# A new method for mapping the visible-near infrared light levels in fruit

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## Introduction

Little is known about the path that light takes inside an intact fruit and the attenuation it experiences through the different fruit regions. We have developed a probe which is able to directly measure the light distributions in fruit with minimal effect on the distribution being measured. Monte Carlo simulations were able to verify the experimental light measurements made by the probe. Knowing the distribution may enable the selection of more effective near infrared (NIR) spectroscopy modes of measurement (reflectance, interactance or transmission). Indeed the ability of optical techniques to detect internal defects or to estimate the blocking effect of a fruit's stone could be assessed directly if the light distribution profile is known.

We have developed a probe system to explore the light intensity at different points in a fruit with minimal effect from the measurement process. The probe consists of a 400 μm diameter glass fibre encased in a stainless steel tube. This assembly is mounted on a translation stage to enable accurate positioning of the probe tip inside a firmly held fruit. The fruit is illuminated with an 808 nm laser or a white light source to measure the monochromatic or spectral distributions respectively. The light collected by the fibre is relayed to a spectrometer for subsequent analysis. Measuring the transmitted light directly in this fashion is less invasive than cutting away sections of the fruit, which can alter the light distribution.[1,2]

Monte Carlo simulations have been generated using varying absorption, scattering and anisotropy parameters for the fruit tissue and different reflective properties to allow for the boundary conditions of the skin. In these simulations photons are traced through the model using the tissue parameters to randomly determine the step size, path length and scattering angles. Photons are traced until they are fully absorbed or exit the model via the partially reflective skin.

While illuminating a 22.5 mm diameter spot on one shoulder of a Royal Gala apple with an intense tungsten lamp, we inserted the fibre optic

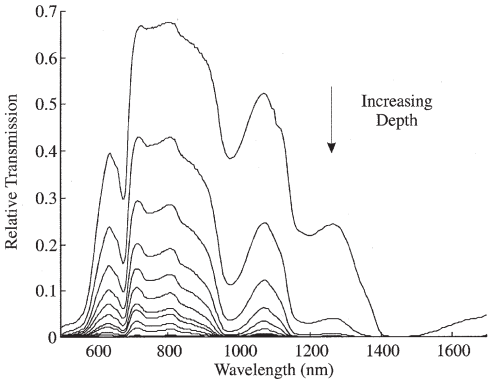


**Figure 1. Transmission spectra recorded inside an apple which is illuminated by a white light source; the largest spectrum indicates a position 1 mm from the illuminated surface, each subsequent measurement is 3.175 mm further into the fruit. (Reprinted with permission of Elsevier Science).**



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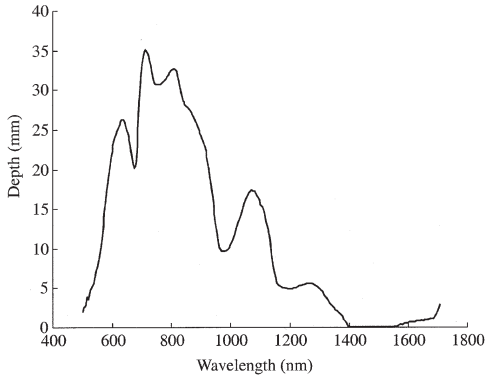


**Figure 2. The depth inside an intact apple where the light has been reduced to 1% of the incident intensity. (Reprinted with permission of Elsevier Science).**

probe into the apple through the centre from the opposite shoulder towards the illuminated area. Light measurements in the spectral range 500–1690 nm were recorded at incremental depths. The spectra (Figure 1) show chlorophyll absorption around 650 nm and water absorption at approximately 950, 1150, and 1450 nm. From the rate of light extinction at each wavelength, we can compute the 1% depth of penetration (Figure 2). This represents the depth into the apple where the light intensity has been reduced to 100th of the initial intensity.

For NIR transmission where the objective is to sample the internal tissue, the greatest signal-to-noise ratio will be achieved by using wavelengths that are not strongly absorbed by water, specifically those in the 'diagnostic window' 700–900 nm. Diffuse reflectance measurements taken at the wavelengths where there is low light penetration will only contain information describing the near surface of the apple.

By using a diode laser the light distribution throughout the fruit can be mapped. Figure 3 shows the light intensity measured along three paths travelled by the probe into a mandarin and the path loca-

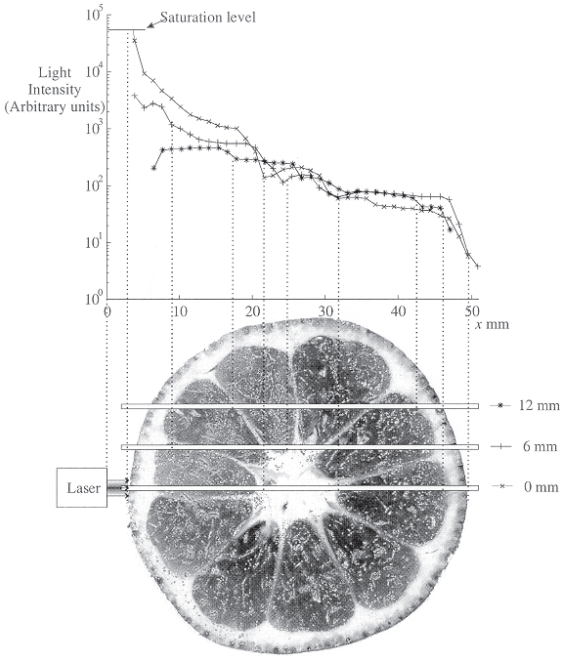


**Figure 3. Light distributions through a mandarin.**

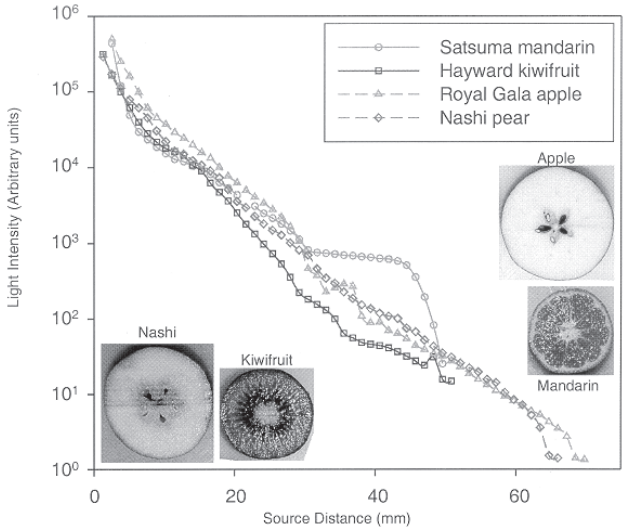


**Figure 4. Light extinction curves at 808 nm for four types of fruit.**

tions. The skin can be seen to reduce the light level by more than an order of magnitude, confirming the assertion[3] that the mandarin skin is highly absorbent and/or scattering. Perturbations are visible at the core, seeds, segment boundaries and skin interactions.

Figure 4 shows the light extinction curves through the centres of four different fruit parallel to and in line with the input laser beam. For each fruit, the initial power law rate of light attenuation reduces to an exponential rate after a characteristic diffusion distance. In this diffusion region the initially forward oriented light becomes isotropic, the distance over which this occurs depends on the tissue's absorption and scattering properties as well as the degree of scattering anisotropy. It can be seen that different regions in each fruit have different exponential rates of light level extinction. The rate of reduction depends on the tissue scattering and absorption properties as well as on the influence of the fruit skin. The mandarin, in particular, stands out as having an elevated light level in the region distant from the illuminated side. The kiwifruit also showed a marked change between inner and outer pericarp.

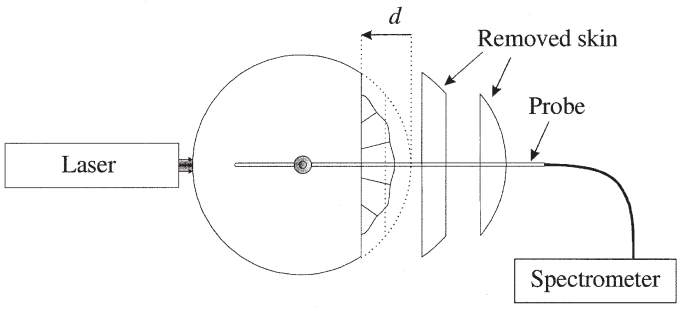


**Figure 5. Experimental investigation of the mandarin skin effect on light levels.**

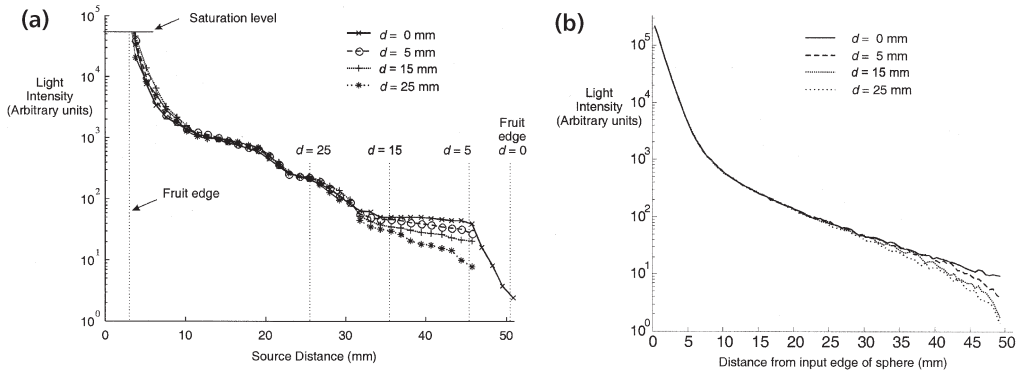


**Figure 6. (a) Experimental light extinction curves for a mandarin with incremental amounts of skin removed. (b) Monte Carlo simulation where the equivalent sections of the boundary are removed.**

There is evidence that the mandarin skin exhibits significant internal reflectance which reduces the rate of light extinction inside the fruit.[2] By repeatedly inserting the probe through the centre of the fruit towards the source as incremental amounts of skin are removed (Figure 5) the influence of the skin on internal light levels can be seen [Figure 6(a)].

Monte Carlo simulations were able to produce a similar effect [Figure 6(b)]. Our simulations used scattering and absorption coefficients based on the measurements of Cubeddu[4] to define the tissue model and made assumptions about the effect of the skin to define boundary conditions.

These results suggest that boundary conditions cannot be ignored for optical measurements of small fruit, which have low absorption coefficients.

## Conclusion

We have developed a probe which is able to directly measure the light distributions in fruit with minimal effect on the distribution being measured.

Monte Carlo simulations were able to help verify the experimental light measurements made by the probe.

## References

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