# Application of time-of-flight near infrared spectroscopy to Satsuma mandarin

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## Introduction

The detection of near infrared (NIR) light from the sample is through either transmittance or reflectance.[1] The transmittance NIR method is very desirable for detecting internal information, whereas the optical information from diffuse reflectance spectra is confined to the subsurface layer of samples. Therefore, it is especially important that progress be made in developing an NIR transmission device for detection of internal characteristics of high-moisture fruit. For example, the nondestructive detection of sugar content in Satsuma mandarin would be of considerable value to the fresh fruit industry. Some techniques and devices for the transmittance method, which could detect inner information of Satsuma mandarin have been proposed previously.[2,3] However, the behaviour of transmitted light from an agricultural product is directly affected by physical and chemical properties of tissues, so that it is preferable to examine the optical characteristics of the tissue and its origin in detail from a new concept.

In this study, an optical measurement system, which was mainly composed of a parametric tunable laser and a near infrared photoelectric multiplier, was introduced to accomplish this purpose from the viewpoint of time-of-flight near infrared spectroscopy (ToF-NIR).[4,5] This system combines the best features of the spectrophotometer and the laser beam, and more advantageously, the time-resolved profile of transmitted output power can be measured sensitively in nanoseconds. The combined effects on the time-resolved profiles of sample diameter, sugar content, the wavelength of laser beam and the detection position of transmitted light were investigated in detail.

## Material and methods

The samples used were Satsuma mandarin (*Citrus unshu* $\mathrm{M}_{\mathrm{ARC.}}$) (location: Wakayama, Japan) having the diameters of 50–84 mm. The sugar content measured by a refractometer varied from 9.9 to 16.3 Brix %.

The wavelength of the pulsed laser $\lambda$ was tuned from 600 nm to 1100 nm by the optical parametric oscillation of a BBO ($\beta$-$BaB_2O_4$) crystal.[6,7] The transmitted output power was measured by an NIR photoelectric multiplier with a spectral response ranging between 300 nm and 1700 nm through an optical fibre cable having a diameter of 7 mm. The equator of the sample was irradiated vertically with the pulsed laser and the detection position was varied at the equator of the sample. The sampling time and the number of averaging of the transmitted output power were 100 ns and 300 times, respectively.

The time-resolved profile refers to the variation of the intensity of the detected light beam with



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time. In this study, the time-resolved profile of the cuticle was employed as the reference. The measure of attenuance $A_t$ is defined as follows:

$$A_t = \log\left(\frac{Pw_0}{Pw}\right) \tag{1}$$

where $Pw_0$ and $Pw$ indicate the peak maxima of the reference and the object, respectively. The measure of time delay of peak maxima $\Delta t$ is expressed as follows:

$$\Delta t = t - t_0 \tag{2}$$

where $t_0$ and $t$ indicate the time at peak maxima of the reference and the object, respectively. The variation of the full width at half maximum value of the profile $\Delta w$ is also expressed as follows:

$$\Delta w = w - w_0 \tag{3}$$

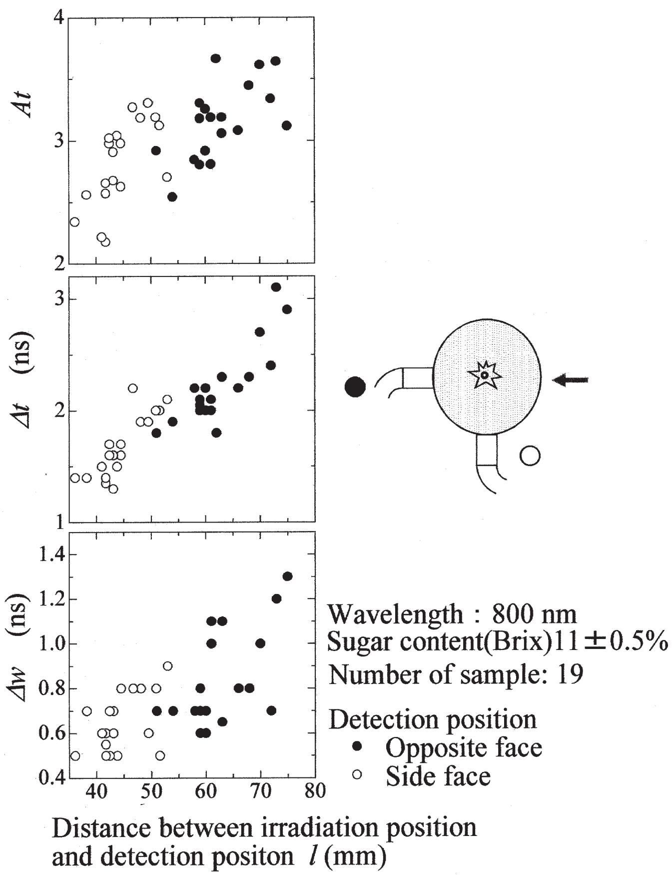


**Figure 1. Variation of attenuance $A_t$, time delay of peak maxima $\Delta t$ and variation of full width at half maximum $\Delta w$ with detection position.**

where $w_0$ and $w$ indicate the full width at half maximum value of the profile for the reference and the object, respectively.

## Results and discussion

Figure 1 indicates the variation of $A_t$, $\Delta t$ and $\Delta w$ with the distance between irradiation position and detection position $l$, respectively. The detection position is either opposite face or sider face (see Figure 1). The diameter of the sample varied from 50 mm to 84 mm. The sugar content in the population is nearly constant at 11 ± 0.5%. These optical parameters increased gradually as $l$ increased to be greatly absorbed and vigorously scattered. In particular, $\Delta t$ is positively correlated with $l$.

Figure 2 indicates the variation of $A_t$, $\Delta t$ and $\Delta w$ with the sugar content, respectively. The diameter in the population is nearly constant at 60 ± 1 mm. Each optical parameter had a tendency to increase as the sugar content increased. Such behaviour was remarkable when the transmitted light was detected at the side face of a sample. However, there is little correlation of sugar content with $\Delta t$ and $\Delta w$ when the transmitted light is detected at the opposite face.

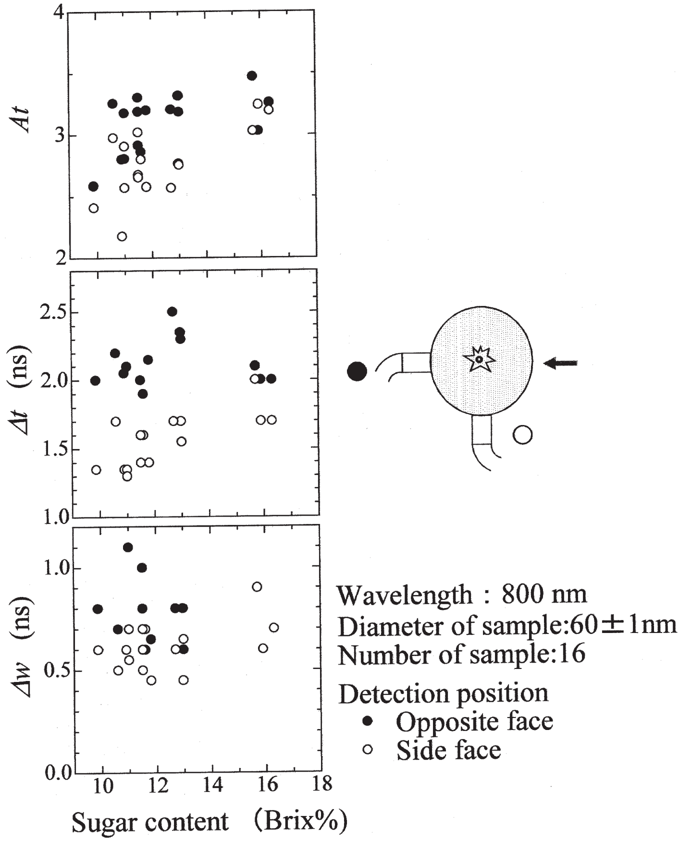


**Figure 2. Variation of attenuance $A_t$, time delay of peak maxima $\Delta t$ and variation of full width at half maximum $\Delta w$ with sugar content.**

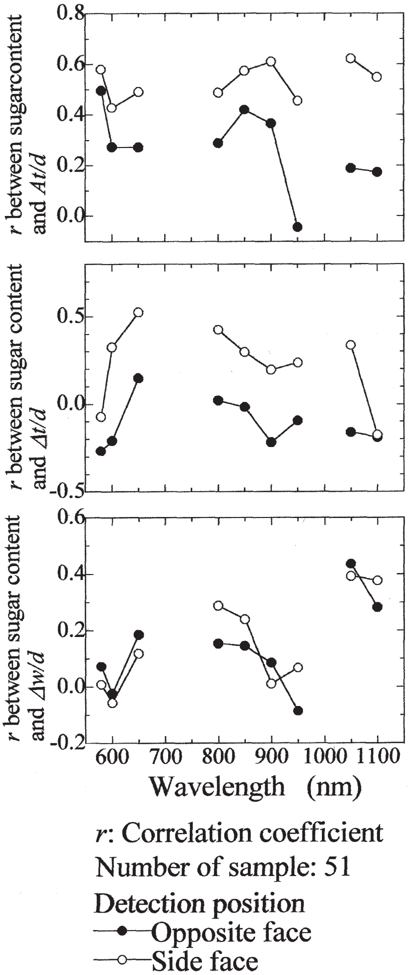


**Figure 3. Correlation coefficient between sugar content and each normalised parameter.**

Next, we examined the relationship between each optical parameter and sugar content of the Satsuma mandarin having various sizes. To compensate the effect of sample size on the time- resolved profile, each parameter was normalised by *l*. Figure 3 shows the correlation coefficient between sugar content and each normalised parameter. The correlation coefficient at the side face shows a larger value than that at the opposite face, independent of wavelength. Furthermore, it is known that the relationship between sugar content and $A_t$ is not necessarily coupled with the relationship between sugar content and $\Delta t$. To correctly interpret these results, however, we may consider that the characteristics of the transmitted light differ with the detection position. The output detected at directly opposite the irradiation position may include the straight-through or near-straight beams. The output at other detection positions could be defined as diffusely scattered light. The difference in the optical characteristics of transmitted beams directly reflects the substantial optical path length.

When we apply ToF-NIR to detection of the information for the inside of fruit with high moisture content such as Satsuma mandarin, it is very important to give attention to the difference in the scattered light within tissues and the semi-straight propagated light. Furthermore, we tried to express the resulting phenomena by using model samples composed of water, sucrose and milk. The variation of the time-resolved profile is strongly governed by the combination of the light absorption component, scattering medium and refractive index.

## Conclusions

In this study, a newly constructed optical measurement system, whose main components were a parametric tunable laser and a near infrared photoelectric multiplier, was applied to detection of the sugar content of Satsuma mandarin using ToF-NIR spectroscopy. The combined effects on the time-resolved profile of sample diameter, sugar content, the wavelength of the laser beam and the detection position of transmitted light were investigated in detail.

The variation of the attenuance of peak maxima $At$, the time delay of peak maxima $\Delta t$ and the variation of full width at half maximum $\Delta w$ were strongly dependent on the detection position and the wavelength of the laser beam. $At$, $\Delta t$ and D$w$ increased gradually as the sample diameter increased to be greatly absorbed and vigorously scattered. On the other hand, each optical parameter had a tendency to increase as the sugar content increased. Such behaviour was remarkable when the transmitted light was detected at the side face of a sample. To find the resulting phenomena of the time-resolved profile, it is very important to give attention to the difference in the scattered light within tissues and the semi-straightly propagated light.

## References

1. B.G. Osborne, T. Fearn and P.H. Hindle, *Practical NIR Spectroscopy with Applications in Food and Beverage Analysis*. Longman Scientific & Technical, Harlow, UK (1993).
2. K. Miyamoto, M. Kawauchi and T. Fukuda, *J. Near Infrared Spectrosc.* **6,** 267 (1998).
3. S. Kawano, T. Fujiwara and M. Iwamoto, *J. Japan Soc. Hort. Sci.* **62,** 465 (1993).
4. L. Leonardi and D.H. Burns, *Appl. Spectrosc.* **53,** 628 (1999).
5. L. Leonardi and D.H. Burns, *Appl. Spectrosc.* **53,** 637 (1999).
6. A. Yariv, *Quantum Electronics,* 2nd Edn. John Wiley & Sons, New York, USA (1975).
7. P.G. Harper and B.S. Wherrett (Eds), *Nonlinear Optics*. Academic Press, New York, USA (1977).