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Delayed Light Emission as a Means of Automatic Color Sorting of Persimmon Fruits (Fart 1)

DLE Fundamental Characteristics of Persimmon Fruits

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Fundamental DLE characteristics of persimmon fruits were investigated to serve as a means for automatic color sorting of the fruits. It was found out that for obtaining the high intensity of DLE, a dark period longer than 15 min, exciting illuminance beyond 2,800 lx and exciting time from 1 to 3 sec would be recommended. Delayed light of persimmon fruits was emitted from the chlorophyll in the peel tissue. The bloom covering the fruit surface had little effect on the DLE intensity of persimmons. The DLE intensity of persimmon had a linear relationship with the chlorophyll content.

INTRODUCTION

Fukuoka Prefecture, Japan, is one of the most suitable areas for producing sweet persimmons "*Fuyu* fruits", and the production area had been increasing every year by 100 hectares. By 1976 the growing area was 1,930 hectares yielding 17,700 tons annually. Quality sorting of this volume of fruits demands much hand labor. For example, twenty of the 70 workers in a sorting plant in Yoshii-Cho, Fukuoka Prefecture are required to be effective in sorting persimmons according to quality. This high labor requirement for sorting justifies the development and use of automated sorting equipment.

One of the most effective means of separating persimmons according to quality is by delayed light emission (DLE). However, before incorporating DLE technology into an automatic sorter it is necessary to study the fundamental characteristic of DLE in persimmon fruits. This paper was written to describe the relationship of DLE to the chlorophyll content of persimmon fruits.

MATERIALS AND METHODS

Samples of persimmons, *Diospyros kaki* Linn. f. var. *Fuyu,* were collected every 7th day from the Kyushu University Farm during the growing season from September to November 1976. The fruits were given special attention to prevent bloom removal during handling. The samples were kept at room temperature until measurements were made.

Fig. 1 shows the procedure followed in preparing the samples for DLE intensity studies (see discussion of Figs. 2, 3 and 4). The DLE was determined from a projected area of the fruit 30mm diameter (7.07 cm^2) near the apex. Two levels of excitation, 1,750 and 5,500 lx, *were* used in this study. Chlorophyll measurements were made by Arnon's Method (Mackinney, 1941) from a disc shaped specimen (28 mm dia. and approximately 5mm thick) at the portion where DLE was measured. DLE measurements were made in accordance with an earlier paper (Chuma and Nakaji, 1976).

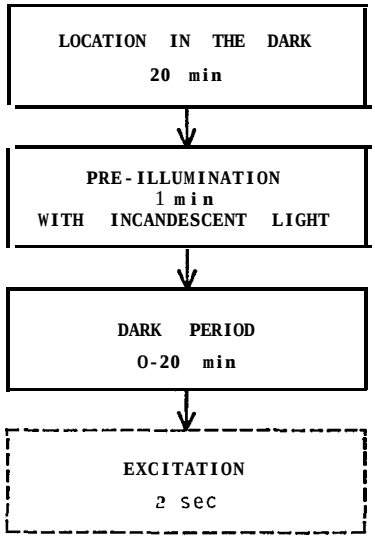

Fig. **1.** Preparatory procedure of sample before excitation.

1. Fruit temperature measurements

Temperature measurements were made by inserting two thermocouples 1 mm beneath the rind in the region of DLE measurements. The fruit temperature was computed as the mean value of the two thermocouple readings.

2. DLE of rind and flesh

Two tests were performed to evaluate the DLE in rind and flesh. For test 1 (the results are shown in Fig. 6) two similar yellow-greenish persimmons were chosen. The DLE of the intact fruit, labeled W, was determined for an excitation of 1,750 lx, a dark period of 10 min. exciting time of 2 sec,

and a fruit temperature of 17°C. One mm of the surface, including the rind, of the second fruit labeled F, was removed and DLE of the exposed flesh was measured under the same conditions used for W above. A plot of DLE intensity vs. decay period was made.

In test 2 two similar fruits were chosen. DLE was measured on each fruit after the fruit was prepared as follows (refer to Fig. 7 for illustrations of the preparation) :

(1) The intact fruit (labeled W).

(2) A 10 mm slice of the opposite side of the fruit (labeled A).

(3) The same slice as in (2) above but with the flesh scooped out (labeled B).

(4) The rind of the fruit (labeled P).

(5) The flesh of the persimmon (labeled F).

Thickness of the slices varied as shown in Fig. 7.

3. Effect of bloom on DLE intensity

A total of 326 fruits were harvested on October 30 and November 16. Of the 326 harvested only *126* fruits were covered with bloom. Fifteen of the fruit covered with bloom were randomly selected. DLE was measured both with bloom and after bloom was removed. Temperature of the fruits ranged from 19.9 to 24.5°C. Ratios of the DLE before and after bloom was removed were tabulated.

RESULTS AND DISCUSSION

Excitation of green persimmons with white light from a tungsten lamp at both 1,750 and 5,500 Ix produced DLE spectra which peaked at 700 nanometer (nm) and have a bulge on the longer wavelength side of the peak. These spectra were similar to the fluorescence spectrum of chlorophyll as determined by Arnold and Davidson (1954).

1. Saturating recovery of DLE due to dark period

Fig. 2 shows the relationships between the dark period and saturation recovery (Chuma and Nakaji, 1976; Itoh and Murata, 1973) of DLE intensity using decay periods of 0.7, 0.9, 1.0, and 1.5 sec. Note that the dark period is the time the fruits were in the dark immediately following excitation.

When excited with 1,750 lx DLE saturation recovery was not fully complete even after 20 min of dark period storage. However, when 5,500 lx was used, saturation recovery of DLE was fully achieved within 15min. Illumination of the persimmons with 5,500 lx for up to one minute, as in the pre-illumination period, caused a negligible temperature rise of only 0.2°C, 0.5 mm below the surface.

2. Relationship between excitation period and DLE intensity

DLE increased abruptly to a peak for excitation periods up to 2 sec and then declined gradually for longer periods of excitation up to 60 sec (refer to Fig. 3). Maximum DLE intensity for 1,750 lx excitation was found to occur

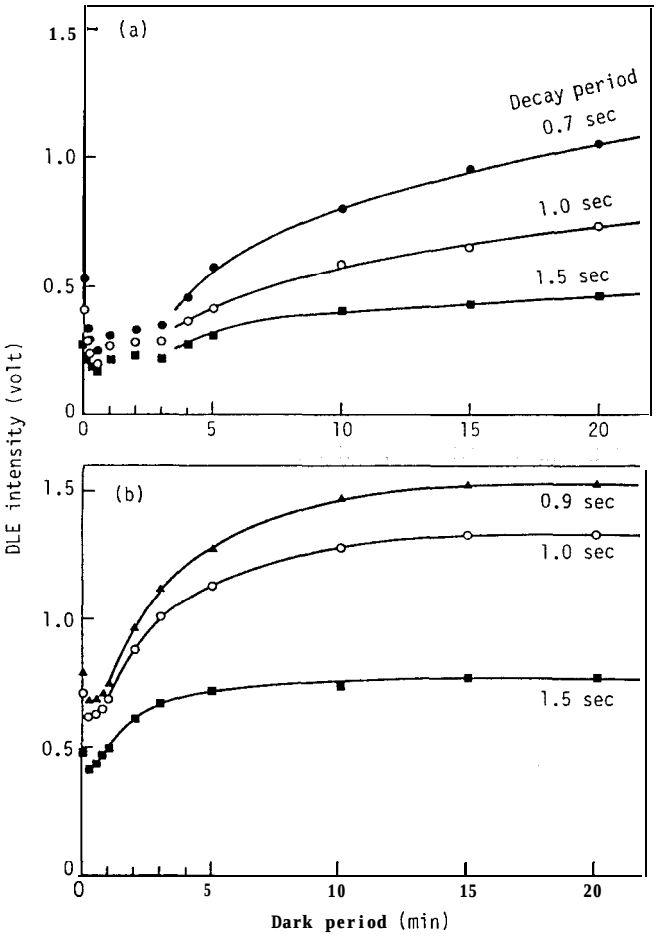

Fig. 2. Dark recovery of DLE intensity of persimmon excited by two different intensities. (a) : 1,750 lx; (b) : 5,500 lx. Conditions for determination of DLE: 60 sec pre-illumination period, 2 sec excitation period, 7.07 cm^2 excitation area, 21°C fruit temperature, and yellow samples.

for excitation times of 1 to 2 sec; 5,500 lx excitation induced maximum DLE for 1 to 3 sec of exposure to the exciting light.

3. **Effect of exciting intensity on DLE**

It can be seen in Fig. 4 that maximum DLE saturation was reached when 2,800 lx excitation was used. In any automatic system using DLE the illumination intensity should not be less than 2,800 lx.

4. **Effect of fruit temperature on DLE intensity**

According to Fig. 5, DLE increased as the fruit temperature increased up to about 22°C. From 22℃ to 32℃ DLE remained fairly constant. Temperatures beyond 32°C caused a degradation in DLE intensity.

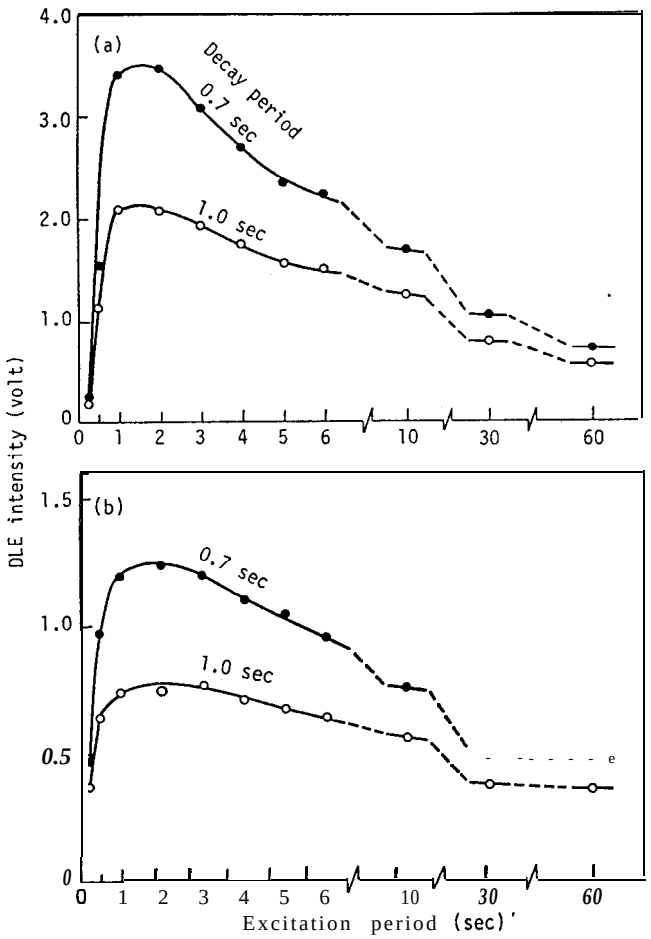

Fig. 3. Effect of excitation period on DLE intensity of persimmon. (a): 1,750 lx illuminance, 10 min dark period, 24°C fruit temperature, and greenish yellow sample; (b) : 5,500 Ix illuminance, 10 min dark period, 21°C fruit temperature, and yellow sample.

5. Appropriate exciting conditions

The optimum exciting conditions appear to be as follows: (1) dark period storage of greater than 5 min, (2) excitation illuminance of 2,800 lx or greater, (3) an excitation period of 1 to 3 sec, and (4) a fruit temperature of 22 to 32°C. However, in the Results and Discussions which follow technical problems with the light source restricted the conditions to a secondary dark storage period of 10 min, an excitation illuminance of 1,700 lx, and an excitation period of 2 sec.

6. DLE of rind and flesh

Fig. 6 confirms the fact that most of the chlorophyll in persimmons is

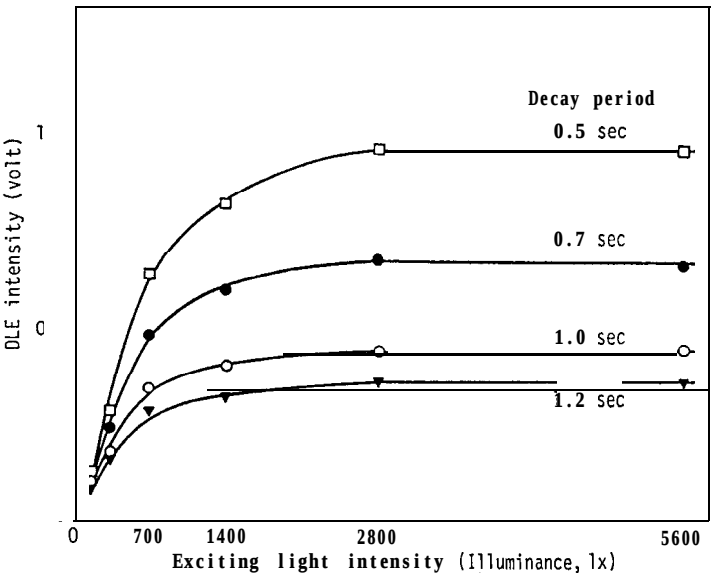

Fig. 4. Effect of exciting light intensity on **DLE** intensity of persimmon. Conditions for determination of DLE: 10 min dark period: 2 sec excitation period, 21°C fruit temperature, and yellow sample.

concentrated in the rind and not the flesh. This, of course, is in contrast with the tomatoes where the chlorophyll is distributed throughout the flesh. It is another reason why DLE is such a good choice for sorting persimmons according to maturity.

From Fig. 7 it can be seen that flesh (F) alone produces very little DLE when excited with 1,750 lx. DLE of the peel (P) contributed approximately 2/3 of the total DLE of the fruit. The additional DLE observed in A and B was probably due to additional excitation caused by the flesh serving as a "reflecting mirror" ; thus, some of the exciting light was reflected by the flesh causing additional DLE excitation of the chlorophyll in the peel.

7. Effect of bloom on DLE intensity

Freshness of persimmon fruits is often associated with the amount of bloom (a white waxy substance) on the surface of the peel. Bloom has an effect on light entering the fruit by acting as a light scattering medium' and consequently can affect the determination of color (Birth and Zachariah, 1973). Table 1 shows the percentage of blooms on fruits gathered from four trees on October 30 and November 16. Table 2 illustrates the fact that DLE is little affected by the presence or absence of bloom, Of the 15 samples tested the ratio of DLE with bloom to DLE with bloom removed ranged from 0.88 to 1.10. This indicates another advantage of DLE measurements over conventional color evaluation techniques for determining maturity of persimmons.

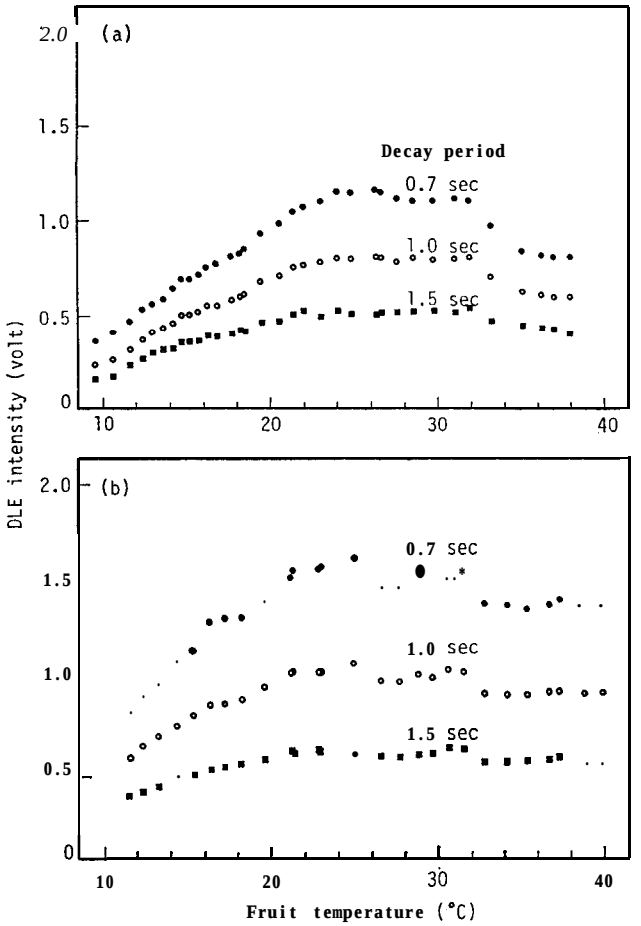

Fig. 5. Effect of fruit temperature on DLE intensity of persimmon. (a) : 1,750 Ix illuminance ; (b): 5,500 lx illuminance. Conditions for determination of DLE: 3min dark period, 2 sec excitation period, and yellow sample.

Table 1. Number of persimmon fruits covered with bloom on two harvest dates.

Date	Tree no.	Total number of fruits	Number of fruits covered with bloom (percent)	Number of fruits uncovered (percent)
October 30	No. 3	134	60 (45)	74 (55)
	No. 4	102	42 (41)	60 (59)
	Total	236	102 (43)	134 (57)
November 16	No. 1	22	11 (50)	11 (50)
	No. 2	68	13 (19)	55 (81)
	Total	90	24 (27)	66 (73)
Total		326	126 (39)	200 (61)

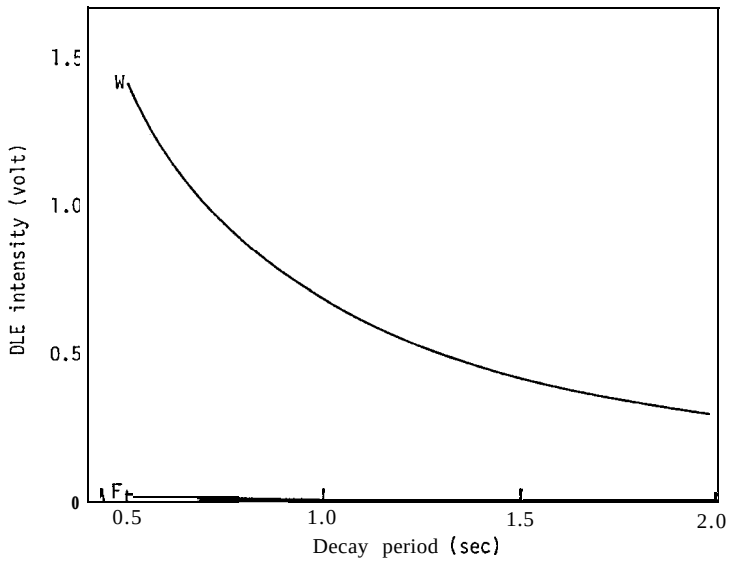

Fig. 6. Decay curves of DLE intensity of persimmon. W: whole persimmon; F : flesh of persimmon. Conditions for determination of DLE: 10 min dark period, 2 sec excitation period, 1,750 lx illuminance, and 17°C fruit temperature.

Table 2. Effect of bloom covering the fruit surface on DLE intensity of persimmon.

Sample no.	Fruit temperature ℃	DLE intensity*		Ratio
		Persimmon covered with bloom volt (A)	Persimmon, bloom wiped away volt (B)	A / B
1	26.1-26.8	1.04	0.96	0.96
2	25.5-26.0	1.02	0.96	1.06
3				0.98
4	25.8-26.3	0.94	0.96	0.96
5	27.2-27.5	0.96	0.94	1.02
6	27.2-27.5	0.88	0.94	0.94
7	27.5	0.94	0.92	1.02
8	27.6-27.9	0.88	0.92	0.96
9	21.0-21.1			
10	19.8	0.72	0.76	0.95
11	20.1-20.4	0.54	0.60	0.90
12				0.88
13	21.2-21.4	0.41	0.42	0.98
14	19.8	0.28	0.29	0.97
15		0.11	0.10	1.10

* DLE intensity was measured after 1.5 sec decay period, 2 sec excitation period, 1, 750 Ix illuminance and 10 min dark period before excitation.

8. Effect of chlorophyll content on DLE intensity

Figs. 8, 9 and 10 show the relationship of chlorophyll a, b and (a+b) respectively to DLE intensity. A regression equation was fitted to each set

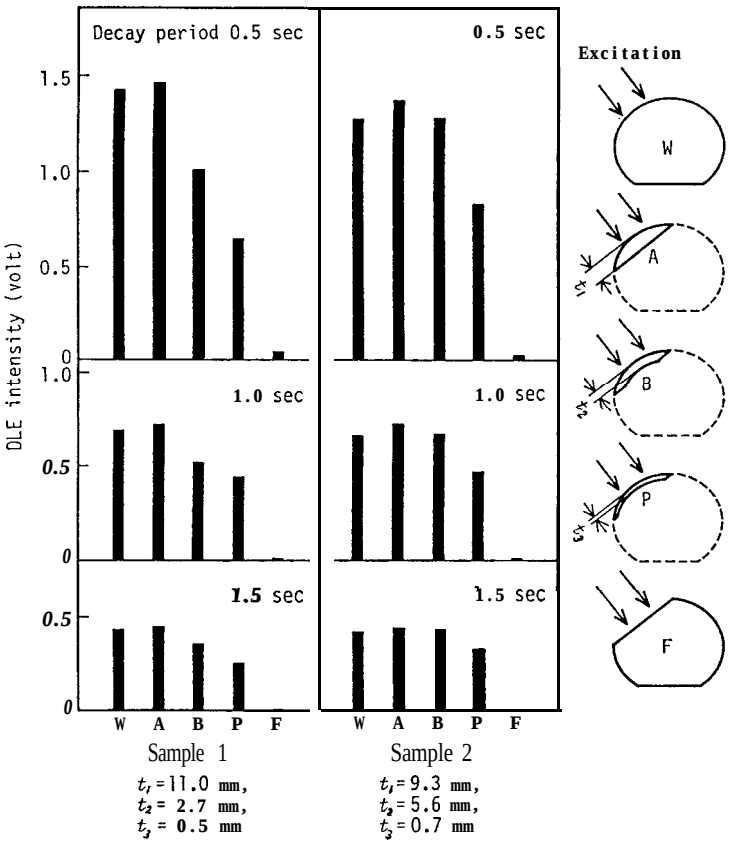

Fig. 7. Effect of flesh on DLE intensity of persimmon.

of data by a least squares linear model. The equations were as follows:

Chl. a: $y = 2.23x + 0.20$ $r = 0.896$,
Chl. b: $y = 4.02x - 0.09$ $r = 0.711$,
Chl.(a+b): $y = 1.53x + 0.01$ $r = 0.861$.

Where x is the chlorophyll content in mg/100 g fresh weight, y is the detector responses to DLE intensity (in volts) and r is the correlation coefficient. All three correlation coefficients were found to be significant at the 0.1 percent level. Although temperature had an effect on DLE, chlorophyll had a more pronounced effect.

SUMMARY AND CONCLUSIONS

DLE characteristics of chlorophyll of persimmons were investigated for the purpose of providing basic data for automatic sorting according to maturity. Based on the results of this study the following conclusions can be made:

1. If high illuminance of 5,500 Ix is used DLE saturation can be achieved

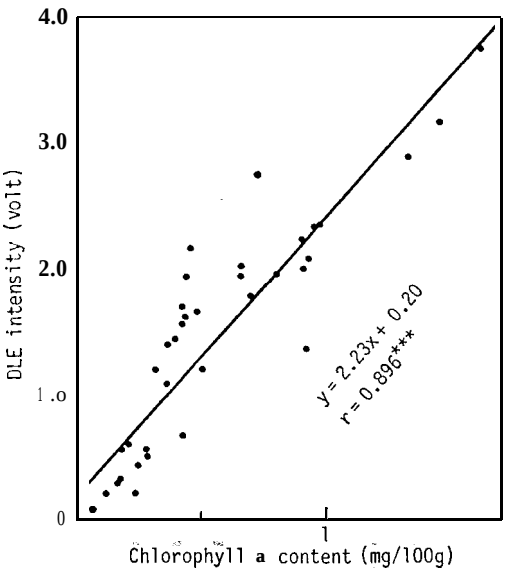

Fig. 8. Relationship between chlorophyll a content and DLE intensity of persimmon. Conditions for determination of DLE: 10 min dark period, 2 sec excitation period, 1,750 lx illuminance, 0.7 sec decay period, and 19.9–24.5°C fruit temperature. *** indicates statistical significance at 0.1 percent level.

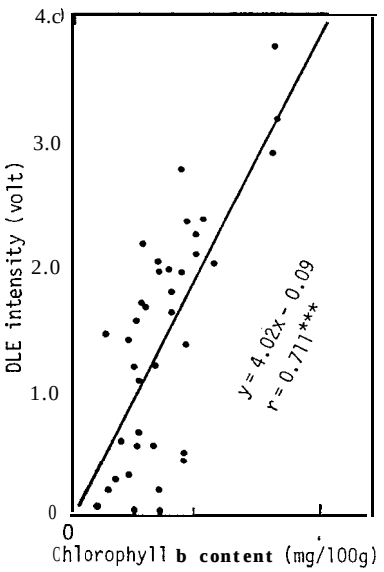

Fig. 9. Relationship between chlorophyll b content and DLE intensity of persimmon.

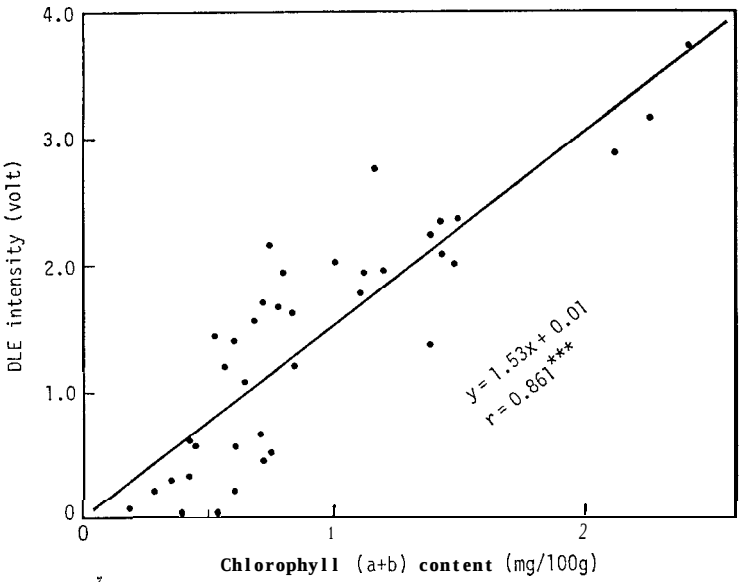

Fig. 10. Relationship between total chlorophyll content and DLE intensity of persimmon.

with a shorter dark period.

2. Optimum exciting conditions were found to be a dark period of 5 min, excitation illuminance of more than 2,800 Ix, an exciting time of 1 to 3 sec, and a fruit temperature of 22 to 32°C.

3. Using a dark period of 10 min and an excitation illuminance of 1,750 Ix for 2 sec the following results were obtained:

(a) The peel contributed the majority of DLE, but the flesh did contribute slightly to the DLE by reflecting the transmitted light to the peel causing additional DLE.

(b) Bloom on the surface of the peel, which could cause misclassification of the fruits according to color, had little effect on the DLE intensity.

(c) The DLE intensity of persimmons had a linear relationship with the chlorophyll content. Higher correlation coefficients were observed in chlorophyll a and total chlorophyll (a+b).

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