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Developing an Index for Determining the Optimal Harvest Timing of *Lagenaria siceraria.*

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Abstract: Harvest timing affects farmer's income as well as cultivation technology. Harvest timing of the fruit crops is usually decided by intuition and experience of farmers or other experts. However it may be difficult to determining the optimum harvest timing for fruits with large and hard surfaces. We only can objectively confirm the fruit maturity after harvesting. Therefore, we attempted to develop more objective method for optimal harvest timing, using the measurement of spectral reflectance. We selected fruits of bottle gourd as the target and the spectral reflectance characteristics were observed during the growth period until the day of harvesting using spectrometer. Measuring positions were set at the fruit base, the fruit body, the fruit apex and the leaf surface. We selected the spectral reflectance of four wavelength bands, the blue band, green band, red band, near infrared band. We analyzed the diurnal variations of four wavelength bands. As a result, in the near the harvesting stage, the value of spectral reflectance tended to decrease in at the fruit base. While, spectral reflectance value in the fruit body tend to increase.

We focused the wavelength on the difference of spectral reflectance curve in the fruit base. One is 550 nm in the green band which shows the local peak of reflectance curve. Another is 720 nm which shows the local reflection point of reflectance curve in the near infrared band. We proposed harvest timing index using spectral reflectance of these two wavelengths (named the base value), after examining the correlation between the degree of fruit maturity and this index. As a result, the base value of 65 shows the threshold value for harvest timing. Thus, we suggest the base value has a potential to determine of optimal harvest timing objectively.

Key Words: Dried gourd shavings, Fruit base value, Optimal harvest timing, Spectral reflectance, Wavelength

1. Introduction

Harvest timing affects farmer's income as well as cultivation technology. Harvest timing of the fruit crops is usually decided by intuition and experience of farmers or other experts. This is also important in arid land agriculture. Because greenhouses have been introduced in arid area and the many fruit crops are cultivated using greenhouses, and those have been contributed to food supply (Zhao *et al*., 2005). However it may be difficult to determine the optimum harvest timing for fruits with large and hard surfaces. The farmers and other experts have been made much effort about judging the optimal harvest timing (Arakawa *et al*., 1998).

Therefore, we attempted to develop more objective method for optimal harvest timing, using the measurement of spectral reflectance. We selected fruits of bottle gourd (*Lagenaria siceraria.*) as the target. A bottle gourd fruits, which harvested after optimal harvest timing, turn to the worthless in the market because of those hardening.

A bottle gourd is an annual plant of the gourd family, and the feature is that it bears big fruit (**Fig. 1**). The size of the fruit grows up to 35 cm - 40 cm large, 7 kg - 8 kg in weight when it is harvested.

In Japan, bottle gourds are generally processing to dried gourd shavings. Those fruits are shaved like slim bands and are dried using sunlight (**Fig. 2**). We Japanese used the dried gourd shavings for a material of rolled sushi and miso soup.

When the bottle gourds were missed optimal harvest timing, the fruits of bottle gourd are getting hard and those become unsuitable for processing, and are abandoned without harvesting.

Therefore, it becomes important not to miss optimal harvest timing to hold the fruit hardness. However, it is not easy to ascertain harvesting time and the harvest timing index is not only with fruit size. From these view points, we

Fig.1. Bottle gourd fruit.

Fig. 2. Processing to dried gourd shavings.

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attempt to find the easy index of optimal harvest timing, and it is useful for the income stability of the farmers.

In recent years, it is clarified that spectral reflectance value is related to protein or the chlorophyll. Many studies on such expectation using spectral reflectance are published in the field of agriculture for the freshness measurement and optimal harvest timing. It is known that an index to be called normalized vegetation index (NDVI) reflects the activity (ability for photosynthesis) of the plant (Rouse *et al*., 1973).

Therefore we examined an objective index to estimate the optimal harvest timing with non-destructiveness. And we suggested that spectral reflectance characteristics of the fruit surface in the growth process are useful for an index to judge optimal harvest timing with non-destructiveness.

2. Materials and Methods

2.1 A measurement site

We measured the spectral reflectance in the bottle gourd farm located at the north Kanto District (Kamimikawa-machi, Kawachi-gun, Tochigi, Japan), where bottle gourd cultivation was the most prosperous in Japan. The farmlands around Kanto area are covered by the soil with good drainage ability and light volcanic ashes (the Kanto loam layer). Because the bottle gourd is a plant setting up a root aside, the bottle gourd is easy to come to set a root in that soil.

2.2 Measuring positions and way of measurement

In the measurement of the spectral reflectance of the fruit, we used a spectrometer, MS -720 (© EIKO co., ltd.) which it's angle of view field is 10 degrees.

We measured the spectral reflectance through the fruit growth process since bottle gourd bears fruit. And we measured several times for two different period of bottle gourd fruit growth, from 14 July, 2009 to 5 August and from 6 August, 2009 to 27 August.

The spectral reflectance characteristics were observed during the growth period until the day of harvesting using spectrometer. Measuring positions were set at the fruit base, the fruit body, the fruit apex and the leaf surface (**Fig. 3**).

At the same time, we measured the spectral radiance about standard white board (Spectralon: Image One company) to calculate spectral reflectance of the objects.

2.3 Objective indices

At first, we focused NDVI (Normalized Difference Vegetation Index) value change during a fruit growth period to clarify an index to get the optimum harvest timing. It takes the value from -1 to +1, and NDVI is known for an index to show the presence and the activity of vegetation, and leaf quantity. When the vegetation activity is high, the value shows large value. NDVI is showed the following expression.

$$NDVI = (NIR-R) / (NIR+R)$$

Where, NIR : Reflectance of Near Infra Band

R : Reflectance of Red Band

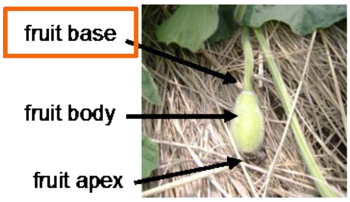

Fig. 3. measuring positions for bottle gourd fruit.

Next, we focused fruit base value as an example of the harvest timing index. Takeuchi *et al*. (2007) suggested an index for harvest timing of melons. They focused the spectral reflectance of melon fruits. When farmers harvest the melons, farmers pay their attention to the color of the base connected a fruit and the stem. So, Takeuchi *et al*. (2007) suggest "Fruit base value" as for an index of the harvest time judgment. As for "Fruit base value" in case of the melon, they aim at a spectrum reflectance change during growing period in wavelength area from 670 nm to 800 nm. They suggested the following expression of fruit base value.

$$\text{Fruit base value} = ((A-B) / (A+B)) *100$$

Where, A: spectrum reflectance at the wavelength, 730 nm.

B: spectrum reflectance at the wavelength, 780 nm.

We guessed the similar tendency to be in the case of the bottle gourd and applied this value, but it was inappropriate for an index in the same expression because spectrum reflection properties were different from a melon. So, we tried to improve the fruit base value for the bottle gourd harvesting time.

3. Results and Discussion

3.1 Observation results on the spectral reflectance

We get the observation result (in the first harvest period) of the spectral reflectance at the leaf, the fruit apex, the fruit base and the fruit body of the bottle gourd. The daily variations of the value at the fruit base during the growth period showed a different tendency from that of the fruit body (**Figs. 4 and 5**). On the other hand, such tendency cannot see at the leaf and fruit apex, we can see only fluctuation (**Fig. 6**).

Therefore, we focused the fruit base and the fruit body and examine spectral reflectance characteristics and relations of the optimal harvest timing.

We selected the spectral reflectance of four wavelength bands, the blue band (470 nm ~ 501 nm), green band (539 nm

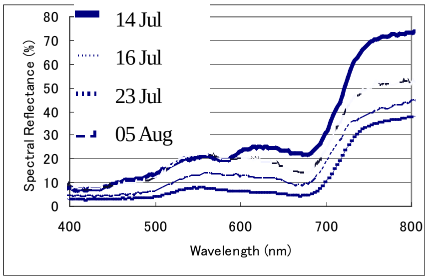

Fig. 4. A variation of spectral reflectance at the fruit base of the bottle gourd.

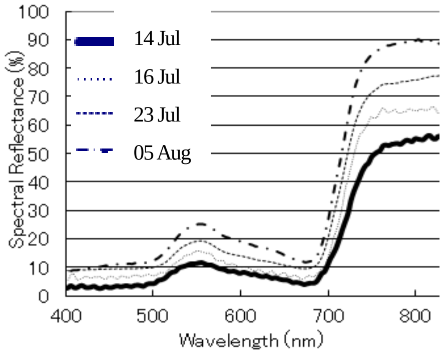

Fig. 5. A variation of spectral reflectance at the fruit body of the bottle gourd.

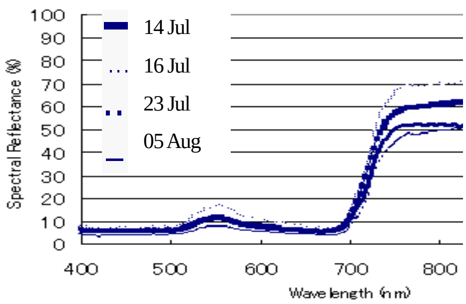

Fig. 6. A variation of spectral reflectance at the leaf of the bottle gourd.

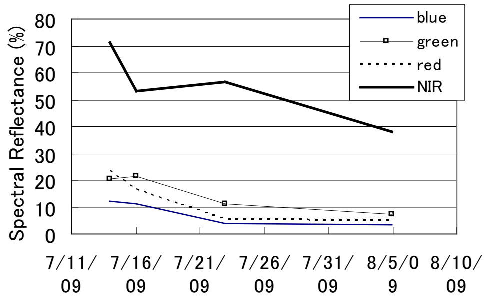

Fig. 7. A variation of spectral reflectance on four wavelength bands at fruit base.

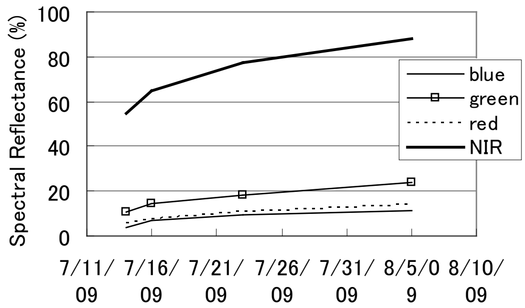

Fig. 8. A variation of spectral reflectance on four wavelength bands at the fruit body.

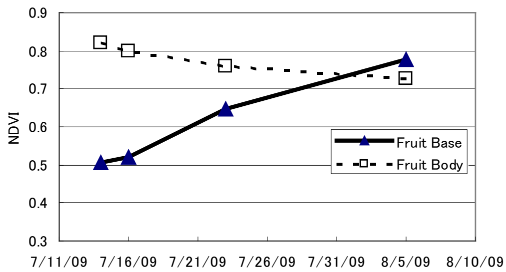

Fig. 9. NDVI value change at the fruit base and fruit body of the bottle gourd.

~ 580 nm), red band (637 nm ~ 680 nm), and near infrared band (801 nm ~ 870 nm).

We analyzed the diurnal variations of four wavelength bands. As a result, in the near the harvesting stage, the value of spectral reflectance tended to decrease at the fruit base (**Fig. 7**). While, spectral reflectance value at the fruit body tend to increase (**Fig. 8**). The ratio of the increase and decrease are particularly large in a near-infrared band.

3.2 The variation of NDVI value during growing period

The NDVI value at the fruit base and the fruit body in the fruit growing period (from July 14 to August 5) are shown **Figure 9**. The value at the fruit base was 0.51 on July 14 when our measurement started, and the value become to 0.78 by harvesting date (August 5). The NDVI value at the fruit base tended to increase near the harvesting stage. On the other hand, NDVI value at the fruit body showed and it decreased gently from 0.82 on July 14 to 0.73 on August 5.

3.3 Estimating by optimal harvest timing using improved fruit base value

We focused the wavelength which showed a great change of spectral reflectance at the fruit base. One is 550 nm in the green band which showed the local peak on reflectance curve. Another is 720 nm which shows the local reflection point of reflectance curve in the near infrared band. We proposed harvest timing index using spectral reflectance of these two wavelengths (improved fruit base value).

We suggest to improve the fruit base value for a bottle gourd and to calculate by the following formula.

Improved fruit base value = {((1+A)) -B)/((1+A)+B) }*100

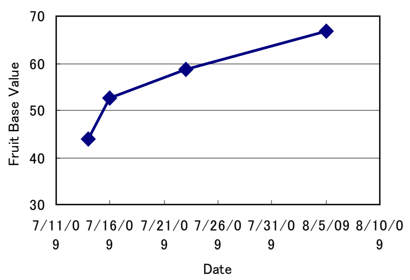

Fig. 10. The variation of fruit base values.

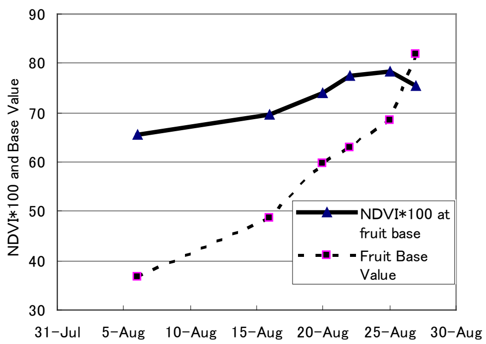

Fig. 11. A variation of NDVI at fruit base and Fruit base value in the second harvesting period.

Where, A : Spectral reflectance at the wavelength 550nm
B : Spectral reflectance at the wavelength 720nm

The improved fruit base value tended to increase near the harvesting stage (**Fig. 10**). The value was 43.8 on July 14, and it became to 66.8 by harvesting date (August 5). In addition, a coefficient of correlation is very high between NDVI value at the fruit base and improved fruit base value.

By the farmer's judgment, our observed fruit was harvested on August 5. That harvested fruit was matured and good for the processing material. Then the improved fruit base value in the harvested date was 66.8. From this result, when the base value is around 65, we can guess that fruit get to be optimal harvest timing. Thus, we suggest the base value has a potential to determine of optimal harvest timing objectively.

3.4 The relation between NDVI and fruit base value

The spectral reflectance of the other bottle gourd fruit was observed in the second harvest period. We have been got the similar tendency with the results of the first harvest period. While this time, we continued the observation over the optimal harvest timing.

The fruit base value tend to increase linearly, from 36.8 to 81.8. While NDVI value tend to increase linearly at first, the value have a peak near the harvest timing. After getting peak value, it tend to decrease (**Fig. 11**). When NDVI value becomesto peak value, the fruit base value is around 65. From this result, we can guess the optimal harvest timing is on 25 Aug.

4. Conclusion

According to the observation results in the growth process of the bottle gourd, we intended to make clear the optimal harvest timing of bottle gourd in non-destructiveness using spectrum reflectance characteristics.

The improved fruit base value tended to increase near the harvesting stage. When NDVI at the fruit base reached to the peak value, the improved fruit base value is regarded as optimal harvest timing around 65. We suggest that the base value has a potential to determine of optimal harvest timing objectively.

Also we need to discuss the relation between the spectral reflectance and the maturity in future. Next step, we must examine the correlation between the degree of fruit maturity and this index. For example, we must know about the hardness of the bottle gourd fruit objectively.

Now a spectrometer is expensive. However, we expect that this method contributes the efficiency of the future agricultural production and grown up for farmers income.

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