PHYSICAL MEASUREMENTS OF MEAT QUALITY: OPTICAL MEASUREMENTS, PROS AND CONS

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INTRODUCTION

Physical measurements of meat quality are important for two reasons. Firstly, although variations in meat quality originate from an interaction of genetic, physiological, biochemical and histological factors, the final pathways that lead to variation in meat quality on the retail meat counter or consumer's plate are often physical in nature. Secondly, a few physical measurements are rapid, non-destructive, non-contaminating, or may be made on intact carcasses, so that they may be adapted for on-line use in industry. The concept of on-line measurements of meat quality was proposed many years ago, but only recently has progress in digital and optical electronics made this a real possibility. In this short review it is possible only to consider a small fraction of what is known about the physical measurement of meat quality and to describe what has happened since the last review of the subject (Swatland, 1989a), which may be consulted for references prior to 1989.

CAUSES OF pH-RELATED PALENESS

By 1989 there was a well-established theory to explain how a low pH causes meat to release fluid, but how does a low pH cause paleness? Protein precipitation at a low pH (Bendall, 1962) is a likely mechanism, since this would cause an increase light scattering, shorten the optical path through the depth of the meat, decrease the relative amount of selective absorbance by chromophores, and increase diffuse reflectance from the surface of the meat. However, in addition, the transverse striations of myofibrils are birefringent, giving rise to the names for the A (anisotropic) and I (isotropic) bands. The Z-line is also birefringent, as shown in Figure 1.

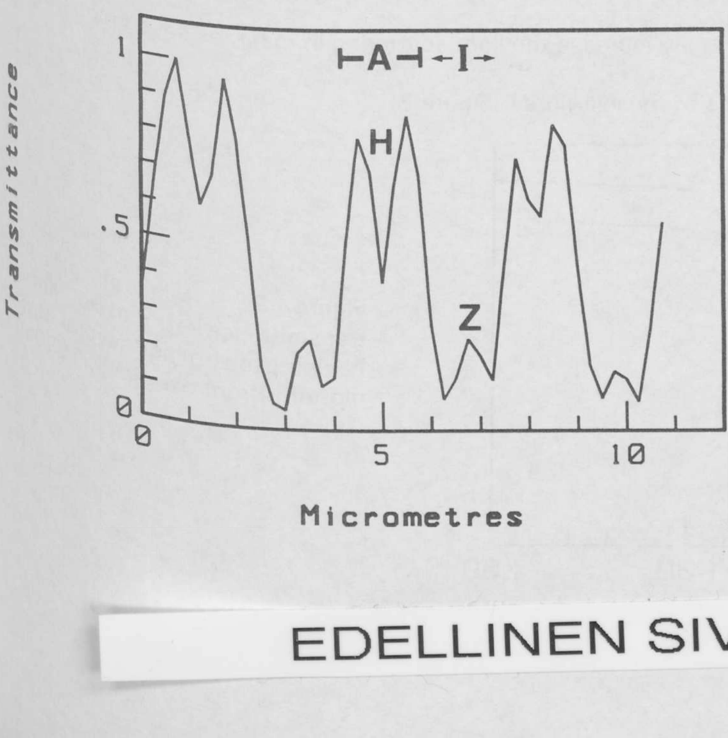

Figure 1. Isotropic (I) and anisotropic (A) bands of a myofibril from porcine psoas major 30 hours post-mortem. From Swatland (1989b).

IMPORTANCE OF WAVELENGTH

Figure 3 also illustrates another optical property of meat - that transmittance of low wavelengths is less than that of high wavelengths. Although meat is a very complex optically anisotropic system, one would still expect to find at least some evidence of Rayleigh scattering (inversely proportional to λ^4) since the lesser dimensions of fibrous myoproteins are considerably less than the wavelengths of visible light. Meat that has been extensively washed in water to remove as much as possible of its sarcoplasm has a diffuse surface reflectance spectrum which shows that it acts as a trap for short wavelengths (Figure 4).

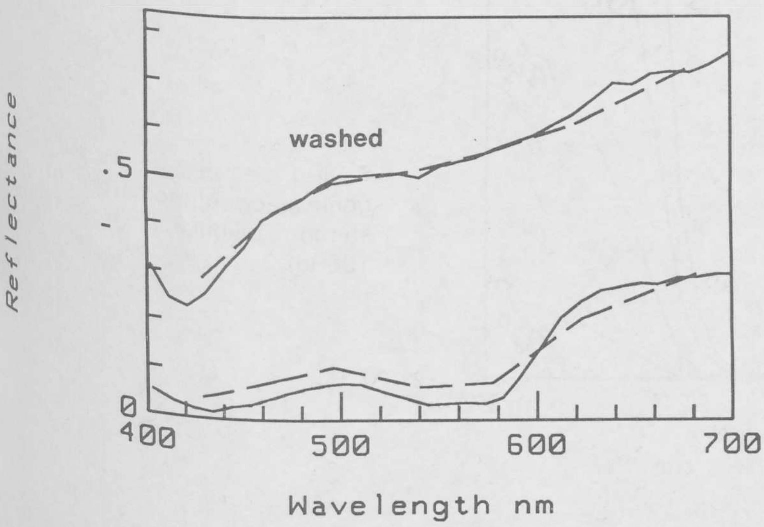

Figure 4 Surface reflectance (measured with an integrating sphere, broken lines) and internal reflectance (measured by fibre-optics, solid lines) of bovine longissimus dorsi (from Swatland, 1989c).

The surface reflectance spectrum of meat (lower broken line in Figure 4) is, therefore, a result of selective absorbance by myoglobin imposed upon a sloping spectrum formed by the scattered light that escapes from meat. In turn, this scattered light spectrum may be related back to the transmittance of individual muscle fibres (Figure 3), which is a function of their birefringence (Figure 2), and which originates ultimately from thick and thin myofilaments (Figure 1). There is no contradiction between this hypothesis and Bendall's (1962) theory: changes in light scattering caused by myofibrillar refractive index may occur over the complete pH range for meat, and may be augmented at lower pH's by protein denaturation. There may also be other factors that remain to be discovered.

Wavelength-related effects are very important in optimizing the performance of meat probes and it is important to grasp the broad trend that is happening technologically. Vacuum-tube photomultipliers are being replaced by solid-state photodiode arrays, which means that the continuous measurement of light intensity (watts) is being replaced by the measurement of light energy over an exposure time (joules). The photodiode array enables all wavelengths to be measured simultaneously, by dispersing the spectrum across the array with a static monochromator. Thus, we have progressed from monochromatic meat probes to true spectrophotometers, but there is no need to stop here, since the next step is to incorporate spatial information - as in goniospectrophotometry. In computational terms, we have gone from a scalar (monochromatic measurement), to a vector (spectrum), and have the possibility of adding information about spatial position (matrix). The matrix may be given W columns for wavelength and P rows for position.

Figure 5 shows a typical result that can be obtained by goniospectrophotometry of meat using optical fibres in a

Refractive index (n) is given by $n = c/v$, where c = velocity of light in a vacuum ($\approx 3 \cdot 10^{10}$ cm sec^{-1}) and v = velocity in the medium of the myofibril. Wavelength (λ) decreases with n, only frequency is constant. In myofibrils light splits into two components that travel at different velocities, the ordinary ray (O) and the extraordinary ray (E), with $O \perp E$. Birefringence, which may be - or +, is given by $n_E - n_O$. Retardation, the decrease in velocity of light caused by interaction with the medium, may be detected as phase retardation, interference caused by path difference, $E \neq O$. The path difference of a depth of muscle (Γ_m) may be measured by ellipsometry with a de Sénarmont compensator (Pluta, 1988), Γ_m [nm] = K_λ [nm/degree] . u°, where u = angle in degrees required for compensation, and K_λ = the de Sénarmont constant (path difference for 1° of rotation). Γ_m changes with pH (Figure 2).

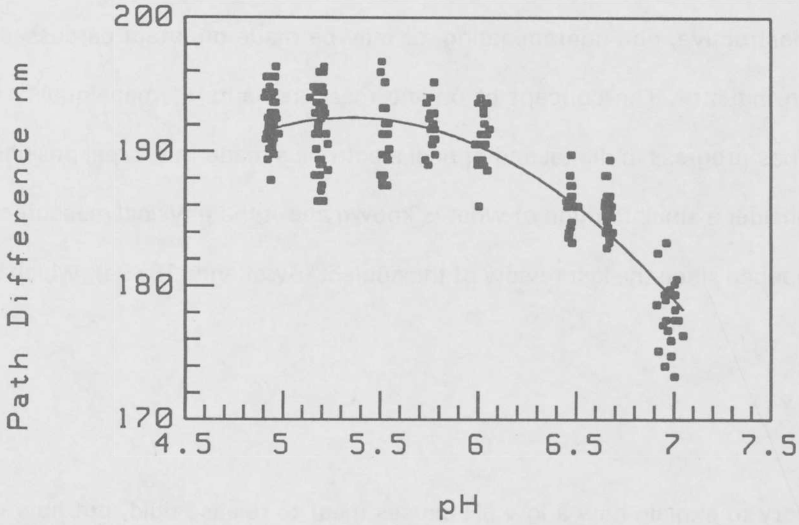

Figure 2. Effect of pH on the birefringence of a muscle fibre from porcine longissimus dorsi at about 24 hours post-mortem (ΔpH = -0.014 pH min^{-1}; from Swatland, 1989b).

For this technique, single muscle fibres are washed with buffer to remove all optically active components of the sarcoplasm (particularly myoglobin), and may be measured subjectively (Swatland, 1990a) or automatically (Swatland, 1989b). There is some variation in the shape of the relationship, because some fibres have a maximum path difference near the isoelectric point of their myofibrillar proteins while others do not, but the general direction of change always holds true and has been confirmed by an alternative technique using polarized-laser ellipsometry (Yeh et al. (1987)

Increases in birefringence caused by a low pH may increase the light scattering in meat, as seen in the effect of pH on transmittance, perpendicular to the long axes of muscle fibres (Figure 3).

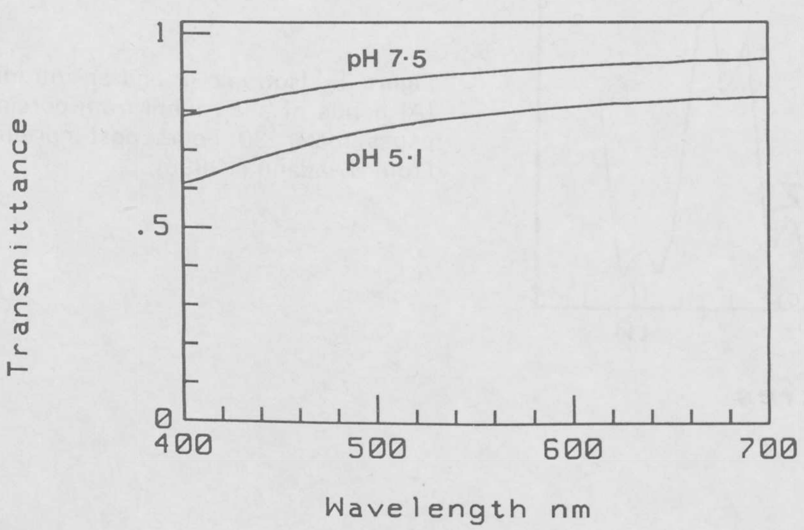

Figure 3. Effect of pH on the transmittance of muscle fibres from bovine psoas minor several days post-mortem (from Swatland, 1990b).

radial pattern so that the path-length through the meat is constant. Low wavelengths tend to be uniformly scatt through the meat whereas high wavelengths are scattered less and have a higher forward transmittance (in Figure at 90° to the incident light, only a low intensity of light at 700 nm is detected). This angular effect contains m information on the physical status of the meat, but is difficult to adapt for use in a meat probe. A more conven approach is to use spatial measurements of scattering, as proposed by Birth et al. (1978) for use with a laser, wh both the angle and the length of the light path are changed.

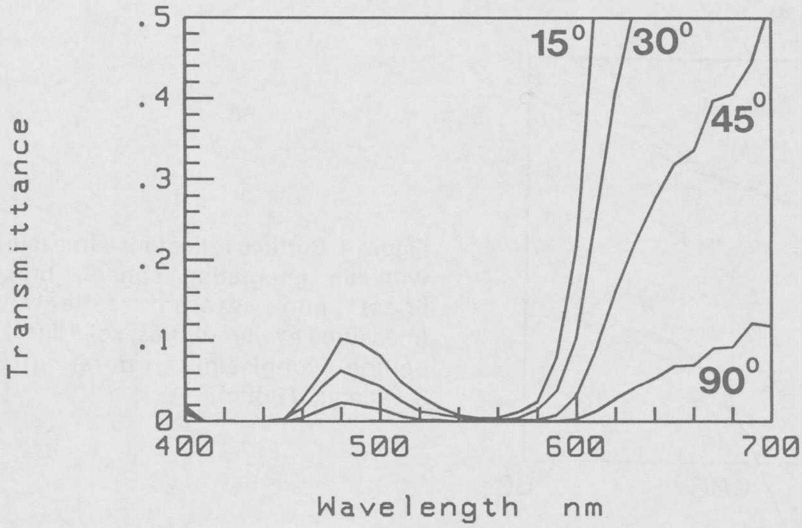

Figure 5. Fibre-opt goniospectrophotometry of bov sternomandibularis (from Swatla 1989d).

Spatial measurements of scattering for meat were introduced by Birth et al. (1978), based on the Kubelka-Mu analysis. With the upper surface of a muscle sample illuminated by a helium-neon laser, log M_T = A - Br, where = radiant exitance on the lower surface, A = β_0 of regression, B = β_1 of regression, and r = path length thro the meat. Birth et al. (1978) showed that B = log 2 (S + K) where S = scatter coefficient (cm^{-1}), and K = absorp coefficient (cm^{-1}). B has no special name but may be called a spatial measurement of scattering (SMS), for the s of convenience. Birth et al. (1978) showed that SMS at 632 nm could be used to predict meat quality. Meat is more complex than the relatively simple situations for which the Kubelka-Munk analysis was intended, but one wo expect an additive effect on SMS of both microstructural scattering and chromophore absorbance. The scat coefficient (S) is probably the major variable in SMS because myoglobin is determined mainly by animal age constant position within a muscle). Despite these extended assumptions, SMS contain useful information abou physical state of meat and, under laboratory conditions, a WP matrix used to calculate SMS may give R = prediction of economic properties of pork such as paleness, drip loss and centrifugation fluid loss (Swatland and 1992a). Figure 6 shows an example of a WP correlation matrix that has been simplified for presentation by pl contour intervals of r = 0.25. This is for a simple correlation of transmittance through slices of pork with subj Japanese pork colour scores. Correlations are negative (-r) at low wavelengths and positive at high wavele reaching a maximum around 640 nm (+r). SMS are obtained by working down the columns, while conven spectral analysis is obtained along the rows. Although this is an unusual way of visualizing relationships between quality and optical properties, it gives an overview of the information content as it strikes a diode array.

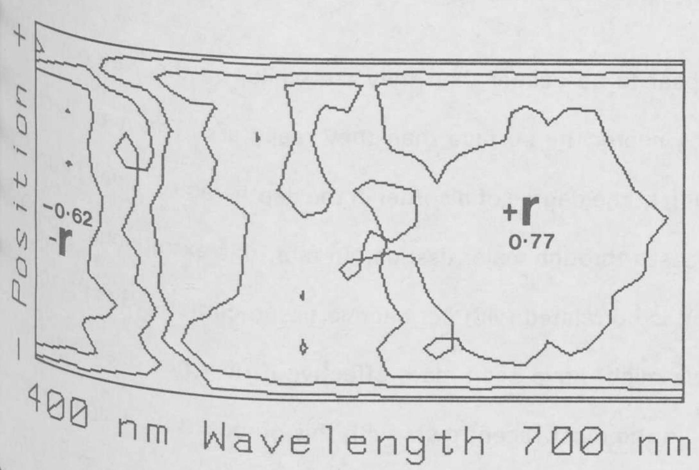

Figure 6. Correlations of transmittance with subjective paleness for slices of pork, arranged in a WP matrix and plotted with contour intervals, r = 0.25 (from Swatland and Irie, 1992b).

ONNECTIVE TISSUE FLUORESCENCE

Connective tissues in meat are strongly fluorescent when excited at around 370 nm. By 1989, this phenomenon ad been exploited to measure the connective tissue content of plates of comminuted meat, and the relationship etween fluorescence emission spectra and connective fibre diameter had been discovered. Since then, a system has een developed for measuring connective tissue fluorescence in slurries used for meat process so that, exploiting elationships all the way from UV to NIR, it is possible to measure a range of commercially important properties such s pH-related protein functionality, gel strength, water holding-capacity and cooking losses (Swatland and Barbut, 990, 1991).

Another development has been to incorporate a single optical fibre fluorimeter into a modified Danish MQM meat probe (Swatland, 1991a), where the NIR diode detector also has been replaced by 64 small-diameter fibres for NIR. The single fluorimetry fibre detects all the major connective tissue septa as the probe window penetrates the carcass, and these are superimposed upon back-ground levels of smaller elements of connective tissue such as perimysium and endomysium (Figure 7).

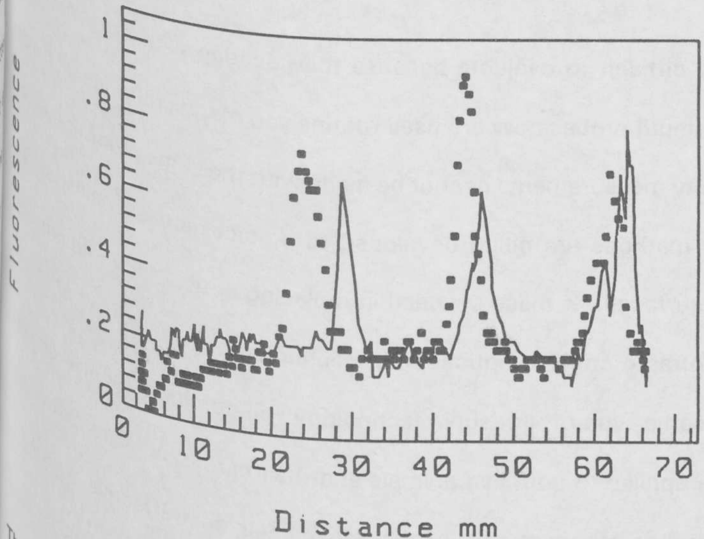

Figure 7. Way-in (solid line) and way-out (broken line) fluorescence signals made intramuscularly in bovine semimembranosus.

The analysis of signals such as these has revealed many interesting properties of meat probes. There is a positive bias on the way into the carcass so that features appear to be deeper than they are while, on the way out, there negative depth bias so that features appear to be nearer the surface than they really are. The overall mechan performance of a probe may be monitored by looking at the degree of disorder in the depth vector, since bouncing is imperceptible to the user occurs as the probe passes through major tissues. In fact, this extraneous informat analogous to that from a needle-penetrometer and is correlated with connective tissue content (Swatland, 199 Thus, earlier generations of carcass tenderometers might have been more effective if they had used one long needle rather than a battery of short, thick ones. In the most recent tests with this probe, using a signal proces algorithm to look at the features of the signal, correlations have been detected with total collagen (R = 0.94) and pyridinoline (R = 0.77).

PROS & CONS

It is technologically possible to build a carcass probe to predict (1) light scattering, (2) fluid-losses, (3) myoglo (4) whiteness and hardness of fat, (5) amount of intramuscular fat, and (6) connective tissue content. Biolo variation within the carcass is a major problem, but is not insurmountable.

Optical carcass probes for meat quality are only viable commercially in situations where there is some degree vertical integration (from production to marketing), so that the feed-back of meat quality information may be use improve meat quality, or the feed-forward of information may be used for carcass quality control and optimizatio meat processing.

The major obstacle to progress is the relatively small market for meat quality probes. This creates a circular prob manufacturers of opto-electronic equipment are not interested until a market can be guaranteed, but the meat indu is not interested until a manufacturer can demonstrate a unit that is rugged, reliable, and water-resistant, and w will increase a profit margin.

Other pros and cons of optical probes are more difficult to evaluate because they overlap with other develo technologies with an uncertain future. Optical fat depth probes now are used routinely in many countries for ca yield grading, and there is no reason why meat quality measurements cannot be made with the same probe at the s time with very little extra cost. However, other methods are being developed to predict carcass yields, su ultrasonic methods and the image analysis of cut surfaces. If these succeed in replacing optical fat depth prob will no longer be possible to build on an existing infrastructure of optical probe technology.

My guess as to how things will develop is that some type of ultrasonic technology will dominate the field for grading within a few years, particularly if it can be applied to both live animals and their carcasses. Optical fat probes then will become obsolete, and optical probes for meat quality will loose their cost-effective adva However, nearly all other industries have made product quality the main criterion in competing globally for cust and I suspect that competing meat industries from various geographical areas will eventually do the same fo quality. When the commercial pressures become strong enough, optical probes for meat quality then may become effective, and the ideas and discoveries of today will become the routine methods of the future.

Optical methods also must be examined critically in comparison with other fundamentally different technologies for predicting meat quality. In my own research, I have not been able to make electronic methods based on membrane capacitance or impedance to perform any better than optical methods for the prediction of pH-dependent aspects of meat quality. The same holds true for optical methods versus electromechanical methods for meat toughness. At the present time, therefore, I regard optical methods as the most promising for the prediction of meat quality.

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