissues. Slices were taken from the dorsal mid-line ('normal' fatty tissue) in the scapula region of the carcass of a pure-bred Large White boar between 4 and 5 years old (Figure 1,C) and from beneath the 'boar-shield' 30 cm from the mid-line (collagen-rich fatty tissue). Strips of inner and outer layers were clamped in the pneumatically operated grips of the materials testing machine and extended along the cranial-caudal axis at 50 mm/min - nominal strain rate 0.028 s^{-1}, at 19 ± 1°C until complete rupture.

2.4 Sensory assessment of backfat texture

Subcutaneous fatty tissue and skin dorsal to M. longissimus thoracis at the 4th/5th rib was dissected from castrated male pigs, 80 - 110 kg live weight, slaughtered in a commercial abattoir.

A panel comprising 6 staff of the Meat Resarch Institute assessed firmness of the chilled fat after handling and recorded their judgements by marking a 200 mm horizontal line. The left extremity was labelled 'extremely soft' and the right 'extremely hard'. An 8-point category scale was devised (Dransfield and Jones, 1984); 1 corresponding to extreme softness and 8 to extreme hardness. The most discriminating panellist used this scale to assess hardness of shoulder fat at 1°C from 120 commercial pigs in which P2 ranged from 6 to 20 mm. ie. near and below the current United Kingdom average (Meat and Livestock Commission, 1984).

2.5 Objective measurement of hardness

An index of hardness was obtained by measuring force during the compression of fatty tissue with a probe. Blocks of subcutaneous fat and skin 60 mm long were taken from the mid-line cranial to the 4th rib (Figure 1,D). They were mounted in a brass holder with the medial surface of the inner and outer layers uppermost. Height of the block was 20 mm. Storage and preparation was at 1°C. A portable compression Response Analyser (Stevens, Ltd. St Albans, UK) was calibrated and operated in the humidity controlled cold roo at 1°C. A 4 mm diameter flat-ended probe was attached to the 10 kgf load cell and the Analyser controls set so that the probe was driven down until it touched the fat. When a trigger force of 25 gf was exceeded it travelled a further 3mm, indenting the fat. Peak force was locked in the digital display. The index of hardness of each layer was the mean of 5 measurements each made at a separation of 10 mm caudally along outer and inner layers. It was calibrated against the sensory assessments of 120 samples by an expert judge .

Results

3.1 Cohesiveness of fat and muscle

In samples from boars and castrates there was a characteristic mode of failure with extension of the cores. A first peak force, often the maximum force recorded before complete rupture, occurred at about 50% extension and coincided with a major structural failure within the innermost sub-layers of fatty tissue adjacent to M. longissimus. These layers were extended preferentially exposing the fine network of supporting tissues. With continued extension to about 400% of the initial length, a complete break occurred within the innermost layers. At breakage the fascia of connective tissue over M. longissimus remained intact. Another partial structural failure occurred between inner and outer layers leading to gaping but not complete rupture. The stress to initiate tissue separation in young boars was about 70% of that in castrates and the maximum stress 78% of that in castrates (Table 1).

3.2 Viscoelasticity of fatty tissue

Isochronal stress-strain data showed the viscoelasticity of fatty tissue to be non-linear. At selected times after compression the time-dependent relaxation modulus (Et) increased with hardness of the fatty tissue (Table 2). At 0.5 sec, Et was about 1500 KN/m^2 for hard fat and 50 KN/m^2 for soft. $\log_{10}E_t$ was linearly related to sensory hardness.

3.3 Tensile strength

For strips of fatty tissue tested along the cranial-caudal axis small (<3%) extension caused little increase in force and thereafter a rapid rise in force occurred until a point of inflexion in the load-extension curve was reached at about 20% extension. A modulus was calculated at this yield poi and defined as maximum stiffness. The outer layer of fat from the back was about 6 times stiffer than the inner and from under the boar shield, tissue was about 50 times stiffer than the inner layer from the back (Table 3). A extension continued, water was expelled from the strip and collected on its surface. When fracture started, propagation was rapid producing a clearly defined peak force. This maximum force dividing by the initial cross-sectional area of the strip was the nominal tensile strength. Tensile strength and extension at break were also higher in the outer fat and in f from beneath the boar shield. (Table 3).

3.4 Objective measurement of hardness

Using the Stevens Compression Response Analyser, 10 samples per hour could prepared and measured at 1°C. The average of five measurements of probe force on the inner layer of subcutaneous fatty tissue ranged from 70 - 27 gf (0.7 - 27N) for 120 samples. Coefficients of variation of sample means (standard deviation/mean) were around 10%. The sensory assessments of the samples occupied all categories of the 8-point hardness scale, with not le than 9 fats in each. Figure 2 shows the relationship between subjective objective hardness. If the probe force (y) was scaled ($y \mapsto y^{1/2}$) then the objective measurement was proportional to the subjective (F(N) ≅ 0.6 Har r = 0.9).

4. Discussion

Although a considerable amount is known about the mechanical properties of refined fats, little is known of the mechanical properties of fatty tissue and this has led to recent problems of soft fat being unpredictable.

The mechanical properties limit meat processing and acceptability to the consumer. A full appraisal requires mechanicl properties under tension compression of the composite tissue as a whole and of the individual substructures.

The whole tissue containing skin, two or three principal fat layers and muscle when extended normal to skin, fails mainly by separation between fat layers particularly in the innermost layers of fat closest to the mu This tissue eventually breaks with stress of 3KN/m^2. The region of fail is therefore the less mature fatty tissue which contains a complete organisation of connective tissue and groups of adipocytes not all of wh are filled with storage lipid (Hausman, 1978). Clearly, this type of mechanical failure could also occur without the presence of the skin, for example in rindless bacon, and also when the meat is subjected to shear stresses which are common during handling, slicing, cutting and packagin meat.

Tensile tests on individual layers of mature fat showed that they were stiffer than the composite whole immature tissue. The inner layer had ultimate tensile strength of about 300 KN/m^2 (ie. about 100 times strong than the whole tissue) and the outer about 1500 KN/m^2. Similar values found for mutton backfat (Tschizhikova et al. 1971a). Connective tissue strength is likely to dominate the ultimate tensile strength. Collagen tissue (from beneath the 'boar shield') in which 20 to 30% of the wet is collagen compared with only 3 to 4% for tissue not under the boar sh (Wood et al. 1984b) is very much stronger with a tensile stength of 11, KN/m^2 for the outer layer.

Compression and stress relaxation were used to study the hardness and time-dependent viscoelastic properties of fatty tissue. Compression be about 4% caused a dramatic increase in stiffness suggesting an involve a network of connective tisue (Dransfield and Jones, 1984). At 10% compression, in 'soft' fats the relaxation modulus was about 30 KN/m^2, sec after compression and 20 KN/m^2 at 1 hour. Relaxation was slower in 'hard' fats and the moduli were about an order of magnitude higher, and dominated by the lipid properties at chill temperatures. When the rela curves were analysed by exponential decay (ie equivalent to spring and dashpot elements in series - generalised Maxwell model) the equilibrium modulus ranged from 10 in soft to 290 KN/m^2 in hard fats, and the elastic moduli were about 3.10^3 to 400 KN/m^2. Viscosity elements were time dependent ranging from 10^4 to 10^8 Pa-sec.

Sensory evaluation of fat firmness is performed at relatively high deformation rates (Dransfield and Jones, 1984) but relaxation parameters determined soon after the start of relaxation were no better at predicting sensory firmness than were parameters at much longer times. Firmness was related to the probe forces which also showed that the outer layer of fat was harder than the inner layer which is consistent with the tensile properties.

5. References

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Table 1. Cohesiveness (Nm^{-2} x 10^3) of pork subcutaneous backfat

	Peak Stress Initiating Tissue Separation	Maximum Stress Before Complete Rupture
Boars	3.3	4.0
Castrates	4.6	5.1
Standard Error Of Difference	0.8	0.7

(Wood, J.D. et al. 1984a)

Table 2. Firmness and Relaxation Modulus of pork backfat

Firmness*	Relaxation modulus (N/m^2 x 10^4)	
	2.5 sec.	1 hour
52	3.4	1.6
71	9.2	3.4
75	6.3	3.0
98	14.9	5.4
181	77.5	27.0
182	79.0	28.1

* 0 = extremely soft; 200 = extremely hard.
(Dransfield and Jones, 1984)

Table 3. Tensile Strength of boar subcutaneous fatty tissue

Position	Maximum Stiffness (Nm^{-2} x 10^6)	Tensile Strength (Nm^{-2} x 10^6)	Extension At Break (% Lo)
Dorsal Mid-line Inner Layer	0.8 (0.08)	0.3 (0.03)	74 (7)
Outer Layer	5.0 (0.5)	1.5 (0.1)	67 (5)
Beneath 'boar shield' Outer Layer	39 (0.6)	11 (0.2)	42 (3)

Standard error in parentheses.

Figure 1 Sampling diagram for measurements of mechanical properties of pork tissues (see Materials and Methods)

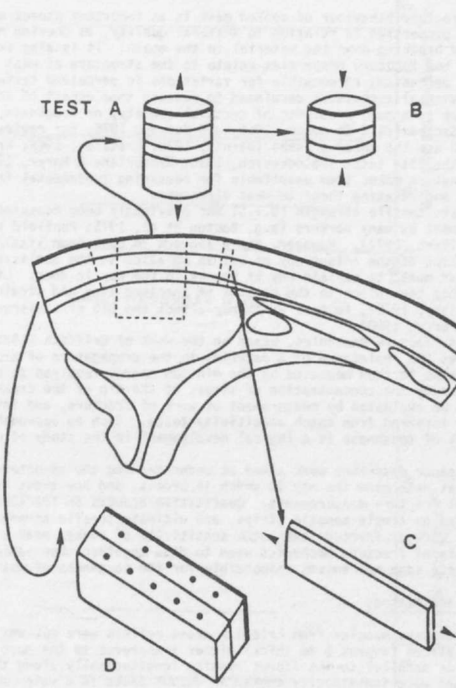

Figure 2. Relationship between probe force and hardness of pork fatty tissue. Category 1 = extremely soft, category 8 = extremely hard. Values are the number of samples and lines their standard error