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Present Condition of Nondestructive Quality Evaluation of Fruits and Vegetables in Japan

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Abstract
Studies on nondestructive techniques for quality evaluation of fruits and vegetables were initiated in the early 1970s in Japan. The studies aimed mainly at the development of methods for the measurement of the surface color of the products using visible light. Thereafter, many studies using delayed light emission (DLE), infrared (IR), fluorescence, sound response, and impact force response have been carried out of develop methods for the detection of maturity, firmness, surface defects, etc. Since the late 1980s, near infrared (NIR) spectroscopy has been studied for determining the chemical composition of various kinds of products such as peaches, Japanese pears, apples, tomatoes, strawberries, satsuma oranges, etc. Automated machines using optoelectronic technology have been developed to sort produce based on the surface appearance such as peel color, presence of defects or bruises and size. Emphasis is currently placed on studies to develop new machines for sorting produce in relation to taste.

Discipline: Agricultural facilities / Postharvest technology
Additional key words: color, defect, imaging, shape, sweetness

Introduction

In 1961 a semi-automated packing house was established for the first time in Japan. Since then a large number of facilities have been constructed in producing areas to respond to a serious labor shortage for sorting and packing products. In parallel with the introduction of packing houses, it became necessary to develop a fully automated grading machine, since the grading operation accounts for more than half of the labor in packing houses. On the other hand, it became increasingly important for shippers to release products with a good quality in terms of appearance as well as internal quality to meet the consumers' needs.

Against this background, R & D activities for the development of fully automated sorting machines including a nondestructive taste detector are currently being promoted.

Outline of research on nondestructive quality evaluation of fruits using NIR spectroscopy

1) Determination of sugar content in intact peaches by NIR spectroscopy with fiber optics in interactance mode[1]

At National Food Research Institute (NFRI), commercially available NIR instruments have been modified geometrically for adaptation to the measurement of NIR spectra of intact fruits and vegetables.

An NIR instrument with fiber optics in the interactance mode was used for determining

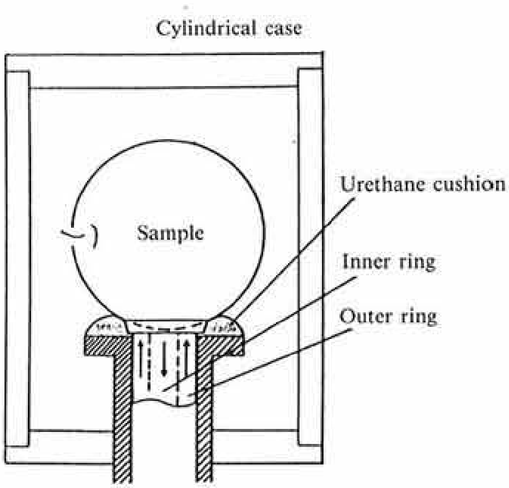

Fig. 1. Schematic illustration of sample placement for making interactance measurements using fiber optics

the sugar content in intact peaches. A schematic illustration of sample placement for NIR interactance measurements using fiber optics is shown in Fig. 1. A commercially available Interactance Probe with a concentric outer ring illuminator and an inner ring receptor, was used as the fiber optics. A cushion made of urethane foam was pasted at the end of the probe to hold a sample. The NIR measurement was performed by placing a sample at the end of the probe. Second derivative spectra of peaches showed special characters and there were clear differences among the spectra of peaches with high, medium, and low Brix values.

In the correlation plot (Fig. 2) where correlation coefficients calculated from the Brix values and second derivative values were plotted against wavelength, high correlation coefficients were observed at 906, 950 and 1,142 nm. In the second derivative spectra, characteristic absorption bands appeared downward. It was therefore considered that the correlation coefficients at a key band necessary for measuring the Brix value should be negative. The key band corresponded to 906 nm. To analyze the relationship between the correlation coefficient

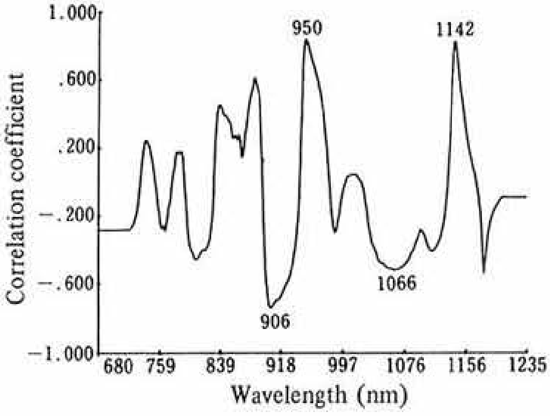

Fig. 2. Correlation coefficients between $d^2\log(1/R)$ and Brix value plotted against wavelength

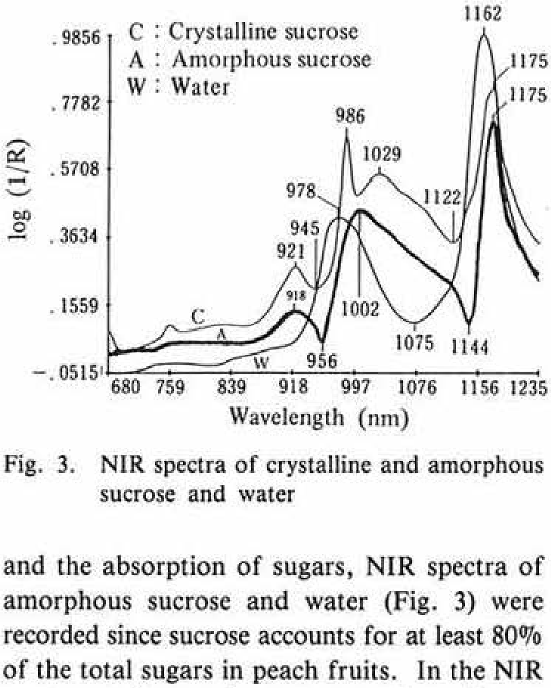

Fig. 3. NIR spectra of crystalline and amorphous sucrose and water

and the absorption of sugars, NIR spectra of amorphous sucrose and water (Fig. 3) were recorded since sucrose accounts for at least 80% of the total sugars in peach fruits. In the NIR spectrum of amorphous sucrose, three characteristic absorption bands were observed at 918, 1,002 and 1,175 nm. The band at 1,002 and 1,175 nm, however, overlapped those of water that occurred at 978 and 1,162 nm. In the vicinity of 918 nm, the fact that the absorption due to water was comparatively weak, accounted for the large downward peak observed at 906 nm in the correlation plot.

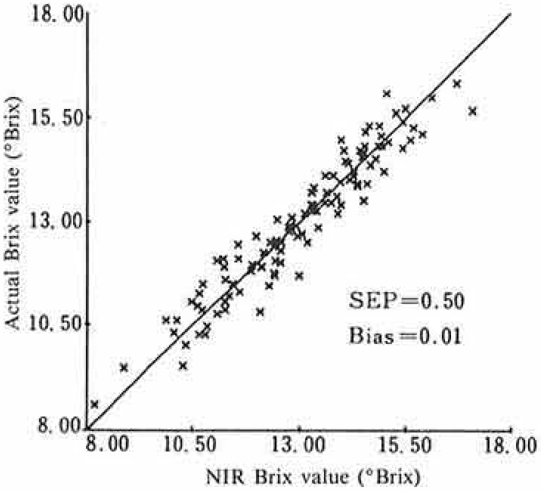

Fig. 4. Scatter plot of actual Brix value versus NIR Brix value calculated with the best calibration equation using predction set

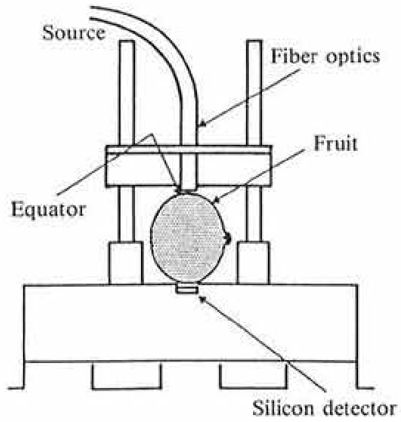

Fig. 5. Schematic illustration of sample placement for measuring NIR transmittance using fiber optics

Multiple linear regression analyses based on NIR spectral data and chemical data of Brix values, revealed high correlations between NIR Brix values and actual Brix values. The highest multiple correlation coefficient (R) was 0.97 with a standard error of calibration (SEC) of 0.48 °Brix. The standard error of prediction (SEP) and bias corresponded to a 0.50 °Brix value and 0.01 °Brix value, respectively (Fig. 4). It was concluded that this method was relatively accurate for nondestructive measurement of the sugar content of peaches.

2) *Nondestructive determination of sugar content in satsuma mandarin using NIR transmittance*[2]

Using the interactance method, it is very difficult to determine the composition of fruits such as satsuma mandarin, which have a thick peel. Therefore, the NIR transmittance method was used. A schematic illustration for sample placement for NIR transmittance measurements is shown in Fig. 5. The top of the sample was illuminated with monochromatic light through fiber optics, and the amount of light transmitted through the sample was measured with a silicon detector located just below the sample. NIR measurements of intact fruits, peeled fruits and fruit juice were made.

The NIR spectra of intact fruits with different sizes but with the same Brix value shifted upward as the diameter increased. The fruit size effect could not be removed by the 2nd derivative treatment. Therefore, it was necessary to develop an alternative method to reduce the fruit size effect.

One of the methods to achieve this objective was to convert the measured spectra to normalized spectra for a unit sample size. By dividing the second derivative spectrum of absorbance by the second derivative value at a wavelength with a strong correlation with the size of the fruit, a normalized second derivative spectrum could be obtained, wherein the effect of fruit size was removed.

Multiple linear regression analyses based on the normalized second derivative spectral data and chemical data of Brix values, revealed high correlations between NIR Brix values and actual values. The validity of the derived calibration equations was determined using a prediction sample set. The highest multiple correlation coefficient was 0.99 with a SEC of 0.28 °Brix for intact fruits. The bias-corrected standard

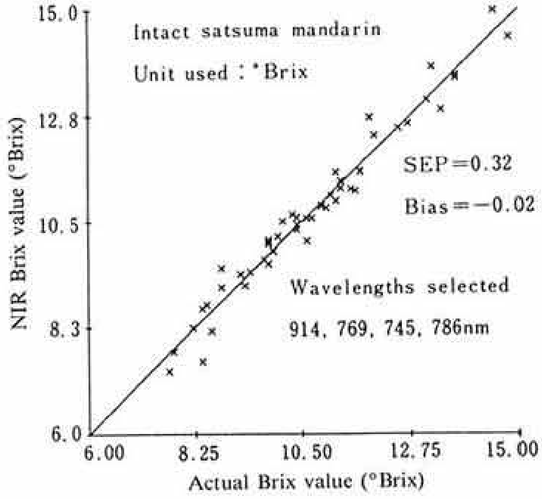

Fig. 6. Scatter plot of actual Brix value versus NIR Brix value calculated with the best calibration equation using prediction set

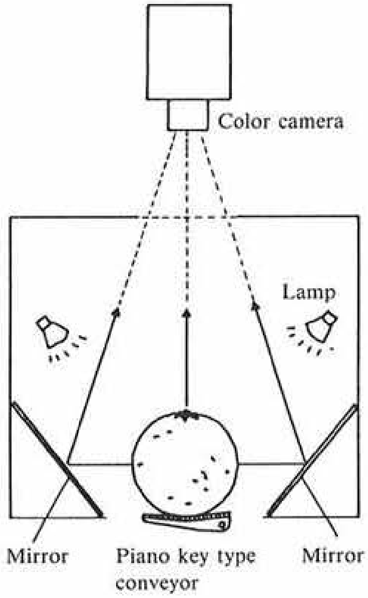

Fig. 7. Sensor unit for detecting color, defects and shape of fruit

errors of prediction (SEP) corresponded to a 0.32 °Brix value for intact fruits. The calibration equation of intact fruits showed nearly the same accuracy as the equation for juice. The actual Brix value and NIR Brix value calculated with the best calibration equation using a prediction sample set were very close (Fig. 6). It was therefore concluded that the NIR transmittance method gives an accurate estimate of Brix value in intact satsuma mandarin.

New on-line sorting machines using nondestructive techniques in packing houses

1) Grading machine[3]

This grading machine, which enables to detect color, defect, shape and size of products, was designed and developed in 1985. The grading machine consists of a vibrator, a line-up brush, a sensor unit, a conveyor, and a data processing unit, etc. The vibrator and line-up brush are used to feed the products in a line to the sensor unit. A piano-key type conveyor, free-tray conveyor or bucket conveyor is used in this machine. According to the signal processed in the data processing unit, all products are discharged onto conveyors which are arranged for respective classes of sorted products.

A schematic diagram of the sensor unit is shown in Fig. 7. The sensor unit consists of one CCD color camera and paired mirrors which enable the camera to observe a near-total view of each product. The product is illuminated by several tungsten halogen lamps arranged around the product. The reflected images from the product are detected by the CCD camera. In the camera, each image is split into two component beams by a semi-transparent mirror. Each component is detected by a linear line-scan CCD sensor through a red filter, or through a blue filter. Each image taken by the CCD camera is divided into 8,192 (64 × 128) small square pixels. The color of each pixel is classified into 64 color levels from green to red. The color of the product is represented as averaged color of color histogram for all pixels. The area of surface defects is calculated from the number of pixels which have a lower intensity of reflected light than the threshold. It is possible to detect defects as small as about 0.3 mm in diameter. Fruit size is determined as diameter or height of the products. The sorting rate is 5 fruits/sec/lane.

This kind of sorting machine has been installed in many packing houses for sorting satsuma oranges, tomatoes or persimmons, for example. The use of the machine enables to sort automatically and simultaneously the products in terms of surface color, defects, and shape or size.

2) Sweetness sorting machine

In 1989, Mitsui Mining and Smelting Co., Ltd. developed and introduced the first operational nondestructive automatic peach sweetness sorting machine in the world. Peaches sorted by this machine were designated as "sweetness-guaranteed". The company has now developed the multi-purpose sensor (MPS) for grading apples and Japanese pears, in addition to peaches, with a single unit.

When fruits on a line-up conveyor are illuminated by tow-focused tungsten halogen lamps, the scattered reflected radiation is measured by the MPS unit. Convergence of the reflected radiation is achieved by a lens and the radiation is projected on a spectroscope to extract the required wavelength and intensity data. The intensity of the radiation at respective wavelengths is measured by the line sensor (Fig. 8).

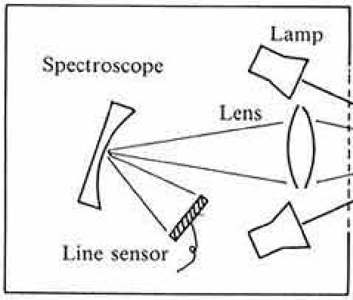

Fig. 8. Multi-purpose sensor (MPS) for determining sweetness of peaches, apples and Japanese pears

The sugar content of a peach is calculated from the measured reflection intensity of NIR radiation by using a statistically developed calibration equation. The calculation requires only 0.13 sec. The sorting rate is 3 fruits/sec/lane.

With the introduction of the MPS system, taste-oriented grading has become feasible. Accumulation of the quality data from the MPS unit in the computer together with data corresponding to the production conditions (such as soil conditions, climate conditions, etc.) will make it possible to formulate guidelines for the production of high-quality products.

Conclusion

In 1990, a company manufacturing sorting machines, which was established as a government subsidised venture company, started a 7-year project for the development of a fully automated nondestructive sorting machine including a taste detector. At present the taste sorting machine commercially available can be used for peaches, apples and Japanese pears which have only a thin peel. However, in the near future, a taste sorting machine for several other products will be disseminated in Japan.

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