Non-destructive near infrared spectrometers: development of portable fruit quality meters

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Introduction

The quality of agricultural products is an important factor for consumers. In Japan, quality is sometimes more important than cost. Quality standards for agricultural products have been established in Japanese markets and it has been determined that price depends on the quality of the product. Usually, the quality of agricultural products is determined in terms of appearance factors, such as shape, colour, size, etc. However, these indices are not always associated with taste, leaving consumers to complain. Today, people are demanding new quality standards related to taste (sweetness, sourness, etc).

Near infrared (NIR) spectroscopy is a proven technique for measuring internal quality of many agricultural products. Since the late 1980s in Japan, on-line NIR graders have been developed and used in grading facilities.[1] Yet, even though these graders are effective, their widespread use has not been realised because they are expensive instruments costing more than $200,000 each.

In 1999, a tabletop fruit quality meter[2] (Fruit Selector: K-FS200, Figure 1) using NIR technology was developed by the Kubota Corporation (Osaka, Japan). This instrument can measure sugar and acid content of fruit or vegetables non-destructively. It is compact and is much cheaper than on-line graders. It has been used widely at grading facilities, wholesalers and supermarkets.

The K-FS200 has enhanced the development of quality standards related to taste. Measurement of taste factors with this instrument provides the consumer with acceptable products, while at the same time, giving the farmer maximum Yen. The disadvantage of this approach is that poor quality products are thrown away.

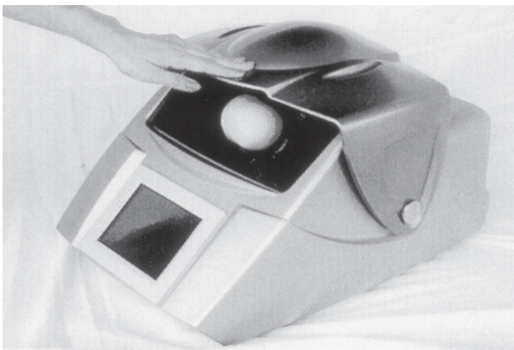

Figure 1. Tabletop fruit quality meter (K-FS200)

Loss of product in grading facilities and market places could be minimised if measurement of taste factors could be made in the field, even before products are harvested. Kubota developed the portable fruit quality meter, Model K-BA100, (shown in Figure 2) to maximise food potential[3] of harvested fruit and vegetables. The portable NIR meter can determine ingredients in the growing product in the field. The farmer can control fertilisers or watering

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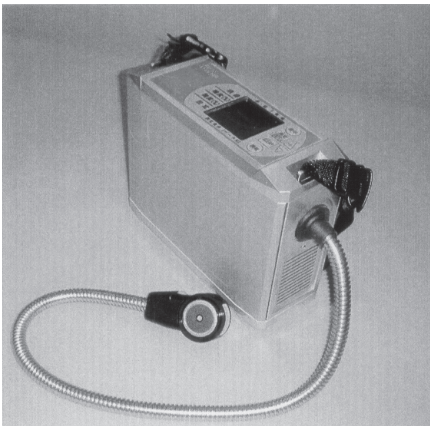

Figure 2. Portable fruit quality meter (K-BA100).

according to information gained with the K-BA100. Thus, quality is improved even before harvest. This relatively new approach results in little or no waste and minimises the use of chemical fertilisers. It is a method of operation that benefits both the grower and consumer and it is environmentally friendly.

This paper discusses the design and performance of the K-BA100 portable NIR instrument.

Features of the K-BA100

Conventional laboratory instruments have been designed to operate in laboratory conditions (25°C, 50% rh) but they are not intended to be moved or carried into the field. On the other hand, the K-BA100 was designed for field use and it can be carried into the field and operated under severe environmental conditions (dusty environment and varying temperature). The features of this instrument are as follows.

(a) non-destructive measurement
- monitoring the quality of the growing sample until harvest
- no waste of samples

(b) stable and precise measurement in the field
- stable and precise under tough conditions such as ambient or sample temperature fluctuation, dusty environment, etc

(c) stand alone and easy operation
- works independently without external equipment and user-friendly design makes operation simple

(d) portability and expandability
- Portable enough to bring to the field (W300 × L 118 × H 240 mm, Weigh 5 kg).
- Optical fibre probe for flexible measurement.
- Development of original calibration model with external computer (RS232C interface and control software).

Key techniques

In this section, we focus and discuss details of two techniques, (a) non-destructive measurement and (b) stable and precise measurement in the field, due to compact design.

Non-destructive measurement

When the fruit sample is measured using NIR, there are some obstacles such as those mentioned below:
- most fruit or vegetables have a high moisture content of more than 80%. NIR light energy tends to be absorbed and weakened by water absorbance
- some fruits, like citrus fruit, have hard and thick peel. The light energy cannot penetrate the sample efficiently

The easiest solution is to use a high-power light source; however, this requires a large battery because of the large energy consumption and a large heat energy that could damage the sample. The following techniques were developed to overcome the problems:

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SW (short wavelength)-NIR (500–1000 nm)

SW-NIR has much lower absorption coefficients so water absorbance is reduced and the energy can penetrate into a sample further than longer wavelength NIR (beyond 1100 nm). If the absorption is reduced, the temperature increase will also be reduced.

Interactance method

An optimal design "interactance" probe (Figure 3) transmits the light into the sample and collects the absorbed light more efficiently than "transmittance" or "reflectance" methods.

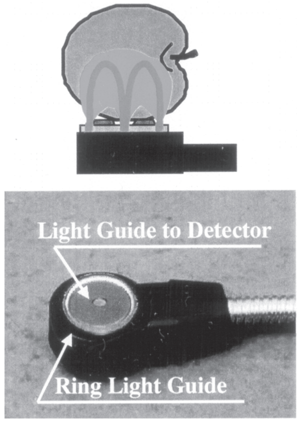

Figure 3. Interactance probe.

Technology for stable and precise measurement in the field

An instrument for field use needs to work in an unstable and dusty environment. In particular, temperature conditions of ambient air and samples are dramatically changed compared with conditions in the lab. The following techniques were developed for the portable NIR meter to allow it to work under those conditions:

Polychrometer with no-moving parts and SW-NIR enhanced detector

The polychrometer (Figure 4) consists of a flat-field concave grating and a linear image sensor (256 pixels). All components are sealed hermetically to prevent dust or shock.

Automatic calibration system (ACS)

ACS (Figure 4) consists of a WC (wavelength calibration) filter and a standard filter to calibrate the wavelength shift and output drift due to temperature variance or change of properties with time. During the operation of the instrument, ACS is working automatically and always maintains the stability of the instrument.

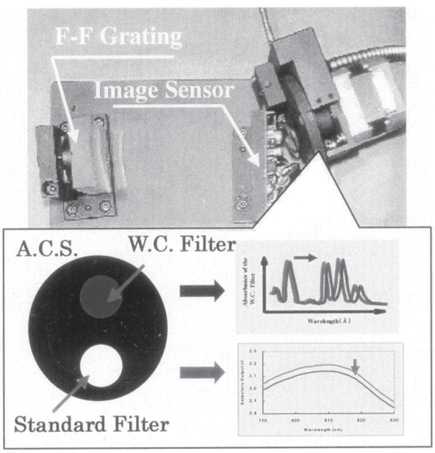

Figure 4. Polychrometer and ACS.

Robust calibration model

According to the nature of NIR absorption, variance of sample temperature affects the prediction value and accuracy in addition to the effect of the environmental temperature on the instrument. The calibration models of the K-BA100 have been developed with samples in various temperature conditions to minimise the effect of temperature variation.

The temperature characteristic of the instrument was tested in a temperature chamber from 5°C to 35°C of ambient air temperature. The fluctuation of predicted sugar content of the mandarin orange was only ± 0.7 Brix% at 13 Brix%. This shows that the instrument works well even under such tough condition.

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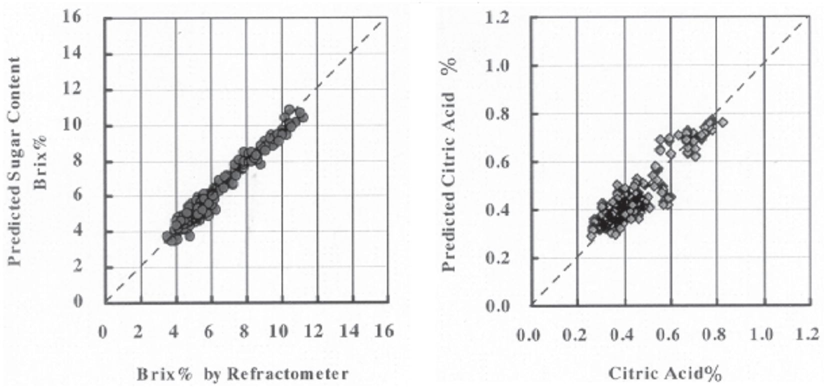

Figure 5. (a) Sugar (*R* = 0.99, *CV* = 4.5%) and (b) acidity (*R* = 0.90, *CV* = 8.3%) of tomato.

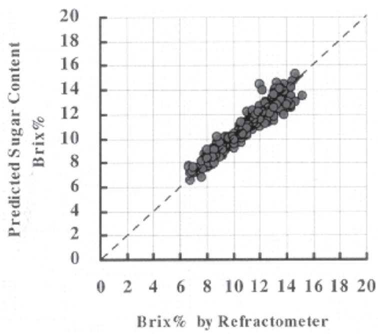

Figure 6. Sugar of citrus fruit (mandarin orange) (*R* = 0.95, *CV* = 5.7%).

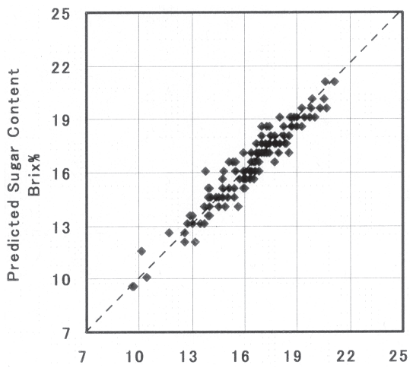

Figure 7. Sugar of grapes (R = 0.92, CV = 4.6%).

Prediction performance

Calibration models for many kinds of fruit were developed. After measurement of spectral data with the K-BA100, the samples were macerated and a refractometer or titratable acidity test was used to measure the sugar content or acid content, respectively. The calibration models for sugar content and acid content were developed using multiple linear regression (MLR) and partial least squares (PLS), respectively. The developed calibrations are listed in Table 1.

Table 1. Calibration models.

Variety	Ingredient
Tomato, apple, mandarin orange	Sugar/acid
Peach, grape, persimmon, pear, melon, strawberry	Sugar

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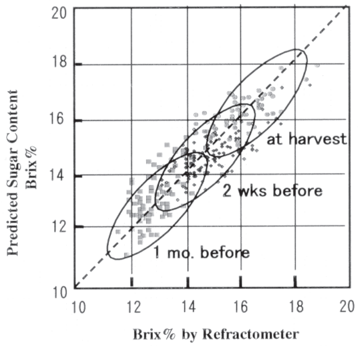

Figure 8. The change in sugar of growing apples on the tree.

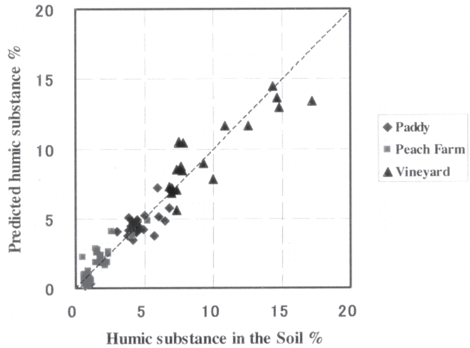

Figure 9. Humic substance in the dried soil (*R* = 0.96, *CV* = 11.7%).

Validation results of harvested samples

Some of the prediction results on the harvested samples are illustrated in Figures 5 to 7. Coefficient of variability ($CV = SEP$ / Mean × 100) of sugar content and acid content is less than 6% and 10%, respectively.

Validation results of growing samples

The performances of calibration models were evaluated for growing samples, too. The validation result for apples on the tree at one month before, two weeks before and at just harvested are illustrated in Figure 8. The results show that the instrument predicts the quality of growing products well.

Other applications

The K-BA100 is not only useful for agricultural products but also for other applications. To take one example of the applications, the calibration result of the humic substance in the dried soil[4] is shown in Figure 9.

Conclusion

The K-BA100 portable fruit quality meter using NIR technology has been developed. This instrument can evaluate the taste quality of fruit or vegetables in the field non-destructively.

The portable fruit quality meter is expected to establish new quality standards and production systems. It also promises various applications in the field, at line, on site, etc.
"Changing the world with a portable NIR spectrometer !!"

Reference

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