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Early Experiments on Meat in Near Infrared (NIR) Light

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ABSTRACT

Experiments with thin slices of meat showed that fat content is the dominant factor affecting NIR transmittance and reflectance. But beyond the peak wavelengths for fat detection, polarized NIR may also detect sarcomere length and *p*H-related aspects of meat quality, provided that the orientation of polarized NIR and muscle fibre orientation is controlled. The same relationships may be obtained from the surface of bulk meat using a combination of fibre optics with a graded index lens.

Keywords: Infrared light, Meat, Fibre optics, Polarized light.

INTRODUCTION

Infrared spectroscopy exploiting empirical correlations is now viewed as a possibility for authentication of meat products [1, 2] and prediction of meat quality [3, 4]. Early research on meat in NIR started with an analytical approach trying to understand how the low scattering of NIR (700 to 800 nm) might differ from the high scattering of visible light (400 to 700 nm). In the 1980s, fat depth probes for grading pork carcasses had just become available (the less subcutaneous fat, the more valuable the carcass). There were electrical probes, ultrasonic probes, and optical probes, and optical probes used either visible light or NIR diodes. Very little was known at this time about how even visible light interacts with meat, and NIR was completely unknown. The initial goal of explaining fat to meat boundaries using NIR was soon answered, but beyond this there was evidence that polarized NIR might detect aspects of meat microstructure.

FIBRE OPTICS

Connecting a lump of meat to optical apparatus has always been a problem. The meat may be very messy, and the optical apparatus may be very fragile. Fibre optics was an obvious way to make this connection, but this soon encountered a new set of problems. The 1980s were a great time for anyone building NIR apparatus – suitable optical fibres from telecommunications were easily available, NIR could be obtained from ordinary tungsten illuminators, and there were responsive photomultipliers and photodiodes. No need for Nernst lamps with ceramic rods heated to incandescence or monochromators with front silvered mirrors, as needed for higher wavelengths.

A Y-shaped or bifurcated light guide could be made by splicing together two optical fibres or bundles of optical fibres – one to illuminate the meat, and the other to record reflected light. But what to call the reflected light? This was a time when medical scientists were using similar systems and they tended to be quite particular in their semantics. One group argued that reflected light entering a two dimensional optical fibre window should be called sterance – flux per unit of a solid angle. The other group argued that the direction of the propagation of the flux could not be normal to the window (as required for sterance) because it was originating from a myriad of reflective tissue boundaries, and it should be termed interactance. It is unwise for anyone attempting to publish a scientific paper to challenge the authority of reviewers and editors swayed by current changes in terminology. Eventually, sterance and interactance gave way to back-scatter as the preferred name, as may be seen in figures reviewed her. One can cut through these semantic arguments by simply using reflectance in a loose way to name the light returning from a bifurcated light guide. But the scientific dilemma is important – which microscopic components in meat reflect and which absorb infrared light?

When this research was undertaken there was the possibility that the widely used NIR diodes detecting fat-lean boundaries in pork carcasses might also be able to detect pale, soft, exudative (PSE) muscle [5]. A pinwheel containing interference filters was mounted in front of a tungsten illuminator to illuminate the meat and the light returned from the meat was measured with a silicon detector. Measurements had to be made in a dark room. A transform was used to enhance the sensitivity of the system (absorbance, base 10 logarithm of the reciprocal of light returned from the bifurcated light guide).

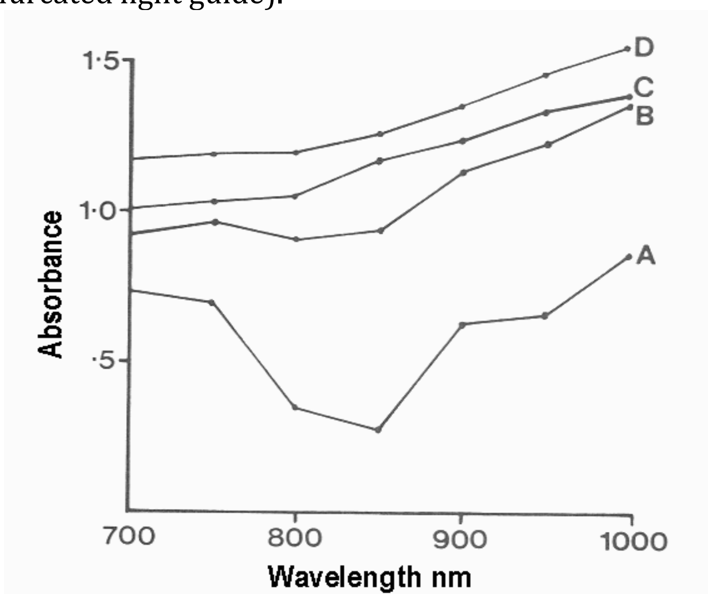

Fig 1: NIR absorbance of pork subcutaneous fat (A), pork *semitendinosus* (B), pork *vastus intermedius* (C), and beef *longissimus thoracis* (D) [5].

The absorbance of beef was the high because of its high myoglobin content while the absorbance of pork muscle was low (Fig. 1). The optimum wavelength for the detection of a fat-lean boundary was at 850 nm, as used in a NIR fat depth probe. This is a tribute to the anonymous engineers who developed NIR probes or a fortunate coincidence because 850 nm diodes are relatively easy to use and they were already widely available in the 1980s. There is no doubt that an 850 nm cut off to detect a boundary between fat and muscle was a good choice, but what about trying to use an 850 nm diode to detect PSE meat at the same time?

Detecting PSE pork is no longer the urgent problem it once was, because the genetic and environmental causes of PSE are now well known and it may be avoided, but might NIR detect anything else about of meat quality? In the 1980s, it had just been found that PSE pork could be detected electrically. Electrical capacitance using an AC current detects intact muscle fibre membranes (lost when PSE develops) and resistivity detects the opposite (leaking membranes that no longer separate fluids within and between muscle fibres). So how might these be correlated with NIR reflectance?

Table 1: Correlations of NIR reflectance with electrical indicators of PSE.

Wavelength nm	Correlation with Resistivity	*P*<	Correlation with Capacitance	*P*<
700	-0.83	0.005	-0.69	0.01
750	-0.84	0.005	-0.66	0.01
800	-0.69	0.01	-0.43	NS
850	-0.61	0.025	-0.33	NS
900	-0.76	0.005	-0.53	0.05
950	-0.73	0.005	-0.55	0.05
1,000	-0..83	0.005	-0.66	0.01

As seen in Table 1, the same wavelength (850 nm) that gave the best separation of fat and muscle (Fig. 1) gave the least useful prediction of PSE. A similar result was found for muscle *p*H (Table 2). The most likely interpretation of these data is that NIR reflectance is very responsive to the lipid content of meat and this obscures any other relationships of NIR reflectance with *p*H related aspects of muscle structure. In other words, attempts to use NIR fat depth probes at 850 nm to predict muscle properties are unlikely to be of much use. But how about using NIR as a research tool to investigate the basic optical properties of bulk meat?

Table 2: Correlations of NIR reflectance with muscle *p*H.

Wavelength nm	Correlation with *p*H	*P*<
700	-0.73	0.005
750	-0.69	0.01
800	-0.38	NS
850	-0.27	NS
900	-0.52	0.05
950	-0.48	NS
1,000	0.63	0.025

NIR BIREFRINGENCE

Having found that it was unlikely that predictions of muscle quality could be obtained from NIR diodes detecting subcutaneous fat depth in pork carcasses, curiosity beckoned concerning the outlying correlations seen in Tables 1 and 2. Might NIR reflectance reveal anything of interest concerning muscle structure?

This is no place for a full explanation of meat microstructure. Briefly, striated muscle looks striated microscopically because thick myosin filaments are pulled between thin myofilaments during contraction. The thick filaments are heavily stained in microscopic preparations, and the serial spacing between stained bands – the striations – is termed the sarcomere length. This is not just a technical curiosity – short sarcomeres make tough meat, while long sarcomeres make tender meat. These relationships well known microscopically, but how might they affect a macroscopic measurements in NIR light?

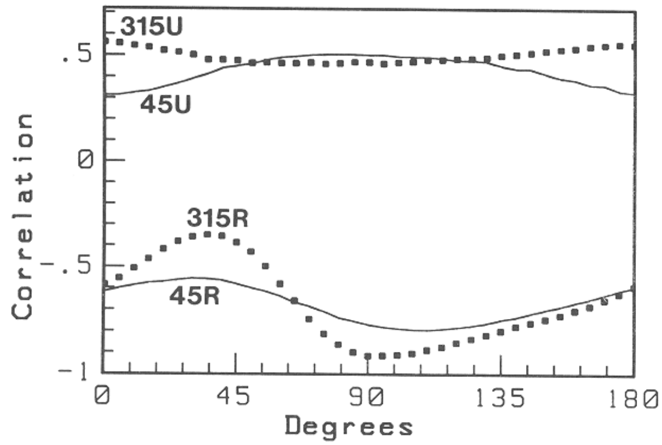

Fig 2: Planes of polarization (degrees) affecting correlations of NIR transmittance with sarcomere length at different degrees of orientation to muscle fibre long axes (either 45° or 315°) from unrestrained (U) and restrained (R) samples of pork neck muscles (*sternohyoideus*) [6].

NIR transmittance through thin slices (1 mm) slices of pork is dependent on their angular orientation to the illumination and measurement (Fig. 2, 315 ° and 45°). Pork samples taken from the neck region during slaughter typically contract if unrestrained to give short sarcomeres (Fig. 2, U) while restrained samples keep long sarcomeres (Fig. 2, R). Thus, as seen in Fig.2, depending on the range of sarcomere lengths and the orientation of thin slices of pork relative to the apparatus, sarcomere length may have a strong effect on NIR transmittance.

As seen in Fig. 2, the orientation of the muscle fibres is important. This was shown in another experiment [7]. Pork and beef neck muscles (*sternohyoideus*) were taken immediately after slaughter, then stretched to 164% of their starting length and compared with unstretched muscles. Using unpolarized light there were no differences. But with polarized NIR there were significant differences between unrestrained and stretched muscles (Fig. 3). Both pork and beef showed the same effect. But why did plane polarized light detect a difference, while unpolarized light did not?

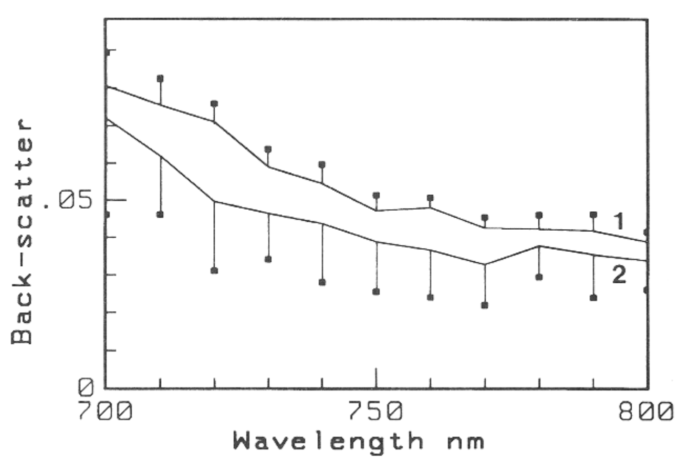

Fig 3: NIR back-scatter (reflectance) from pork stretched neck muscles (1) compared with unrestrained muscles (2). Error bars are standard deviations [7].

Once the potential information content of polarized NIR became apparent, experiments with UV and visible light were extended into the NIR range and this produced another set of intriguing results when compared with fluorescence measurements of connective tissue in beef [8]. For example, there were correlations of NIR birefringence with the number of fluorescent connective tissues detected. Was the penetration of UV through meat affected by aspects of meat microstructure that were also affecting NIR birefringence?

Fibre optics may be a convenient way to connect slices of meat with optical apparatus but dealing with the plane of polarization *versus* muscle fibre orientation is difficult because ordinary optical fibres depolarize light by countless internal reflections at the cladding. How may NIR measurements be made on bulk meat without slicing it? A solution to this problem was found by mounting a polarizer in the light path into the meat, and using a graded index lens to maintain the plane of polarization of reflected light and then to rotate an analyzer before the photometer (Fig. 4) [9]. Using beef neck muscles, surface detection confirmed the same effect of muscle stretching on NIR as shown in Fig. 3 for transmittance of NIR through thin slices of pork muscles.

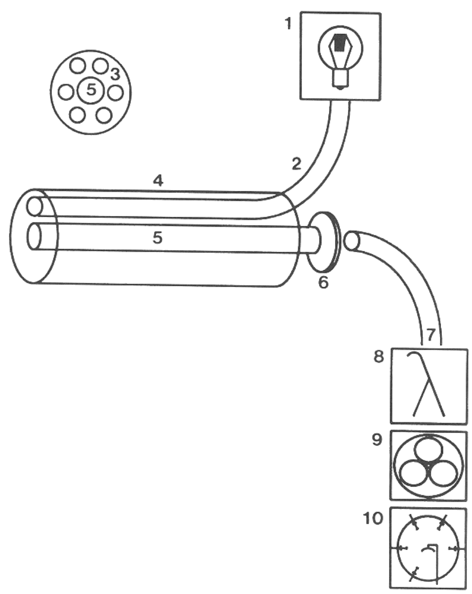

Fig 4: Optical components of a surface detection system, showing the tungsten light source (1), illuminating light guides (2), fixed polariser on the tip of the probe (3), surface detector (4), graded index relay lens in the centre of the detector and protruding through the fixed polariser (5), rotary analyzer driven by a stepper-motor (6), receiving light guide (7), grating monochromator (8), stray-light filter (9), and photomultiplier (10) [9].

DISCUSSION

So what might these early experiments on meat in NIR tell us? They suggest how NIR reflectance may be underlying some empirical correlations of NIR with meat species and quality, such as fat content, sarcomere length, and *p*H related aspects of meat quality [1-4]. But if studies on meat are ever to become scientific rather than empirical, we need to understand how NIR is reflected and absorbed by meat microstructure. The early results on meat in NIR show that planes of NIR polarization, if controlled relative to muscle fibre orientation, are detecting something worthy of further investigation.

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