Iridescence in Meat and Fish

ABSTRACT

The iridescence of meat and fish was investigated by fiber optic and microscope spectrophotometry. The metallic colors of iridescence were thought to originate from multilayer interference along myofibers. When muscles are not iridescent these multiple reflectances contribute to light scattering and meat paleness.

1. INTRODUCTION

This chapter is an overview of published refereed papers that may be consulted for details of instrumentation, sample provenance and replication. Most of the data shown here were obtained by fiber optic or microscope spectrophotometry [1]. Iridescence in meat may pose problems for retailers, especially if it is green. Meat may develop a green color if it is rotten, but this is almost impossible in a modern food chain. One exceptionthat may escape detection in a food chain is deep pectoral myopathy in poultry [2]. The deep layers of breast meat in poultry may be green from live birds vigorously flapping their wings at some point on the farm when they are moved or collected. This causes the deep muscles to expand in volume, and muscles within a tight superficial layer of connective tissue then cut off their own blood supply and degenerate. This is rare in poultry and is prevented by the proper handling of live birds, but a green coloration in meat is always worthy of investigation. The difference between myodegeneration and iridescence is quite obvious spectrophotometrically (Fig. 1, [3]). Without instrumentation, iridescence may be distinguished frommyodegeneration by cutting thin slices of meat – green iridescence is lost when viewing a slice with transmitted light and, in reflected light, the iridescence colors change as the slice is rotated or tilted [4].Iridescence may appear on cut meat surfaces, especially on sections of raw beef semitendinosus [5] and cured beef and pork products [6-8].Iridescence has sharp reflectance peaks (Fig. 1) – but what causes them?

Comment [D1]: How we can differentiate between rotting andIridescent one

Comment [D2]: It would be helpful for reader if you add a figure foriridescent andmyodegenerated meat

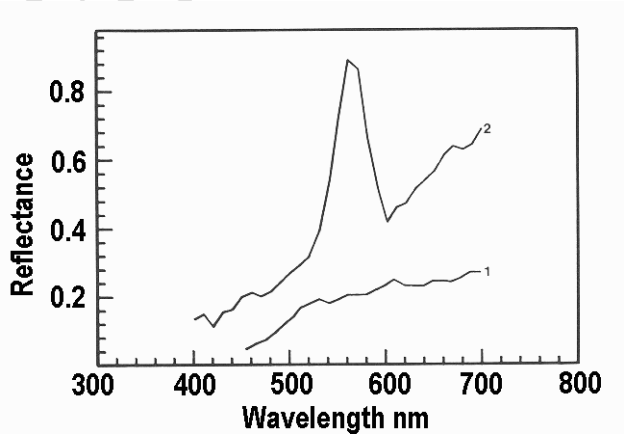


Fig. 1. The difference between green iridescence in beef (line 2) and green myodegeneration in turkey breast meat (line 1), measured by fiber optics and microscope spectrophotometry [3].

2. MULTILAYER INTERFERENCE

There are many ideas about what causes iridescence in meat, and none of them can be rejected with total certainty because we are not all investigating the same samples. Iridescence on bacon and ham may originate from refraction from the different refractive indices of water and fat at the surface [9]. Diffraction along myofibers is also a possibility [10]. Another possibility is that a staggered surface array of myofibers may create a diffraction grating [11]. The view taken here is that iridescence in meat and fish muscle has the same cause as iridescence in minerals – multilayer interference [12-13]. But where are the layers in meat and fish muscle?

Comment [D3]: Can you add a figure for muscle describing he phenomena of meat iridescence https://atoptics.co.uk/blog/opod-meat-iridescence/

To answer this question, we must return to the early days of muscle histology, long before microtomes were usedto cut thin sections for light and electron microscopy. The pioneers simply dissected out singlemyofibers and looked at them using a light microscope, and Fig. 2 shows what was observed. Early microscopists treated their samples in such a way that weakening of the Z lines may have allowed fibers to fragment into Bowman's discs centered on the A band [14 – 15].

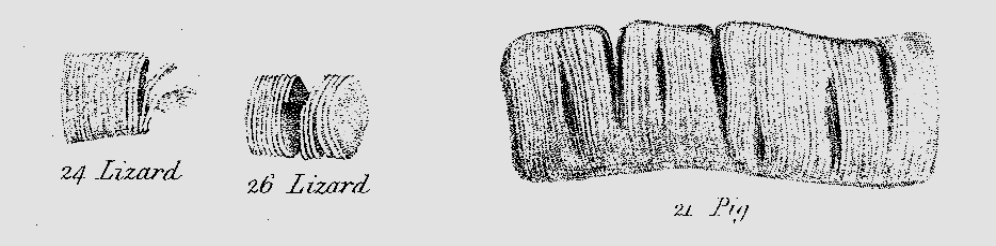


Fig. 2. Bowman's discovery in 1840 - striated skeletal myofibers may separate into discs [14].

What is the evidence that intact myofibers in meat retain this multilayer structure? Refractive index is defined by c, the velocity of light in a vacuum and v, its velocity in various components of a myosystem, n = c/v. Passing through myofibrils, light splits into two components at different velocities, the ordinary ray (O) and the extraordinary ray (E), with O $\perp$ E. Birefringence, nE - nO, may be either negative or positive in sign. Figure 4 shows how this multilayer system appears when scanning along intact myofibers with a polarizing microscope.So each of Bowman's A discs hasAa reflective boundary and be capable of acting as a reflective layer for multilayer interference. In meat or fish muscle without iridescence, this reflective layer may contribute to general light scattering in meat, an important factor in meat colorimetry [18].

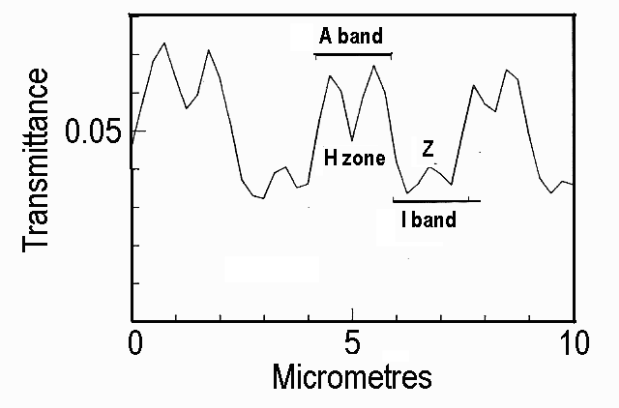


Fig. 3. Birefringence from three sarcomeres measured by scanning with a polarizing microscope [17].

3. COLORIMETRY OF IRIDESCENCE

This gets us into a complex area where the human perception of a myriad of flashing metallic colors has seldom been investigated and where macroscopic colorimeters are likely to give strange results. The safe approach taken here is to examine myofibers individually by microscope spectrophotometry – although this is not completely safe, because multilayer interference originates from myofibrils, and one side of a myofiber may differ from the other.

Iridescence in beef roasts may survive cooking – how does it appear under a light microscope using colorimetry (Fig. 4)? The weighted ordinate method of colorimetry may be used for microscopy as well as for colorimeters [19]. The weighted-ordinate calculation for color coordinates in the CIE system was taken from Billmeyer and Saltzman [20]. The hypotenuse in color x-y space from the central white at 0.33 x and 0.33 y is a measure of chromatic intensity. With the Pythagoras theorem, all results are positive in sign.

$$\text{Hypotenuse} = ((0.33 - x)2 + (0.33 - y)2)0.5$$

In other words, 0.33 x and 0.33 y were used as a measure of colorless scattering, while the length of the hypotenuse into the color space was used as a measure of iridescence. Extensive testing has shown that the weighted-ordinate method may be used for light microscopy with negligible complications from different corrections for chromatic aberration and illuminator emission spectra, provided that the area to be measured uniformly fills the photometer aperture.

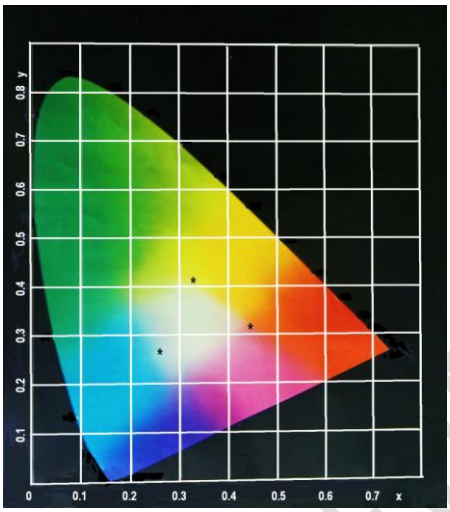


Fig. 4. The CIE color space (Commission Internationale de l'Éclairage) showing coordinates for three myofibers (*) with a strong metallic appearance [20].

Subsurface reflective interference from A-bands in roast beef persists under water, thus removing the possibility of possible surface effects [9, 11]]. Some myofibers have interference peaks exceeding the reflectance of white barium sulfate, thus indicating constructive interference. The number of interference peaks is correlated with CIE Y% ($r = 0.51$, $P < 0.001$). As the number of peaks increases, the distance from the central white of the CIE chart decreases ($r = - 0.52$, $P < 0.001$). Myofibers with low scattering have fewer interference peaks (2.9 ± 0.3, $n = 10$) than myofibers with high scattering (4.9 ± 1.3, $n = 31$, $P < 0.001$). Thus, the number of reflecting and interfering layers may be important in relating light scattering along myofibers to surface iridescence. One or a few reflective layers may produce strong interference colors while many layers may produce colorless scattering. In other words, when iridescence is not apparent, multilayer interference contributes to overall light scattering.

In Fig.1, there is one reflectance peak corresponding to a metallic green color, but the data above deal with the occurrence of multiple peaks, as in Fig. 5. In other words, iridescence is not just a curiosity in the appearance of meat and fish muscle, but provides us with an understanding of how multilayer interference contributes to light scattering in meat and fish muscle.

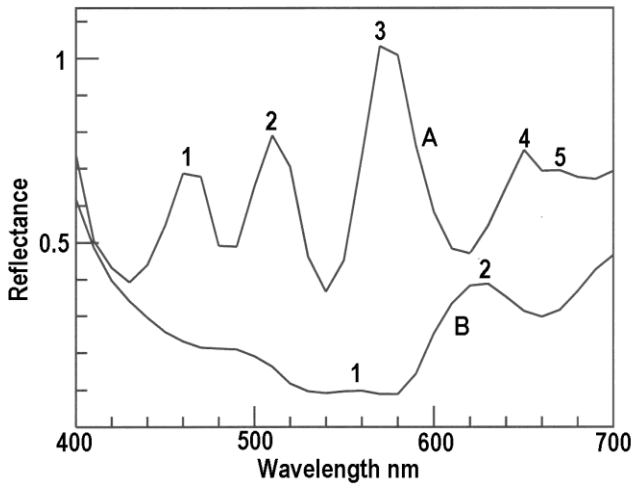


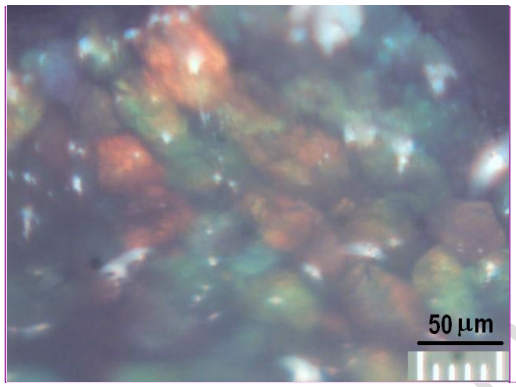
Fig. 5. Reflectance spectra of iridescent myofibers with five (line A) or two peaks (line B) as counted by a signal processing algorithm. Note that descending peaks starting at 400 nm and uncompleted peaks at 700 nm were not counted and peaks might start with only a very small increase in reflectance (A5 and B1).

4. IRIDESCENCE IN OTHER MEATS AND FISH

The data presented so far are an attempt to explain how iridescence is not just a curiosity on the meat counter but offers an explanation of how multilayer interference contributes to light scattering in meat and, hence, an important part of meat colorimetry everywhere.

Microscope spectrophotometry was used to investigate strong iridescence occurring in yellowfin tuna steaks (Thunnusalbacares) (Fig.6) [21] . Iridescence was restricted to the axes of myofibers when sectioned transversely. Sometimes groups of adjacent myofibers all had the same iridescence colors, but colors sometimes differed between adjacent myofibers; thus, myofibers were optically isolated. Iridescence colors were not changed by rotating a polarizer in the illumination pathway, or by rotating a polarizer in the measuring pathway. But when both pathways contained polarizers, and the polarizers were crossed, both specular reflectance from the meat surface and iridescence from within myofibers were completely extinguished. The reflectance spectra of iridescence colors all showed multiple interference peaks, with a strong dependency on angles of illumination and measurement. Thus, iridescence in tuna muscle exhibited the same optical properties as iridescence previously reported in beef; the most likely cause was multilayer interference from A-bands at different depths. Figure 10 is of particular interest because it shows how multiple peaks in multilayer interference fade into a generalized light scattering. The iridescence colors were lost when the tuna was cooked, unlike the situation for mammalian muscle with a range from beef to venison where cooked meat may have stronger iridescence than raw meat[22].

Comment [D4]: suggesting adding afigure for cooked tuna and other mammalian beef



Comment [D5]: the photo resolution can be modified ?

Fig. 6. Iridescent myofibers in tuna muscle.

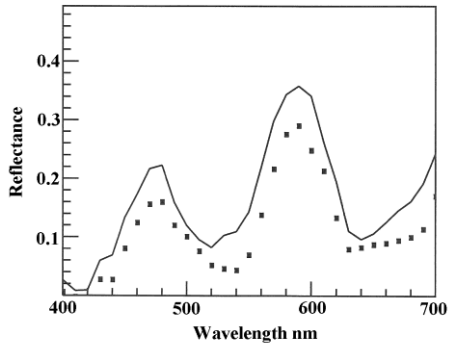


Fig. 7. Reflectance spectra of yellow iridescence in tuna muscle, showing mean (line) and mean – SD (■) for 10 myofibers.

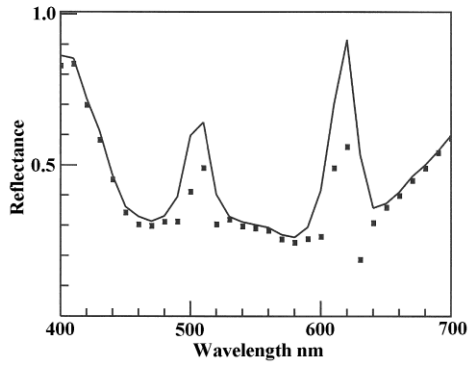


Fig. 8. Reflectance spectra of orange iridescence in tuna muscle, showing mean (line) and mean – SD (■) for 10 myofibers.

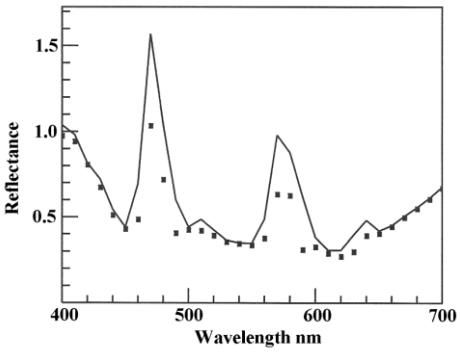


Fig. 9. Reflectance spectra of blue iridescence in tuna muscle, showing mean (line) and mean – SD (■) for 10 myofibers.

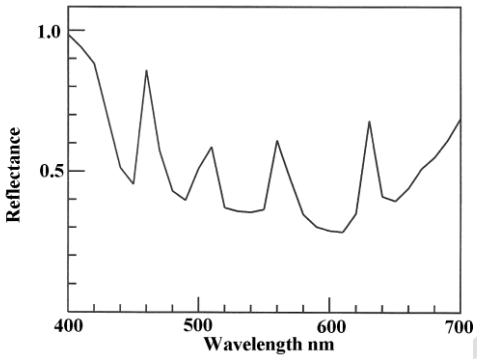


Fig. 10. Reflectance spectrum of a misty pale blue myofiber in tuna muscle with multiple interference peaks.

Comment [D6]: what about adding final part including how to avoid the phenomena of meatiridescence

5. CONCLUSION

The importance of iridescence in meat colorimetry is an ongoing research area [23]. Who would have guessed that Bowman's discovery [14] so many years ago would still be keeping us busy? Provided that we can avoid confusing green iridescence with green myodegeneration (Fig. 1), iridescence is not a life threatening problem. Some meat scientists may work to avoid iridescence, [5-8] but there are many consumers who either ignore iridescenceor desire it in their favorite processed meats. To understand the causes or iridescence, why not return to the year 1665 when Hooke [24] first explained the difference between multilayer interference and surface diffraction as causes of iridescence? Still true today, multilayer iridescence is unaffected underwater while surface diffraction is lost [25]. Support for multilayer iridescence in meat is growing [26, 27], but keep an open mind. One clever experiment might invalidate everything written here.

REFERENCES

[1] Swatland HJ. Computer Operation for Microscope Photometry. CRC Press, Boca Raton. 1998:238.

[2] Siller WG, Wight PAL. The pathology of deep pectoral myopathy in turkeys. Avian Pathology 1978; 7:483-617.

[3] Swatland HJ. A review of meat spectrophotometry (300 to 800 nm). Canadian Institute of Food Science and Technology 1989; 22: 390-402.

[4] Swatland HJ.Optical characteristics of natural iridescence in meat. Journal of Food Science 1984; 49: 685-686.

[5] Kukowski AC, Wulf DM, Shanks BC, Page JK, Maddock RJ. Factors associated with surface iridescence in fresh beef. Meat Science2004; 66: 889-893.

[6] Lawrence TE, Hunt MC, Kropf DH. Surface roughening of precooked, cured beef round muscles reduced iridescence. Journal of Muscle Foods2002;13: 68-73.

[7] Fulladosa E, Serra X, Gou P, Arnau J. Effects of potassium lactate and high pressure on transglutaminase restructured dry-cured hams with reduced salt content. Meat Science2009; 82: 213-218.

[8] Realini CE, Guàrdia MD, Garriga M, Pérez-Juan M, Arnau J. High pressure and freezing temperature effect on quality and microbial inactivation of cured pork carpaccio. Meat Science,2011; 88, 542-547.

[9] Warriss PD. Meat Science. An Introductory Text. CABI, Wallingford, Oxford. 2000; 239-240.

[10] Dennis RG. Measurement of pulse propagation in single permeabilized muscle fibers by optical diffraction. Ph.D. Thesis, University of Michigan. 1996.

[11] Martinez-Hurtado JL, Akram MS, Tetisen AK. Iridescence in meat caused by surface gratings. Foods 2013; 2: 499-506.

[12] Raman CV, Jayaraman A. The structure of labradorite and the origin of its iridescence. Proceedings of the Indian Academy of Science, 1950 ;A32, 1-16.

[13] Rayleigh, Lord. Studies of iridescent colour and the structure producing it. III. The colours of Labrador felspar. Proceedings of the Royal Society of London. Series A, 1923; 103, 34-45.

[14] Bowman W. On the minute structure and movements of voluntary muscle. Philosophical Transactions of the Royal Society of London, 1840; 130, 457-501.

[15] Benda C, Guenther P. Histologischer Hand-atlas. Franz Deuticke, Leipzig und Wien. 1895.

[16] Schäfer EA, Thane GD. Quain's Elements of Anatomy. Longmans, Green & Co., London. 1898: 285-302.

[17] Swatland HJ. An explanation of subsurface optical pathways through food myosystems and their effect on colorimetry. Asian Journal of Agriculture and Food Sciences 2021; 9: 2321-1571.

[18] Swatland HJ. A review of microcolorimetry for textile, food, dental and optoelectronic industries. Asian Journal of Engineering and Technology 2017; 5: 2321-2462.

[19] Swatland HJ.Signal analysis of optical interference in relation to colorimetry for measurements made along individual myofibers in cooked beef. Asian Journal of Agriculture and Food Sciences 2019; 7: 2321-1571.

[20] Billmeyer FW, Saltzman M. Principles of Color Technology. Wiley, New York. 1981.

[21] Swatland HJ.Muscle iridescence in yellowfin tuna (Thunnusalbacares). Food Research International 2012; 48: 449-453.

[22] Swatland HJ. Iridescence in cooked venison – an optical phenomenon. Journal of Nutritional Health and Food Engineering. 2018; 8: 105-108.

[23] Rüdt C, Gibbis M, Weiss J. Meat color and iridescence: origin, analysis and approaches to modulation. Comprehensive Reviews in Food Science 2023; 22(12).

[24] Hooke, R. Micrographia or Some physiological descriptions of minute bodies made by magnifying glasses with observations and inquiries thereupon. Royal Society, London. 1665. Facsimile reproduction, Dover Publications, New York, 1961; 168.

[25] Swatland HJ. On wetting Muscovy glass and a peacock feather, following Robert Hooke to investigate the colourimetry of meat iridescence. Quekett Journal of Microscopy 2017; 43:125-130.

[26] Ruedt C, Gibis M, Barbut S, Weiss J. Color change with longitudinal compression supports hypothesis of multilayer interference as cause for meat iridescence. International Journal of Food Science and Technology 2020; 56: 250-258.

[27] Ruedt C, Gibis M, Weiss J. A research note: effect of pH in meat iridescence in precooked cured pork. BMC Research Notes 2022; 15: 7.