Evaluation of Change in Quality of Ripening Bananas Using Light Reflectance Technique

Kazuo MORITA, Thoru SHIGA* and Shôji TAHARAZAKO
(*Laboratory of Agricultural Systems Engineeing Laboratory*)
Received for Publication September 10, 1991

Introduction

Bananas have been one of the most popular fruits in Japan. Almost all the popular fruits such as Satsuma mandarins, apples and so on are produced in Japan, but banana fruits are imported from abroad under a condition of green-ripe stage. In general, an artificial ripening treatment of banana fruits is conducted in a special facility, after that, the banana fruits are carried to markets. The banana fruits are typical fruits having a climacteric rise. The climacteric rise is a physiological phenomenon caused by ethylene gas[11]. The ripening treatment of banana fruits with climacteric rise could be artificially made by using controlled ethylene gas. Recently, the quality of ripening banana fruits could be controlled by artificial ethylene treatment in commercial practice[9].

With the increase of imported banana fruits, an airtight ground-warehouse came to be made use of as the facility for the ripening treatment of banana fruits in stead of the underground-warehouse. There are two different types of ripening treatment of banana fruits in these facilities. In the underground-warehouse, the banana fruits are heated by the burning of coal gas and cooled by top ice. In the ground-warehouse, the banana fruits are heated and cooled by an air-conditioner with ethylene gas control system. The ripening treatment of banana fruits has been improved through an empirical method by the practices of trained laborers into a programmatic ethylene gas control method. However, the method has not always succeeded in bringing the uniformed ripening of banana fruits, because of its being devoid of any monitoring system for detecting the ripening stage of banana fruits.

In order to estimate the ripening quality of banana fruits during the ripening treatment, it is necessary to establish non-destructive detecting method of the ripening stage in easy practical application. Not with standing this there has been quite few reports to have been published in this field. Finney et al.[3] measured changing in firmness of banana fruits during the ripening treatment by means of a sonic technique. Chuma et al.[1] tried to apply a delayed light emission to the evaluation of ripening quality of banana fruits. These attempts were fundamental approaches and they were far from reaching a practical application. Therefore, it is very important to eatablish the evaluation system for the ripening quality of banana fruits.

The purpose of this study is to obtain some basic data for the evaluation of ripening quality of banana fruits during the artificial ripening treatment by spectral reflectance properties aiming to apply the reflectance technique to an automatic control system for the ripening of banana fruits.

* Faculty of Agriculture, Utsunomiya University, Utsunomiya 311

Materials and Methods

1. Materials

Banana fruits (Giant Cavendish) to be shipped out from the Republic of the Philippines were used in this experiment. It took seven days for transportation from there to Japan and the banana fruits have been kept to store at 14°C temperature during the transportation. Fifteen bunches of bananas were visually selected to be the normal without defects. The spectral reflectance properties were measured at a center part of an individual banana fruit. The measurement was carried out about ten banana fruits which were selected in the fifteen bunches of bananas, and it was continued during nine days, or the period assumed to be the one from the ripening treatment until the marketing.

The experiment was carried out at practical ground-warehouse with a great deal of banana fruits for five days, the needed time for completing the ripening treatment of banana fruits. Ethylene gas with 1000 ppm concentration was treated during 24 hours at the second day, in order to give an artificial climacteric rise of banana fruits. After the treatment, samples were stored at about 30°C temperature in the university laboratory during four days as a shelf-life period.

2. Measuring of light reflectance properties

The experimental apparatus and measuring of light reflectance properties were showed in the previous paper[8]. Considering the possibility of practical application, the sample port size of 3.14 cm^2 (20 mm diameter) was adopted, and spectral reflectance properties were measured at center part of an individual banana fruit with small curvature. The effect of stray light reflected from the black felt walls of the chamber was about 10% of the total specular intensity. As this effect was not negligible, the spectral reflectance ratio of each banana fruit was calculated from the following equation.

$$R=(I_s-I_b)/(I_w-I_b)\times 100$$

where

R =spectral reflectance ratio (%),
I_s =spectral intensity of banana fruits (V),
I_w =spectral intensity of the white standard (V),
I_b =spectral intensity of black felt walls in the chamber (V).

3. Analyzing chlorophyll content

The 5 gr weight of peel was sampled from the area of peel of which the reflectance was measured. Chlorophyll content of the peel was determined by a spectrophotometric technique preceded by 80% acetone extract procedure[7]. Total chlorophyll content (a+b) was calculated from the following formula:

$$\mathrm{Chl.a}=12.72\times A(663)-2.59\times A(654)$$
$$\mathrm{Chl.b}=22.88\times A(645)-4.69\times A(663)$$
$$\mathrm{Chl.(a+b)}=(\mathrm{Chl.a}+\mathrm{Chl.b})\times V/50$$

where

A(663) = absorbance of the extract at 663 nm,
A(645) = absorbance of the extract at 654 nm,
Chl.a and b = chlorophyll content (mg/l),
Chl.(a+b) = total chlorophyll content (mg%),
V = volume of acetone extract (ml).

4. Measuring of firmness

Firmness of banana fruits was measured by a universal hardness meter (maximum range: 5 kg/cm^2). The firmness was determined about in the four directions at the center part of an individual banana fruit including the area of which the reflectance was measured. The probe diameter is 12 mm and its distance of penetration is 10 mm from a fruit surface. Values of the firmness were averaged in the four directions.

5. Analyzing total sugar content

The 3 gr weight of flesh was sampled from the center part of an individual banana fruit. The total sugar content of the flesh was determined by a spectrophotometric technique preceded by 5% phenol-sulfuric acid extract procedures[5]. The total sugar content was calculated as ratio of sucrose in gram to the weight of the flesh in 100 gr.

Results and Discussion

1. Change of spectral reflectance

Spectral reflectance curves of banana fruits during the ripening treatment were showed in Fig. 1. The spectral reflectance properties were measured over the wavelength regions of 400

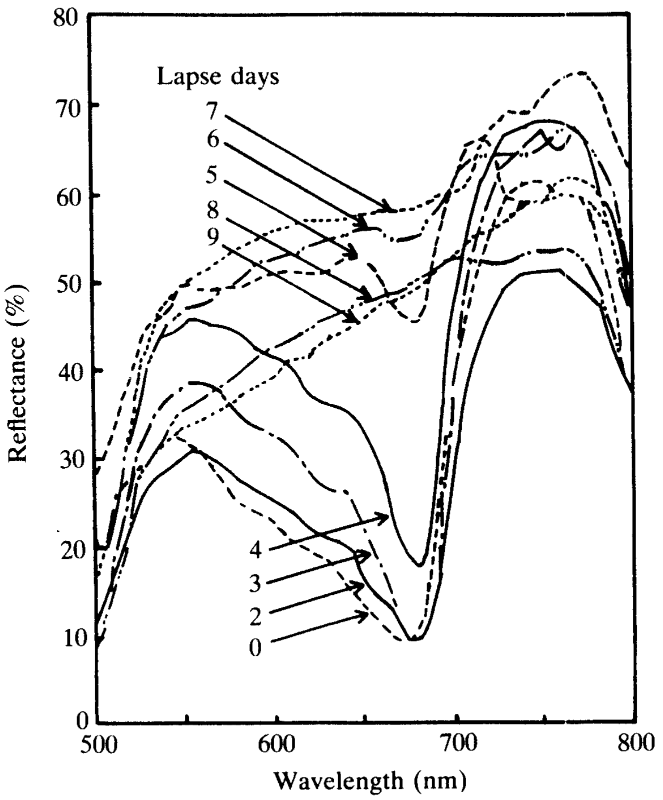

Fig. 1. Spectral reflectance curves for different colors of bananas during ripening.

to 800 nm on all samples. Since the spectral reflectances were virtually negligible level in the wavelength regions of 400 to 500 nm, the subsequent curves presented in this paper did not showed no values of spectral reflectances in the wavelengths of below 500 nm. The most outstanding characteristic of spectral reflectance curves was the chlorophyll absorption band at wavelength of approximately 680 nm. It was also noted that the spectral reflectance curves over the wave length regions of 550 to 700 nm were markedly increased with the ripening stage of banana fruits. After seven days from beginning of a test, the characteristic of absorption band disappeared on the spectral reflectance curves, because of the changing from green-ripe stage to full-ripe stage on banana fruits. The spectral reflectance at the wavelength of 680 nm changed from 10 to 70% during this period.

In the over-ripe stage, the spectral reflectances were lower than the spectral reflectance curves at full-ripe stage over the wavelength regions of 550 to 700 nm. This tendency of reflectance drops was different from the peculiar change of the spectral reflectance curves at chlorophyll absorption band. This difference of reflectance between full-ripe and over-ripe fruits was attributed to discoloration and darkness in color of the surface with black spots which occurred from the aging of fruits.

2. Change of attenuance at 680 nm

Chnage of attenuance at the wavelength of 680 nm during the ripening treatment of banana fruits was showed in Fig. 2. The attenuance representing absorbance properties of banana fruits is expressed by the longarithm of inverse reflectance, i.e. log(1/R). Change of the temperature during the ripening treatment and shelf-life period was also showed in Fig. 2. The attenuance at the wavelength of 680 nm, Er(680), remarkably decreased from 1.0 to 0.25 just after the ethylene treatment. The attenuance, Er(680) during the last two days at shelf-life period was found to be

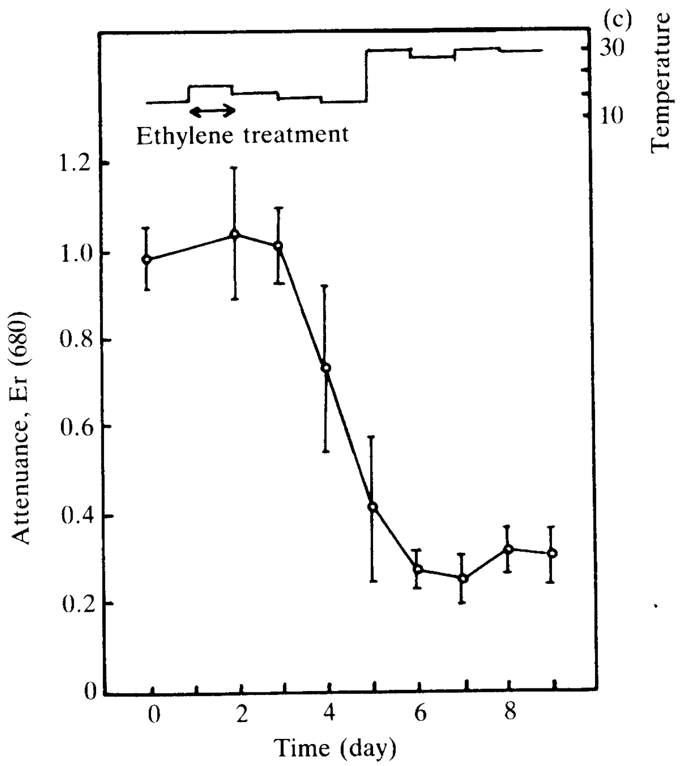

Fig. 2. Change in attenuance at 680 nm Er (680) during repening.

increased because of over-ripening of banana fruits with black spots on the surface.

In this experiment, the ripening treatment of banana fruits was carried out for five days and the banana fruits were kept at a room temperature after the ripening treatment. As the room temperature was slightly high at approximately 30°C, the banana fruits had been rapidly getting soft in flesh and dark color on the peel, losing commercial value at all. During this period, the attenuance, Er(680) precisely expressed the change of ripening stage of banana fruits from green-ripe to over-ripe. This tendency was corresponding with the result in previous studies[3]. Therefore, it was ascertained that the ripening stage of banana fruits was to be estimated by the attenuance at the wavelenght of 680 nm.

3. Change of chlorophyll content

In order to investigate the change of ripening stage of banana fruits, the chlorophyll content of the peel was measured during the ripening treatment and the shelf-life period. Fig. 3 showed the change of chlorophyll content of the peel with average values and standard deviations. The total chlorophyll content decreased from 3.7 to 0.7 mg% during seven days. The total chlorophyll content was divided into chlorophyll content-a and b, and the change of chlorophyll content-a was apt to be similar to the change of the total chlorophyll content. On the other hand, the chlorophyll content-b was constant during this period. Therefore, it was found to be obvious that decreasing of the chlorophyll content of the peel depended on the chlorophyll content-a, and the peel color changed with the decreasing of the chlorophyll content-a.

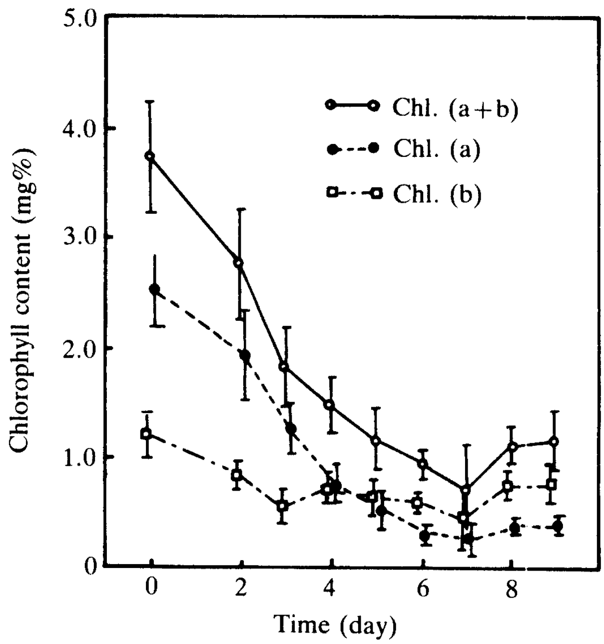

Fig. 3. Change in chlorophyll content during ripening.

The wavelength of 680 nm is the chlorophyll absorption band, and the change of the chlorophyll content of the peel was corresponding with the change of the attenuance, Er(680) in Fig. 2, excepting the high concentration of the chlorophyll content. The previous study indicated that the spectral reflectance properties were related to chlorophyll content of peel containing in limited thickness of the peel[2]. In this experiment, the peel of banana fruits contained high concentration of chlorophyll content during green-ripe stage. As the chlorophyll content in more than limited thickness of the peel was not concerned in the spectral reflectance properties, the attenuance, Er(680) was not related to the chlorophyll content of the peel estimated by chemical analysis.

4. Change of internal quality

It is very important to control temperature, humidity and ethylene gas concentration in the warehouse, in order to give an artificial climacteric rise of banana fruits during the ripening treatment. Difference of ripening condition gave effect on the internal qualities of banana fruits. Fig. 4 showed the change of firmness, one of the main internal qualities of banana fruits, during the ripening. The firmness of banana fruits linearly decreased from 4.32 to 0.49 kg/cm^2 after the ethylene treatment. The firmness of banana fruits did not change during the ethylene treatment but it decrease remarkably after the ethylene treatment. The change of firmness was of the same tendency as in case of the attenuance, Er(680) as showed in Fig. 2. It was also corresponded with the change of the peel color given by the climacteric rise[4]. Therefore, the attenuance, Er(680) was considered to be suitable for the evaluation of the ripening stage, because the firmness of banana fruits decreased with various ripening stages from green-ripe to over-ripe.

Sugar content of banana fruits is another main internal quality. Fig. 5 showed the change of the sugar content during the ripening. The sugar content of banana fruits increased up to about 20%. But comparing with the change of the chlorophyll content and the firmness, the measuring data of the sugar content were drifted after the full-ripe stage. They were not consistent during over-ripe stage, and their increasing was considered to be saturated. Essentially, a banana fruit contains about 20% starch and it changes to sugar by hydrolysis with the ripening. Final sugar content is considered to be effected on the initial starch content which the banana fruits at green-ripe stage had. Therefore, it was found to be impossible to estimate the final sugar content under the green-ripe stage. Nevertheless, the measuring data of the sugar content from green-ripe until full-ripe stage constantly showed increasing without drift. It indicated that the ripening uniformly occurred on each banana fruit just after the ethylene treatment. Consequently, it was

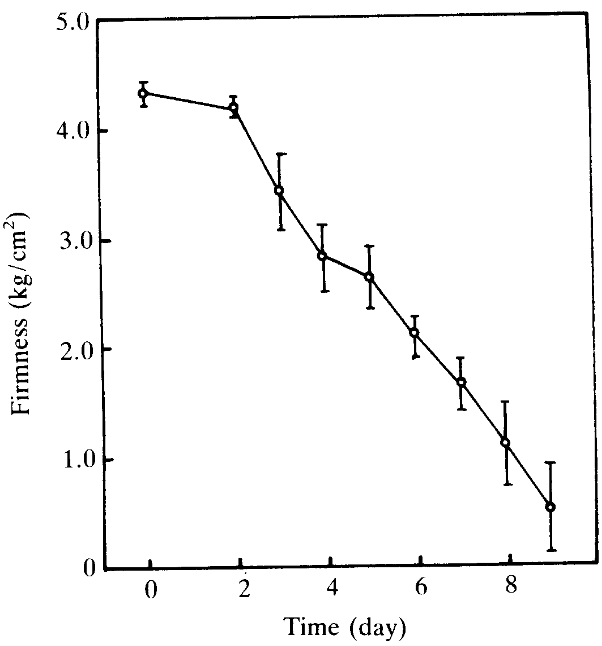

Fig. 4. Change in firmness during ripening.

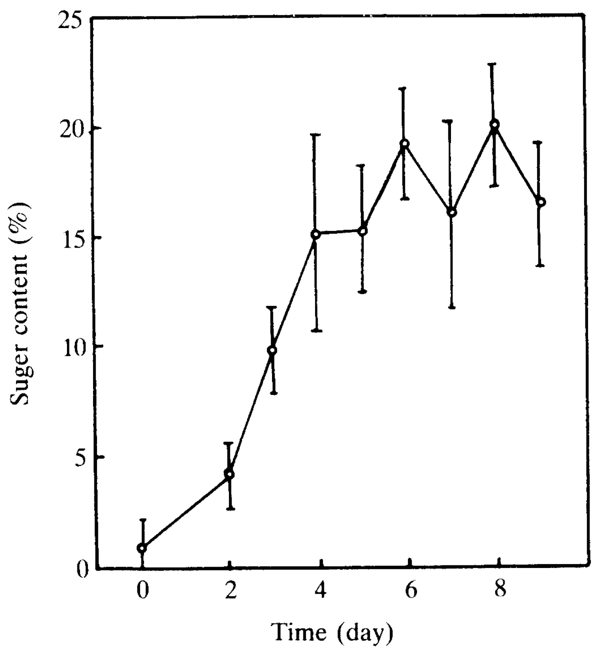

Fig. 5. Change in suger content during ripeing.

indicated that the change of the sugar content was corresponded with the change of the attenuance, Er(680) between green-ripe and full-ripe stage.

5. Relationship between Er(680) and internal quality

It was found that the changes of the chlorophyll content, the firmness and the sugar content of banana fruits were closely related to the ripening. In order to discuss about an application of light reflectance properties to a ripening index, the relationships between the attenuance, Er(680) and the chlorophyll content, the firmness and the sugar content were investigated. Fig. 6 showed the relationship between the attenuance, Er(680) and the total chlorophyll content. Its relationship was linearly correlated, and the linear regression and its coefficient were as follows.

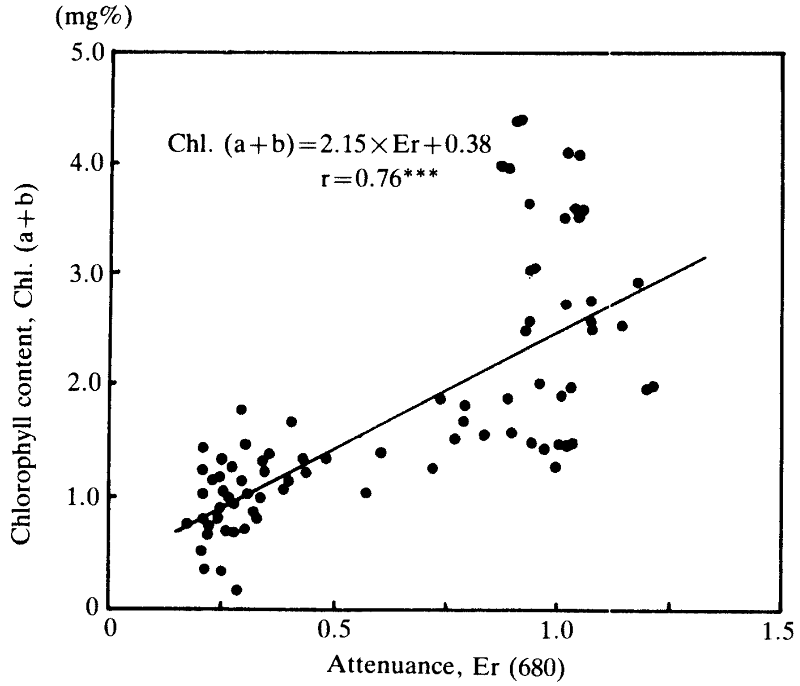

Fig. 6. Relationship between chlorophyll content and attenuance at 680 nm.

$$\mathrm{Chl.(a+b)} = 2.15 \times \mathrm{Er(680)} + 0.38$$
$$r = 0.76^{***}$$

The correlation was significant at 99.9% confidence level. The change of the total chlorophyll content was depended on the chlorophyll content-a. Therefore, the relationship between the attenuance, Er(680) and the chlorophyll content-a was linearly correlated.

$$\mathrm{Chl.a} = 1.88 \times \mathrm{Er(680)} - 0.19$$
$$r = 0.84^{***}$$

It was also obvious that the chlorophyll content-a was more highly correlated with the attenuance, Er(680) than the total chlorophyll content. The high correlation between the attenuance, Er(680) and the chlorophyll content-a was considered to be indicating that the attenuance, Er(680) could be available as an index of chlorophyll content.

The relationship between the attenuance, Er(680) and the firmness was showed in Fig. 7. Although the measuring data showed firmness was scattered at near 0.25 on the attenuance,

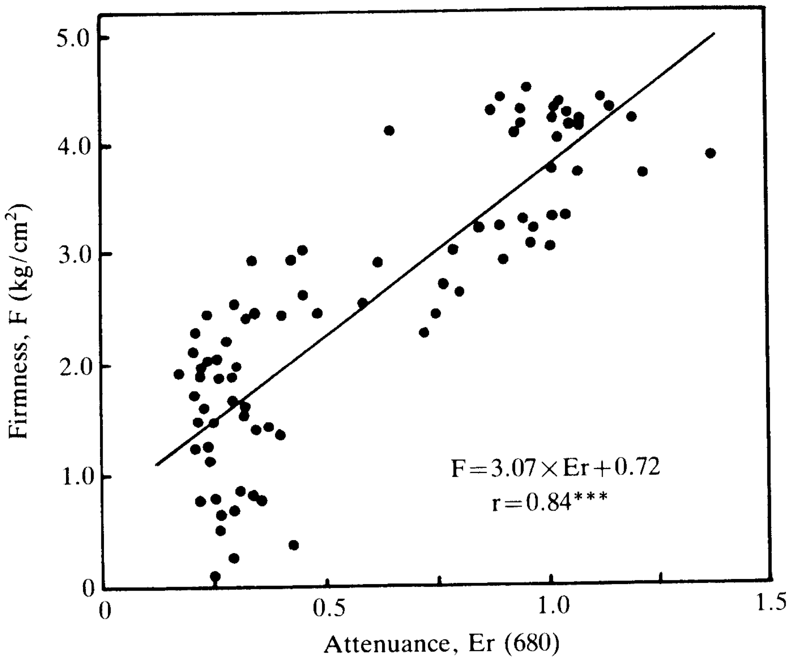

Fig. 7. Relationship between firmness and attenuance at 680 nm.

Er(680), the relationship between the attenuance, Er(680) and the firmness (F) was linearly correlated, and the linear regression and its coefficient was as follows.

$$F = 3.07 \times Er(680) + 0.72$$
$$r = 0.84^{***}$$

In general, the firmness of banana fruits consists of the pectin celllar bonding power, the mechanical strength of cell wall and the expanding pressure of cells[6]. The firmness of banana fruits was not directly related to the attenuance, Er(680). However, the higher correlation

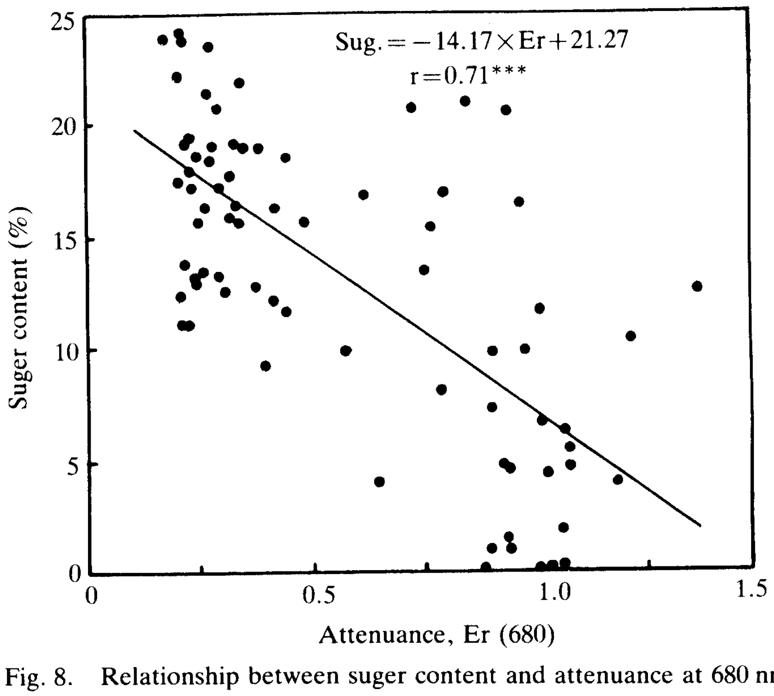

Fig. 8. Relationship between suger content and attenuance at 680 nm.

between the attenuance, Er(680) and the firmness was considered to be indicating that the attenuance, Er(680) could be available as an index of firmness as same as the high correlation between the attenuance, Er(680) and chlorophyll content was. This conclusion was corresponded with the result that Finney et al.[3] showed in the previous paper.

Fig. 8 showed relationship between the attenuance, Er(680) and the sugar content (S.C.). Comparing with relationships between the attenuance, Er(680) and the chlorophyll content and the firmness of banana fruits, the correlation coefficient was slightly lower. However, the correlation was significant at 99.9% confidence level. The linear regression was as follows.

$$S.C. = -14.17 \times Er(680) + 21.27$$
$$r = 0.71^{***}$$

The quality of banana fruits was effected by ripening temperature[10,12]. As an optimum temperature for the ripening treatment and a high temperature for shelf-life period had been kept, the ripening of banana fruits was steadily carried out in this experiment. Therefore, the relationships between the attenuance, Er(680) and the chlorophyll content, the firmness and the sugar content of banana fruits were highly correlated. It was found to be possible to estimate the change of the peel color and the internal qualities of banana fruits by the measurement of the attenuance, Er(680). However, in case of being kept within low temperature during the ripening treatment, the change of peel color was considered not to be corresponded with the change of internal quality. It was considered to be necessary to obtain more exhaustive data in order to apply the attenuance, Er(680) to the index of ripening.

Consequently, in order to control the quality of banana fruits during the ripening treatment, it is necessary to determine accurately the chlorophyll content, the firmness and the sugar content. The attenuance, Er(680) related to the quality of banana fruits was considered to be a valid index by non-destructive measuring method. The evaluation of quality of banana fruits from green-ripe to over-ripe stage was assumed to be attainable by the measuring the attenuance, Er(680).

Summary

Light reflectance properties of banana fruits were investigated in order to develop a rapid and non-destructive ripening evaluation method for the purpose of handling and controlling their ripening treatment. Green-ripe banana fruits have large absorption band between 550 and 700 nm wavelengths and the peak absorption band was at the wavelength of 680 nm. Their spectral reflectance increased remarkably with the ripening stage, reaching a maximum value over the whole measured wavelengths at the full-ripe stage. But, the spectral reflectance of banana fruits at over-ripe stage decreased at the whole wavelengths. The spectral reflectance indicated a maximum change at the wavelength of the absorption band of chlorophyll, 680 nm. Therefore, attenuance, Er(680) changed remarkably from 1.0 for green-ripe banana fruits to 0.25 for full-ripe ones after a period of seven days. The attenuance, Er(680) had a high correlation with total chlorophyll content, Ch.(a+b), of peel, and correlation coefficient was 0.76. However, the change of the total chlorophyll content was almost entirely depended on that of chlorophyll content-a. The relationship between firmness (F) and the attenuance, Er(680) was described by a linear regression and indicated significant correlation coefficient of 0.84, although the data were spread at the over-ripe stage. Sugar content of flesh increased with the ripening, and having a correlation with the attenuance at the wavelength of 680 nm.

Acknowledgment

The authors are much indebted to Professor Dr. M. Miyazato (Kagoshima Univ. Fac. of Agri.) for his kindness in reading and criticizing the manuscripts. The authors wish to express their deep appreciations for the helpful suggestions of Dr. Y. Chuma (Kumamoto) and Dr. S. Ishibashi (Fukuoka).

References

1) Chuma, Y., Nakaji, K. and Ohura, M.: Maturity evaluation of bananas by delayed light emission. Trans. of the ASAE, **23(4)**, 1043–1047 (1980).
2) Chuma, Y., Shiga, T. and Morita, K.: Evaluation of surface of Japanese persimmon fruits by light reflectance. J. Soc. Agr. Machinery Japan, **42(1)**, 115–120 (1980) (in Japanese)
3) Finney, E. E., Ben-Cela, I. and Massie D. R.: An objective evaluation of changes in firmness of ripening bananas using a sonic technique. J. Food Science, **32(6)**, 642–646 (1967)
4) Hosokawa, A. and Seo, Y.: Studies on the automation of the precess of banana ripening I. J. Soc. Agr. Machinary, Japan, **37(1)**, 86–91 (1975) (in Japanese)
5) Inokawa, T.: Seikagaku Kenkyuhou I. Asakura Press, Tokyo, 258 (1967) (in Japanese)
6) Iwata, T.: Seikahozou Hanron. Kenmensha, Tokyo, 289–290 (1977) (in Japanese)
7) Mackinney, G.: Absorption of light by chlorophyll solutions. J. Biol. Chem., **140(2)**, 315–322 (1941)
8) Morita, K., Shiga, T. and Taharazako, S.: Light reflectance properties of defects of Satsuma mandarin. Mem. Fac. Agr. Kagoshima Univ., **26**, 77–85 (1990)
9) Murata, T.: Studies on post-harvest ripening and storage of banana fruits VIII. Nippon Shokuhin Kogyo Gekkaishi, **17(10)**, 32–36 (1970) (in Japanese)
10) Murata, T. and Ogata, K.: Studies on post-harvest ripening and storage of banana fruits IV. Nippon Shokuhin Kogyo Gakkaishi, **13(9)**, 367–370 (1966) (in Japanese)
11) Terai, H., Ueda, Y. and Ogata, K.: Studies on the mechanism of ethylene action for fruits ripening I. J. Japan. Soc. Hort. Sci., **42(1)**, 75 -80 (1973) (in Japanese)
12) Yoshioka, H., Ueda, Y. and Ogata, K.: Effect of elevated temperatures on ripening of banana fruit. Nippon Shokuhin Kogyo Gakkaishi, **25(11)**, 607–611 (1978) (in Japanese)