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Delayed Light Emission as a Means of Sorting Tomatoes

DLE Characteristics of Tomatoes Excited by Flash Light

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An apparatus for measuring the DLE of tomatoes using flash light excitation was devised to examine the DLE characteristics of the tomatoes. The DLE of tomatoes was saturated in the dark chamber for a duration of 5 minutes and was hardly affected by fruit temperature. The intensity of the DLE correlated well with the value of peel color, suggesting the possibility of maturity evaluation and sorting of tomatoes according to their DLE intensity.

INTRODUCTION

Green fruit contained in the processing tomatoes, lowers the grade rating of the finished foods, hence sorting of green fruit from a pile of fruit is necessary for the insurance of a uniform and high grade of finished product. Currently, tomatoes harvested by machine are still sorted by manual operation which lacks sorting accuracy and requires too much labor. Automatic mechanization in the sorting of tomatoes is therefore of a genuine need. However, before this could be achieved a standard for the sorting and maturity evaluation of tomatoes based on physical properties must be established.

Sorting of tomatoes by using light reflectance or transmittance has been reported by several authors in the U. S. Chuma and Nakaji (1976) investigated the DLE characteristics of tomatoes after they were excited by white light for several second's duration.

Previous experimental apparatus used for the DLE measurement was adequate for laboratory use, (Chuma et *al.*, 1977; Chuma and Nakaji, 1979a, b, c; Chuma et al., 1980a, b), however, in this case, mechanical shutter was used to adjust the duration of excitation, and to protect the photomultiplier tube from overcharging, thus hindering rapid measurement. Furthermore, this mechanism will not be used for a long period of time for the practical sorting work. The number of mechanical parts in the apparatus should be minimized for the rapid and repeated measuring operation.

In this report, an instrument for DLE measurement using flash excitation was constructed in an attempt to set up a facility capable for continuous and rapid sorting of tomatoes.

INSTRUMENT DESIGN

The light source used was a donut-shaped ring flash lamp. After flashing, the DLE from the fruit passed through the ring and collected in the photomultiplier tube. The main point of improvement was the omission of the shutter which controlled the excitation in the previous apparatus. Fig. 1 shows a simplified schematic diagram of the experimental apparatus.

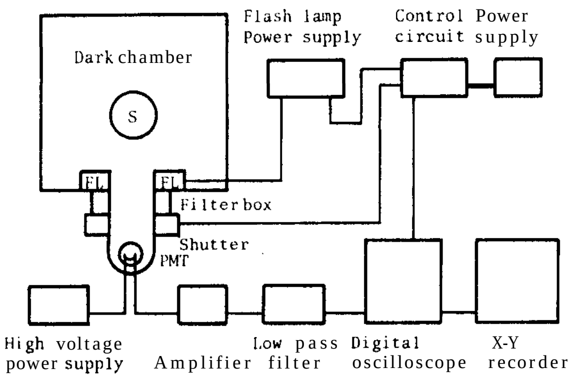

Fig. 1. Schematic diagram of the experimental apparatus for detecting DLE intensity. S: sample, FL: ring flash lamp, PMT : photomultiplier tube.

1. Optical part

A ring-type flash lamp (Sugawara Manufactory : PS-240 D) was used as the exciting light source in the apparatus. This enabled good alignment of the sample products with the light source and DLE detector within the sorting line. The flashing duration was 24 μsec (half-width) and the power of the exciting tube was 60 watts.

The delayed light emitted from the sample passes through the central space of the shutter (Copal: DC-494, 45 mm dia.), and is detected by the photomultiplier tube. The photomultiplier tube is a side-on type (Hamamatsu TV: R-758) of 28 mm in diameter with a photocathode area of 36 mm^2 (3×12), and has a constant photocathode radiant sensitivity within the range of 300 to 800 nano meters. Considering the durability and dark current of the photomultiplier tube, the anode to cathode voltage was kept 750 volts. Unlike in the former apparatus, a mask for the regulation of the area of DLE emission was omitted. The sample was placed within the visual field through a cylinder having a 40mm inside diameter set in front of the photomultiplier tube.

2. Recording part

The delayed light emitted from the sample was converted into the electric signal by the photomultiplier tube and pre-amplifier circuit. This signal passes through the amplifier (x 100) and the high frequency noise is removed by a low-pass filter (Nippon Denki Kogyo: F-5L, 180 Hz) and is recorded on the digital storage oscilloscope (D. S. O., Nicolet Instrument Corp.). The DLE signal was analyzed with a microcomputer (NEC: PC-8001) and the calculated results were recorded on a printer (TEAC: PT-210) and X-Y plotter (Watanabe Sokki : WX-4671).

3. **Controlling part**

A C-MOS IC regulatory circuit was attached to control the strength of

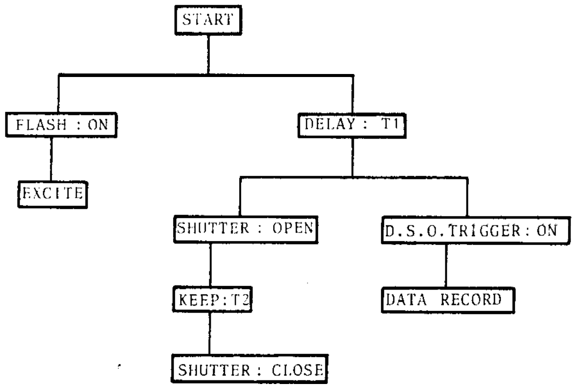

Fig. 2. Flow chart for DLE measurement.

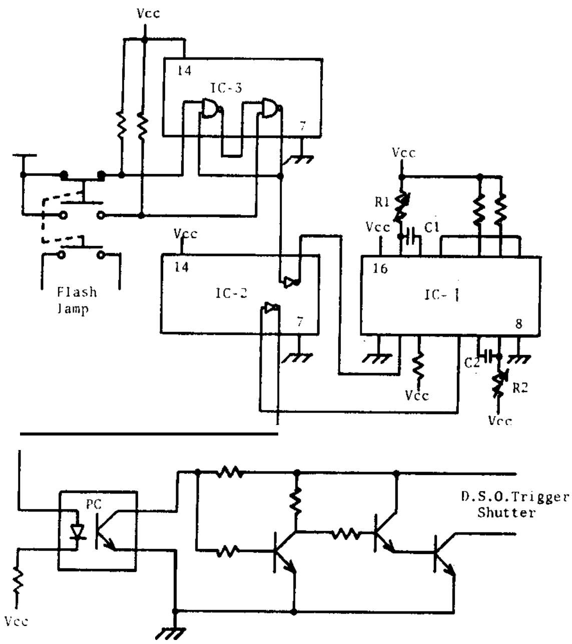

Fig. 3. Control circuit for DLE measurement. IC-1: LS123, IC-2: 7404, IC-3: 7400. PC: photocoupler.

light emitted by the flash lamp, the time of opening and closing of the shutter, and the trigger signal for the input of DLE signal. The flow chart is shown in Fig. 2. By pushing the starting button the circuit of flash lamp is closed, then the flashing occurs. After T1 milli-second, the shutter is opened by operating the shutter control signal. At the same time, the D.S.O. is triggered, followed by the input of signal. The shutter is opened for T2 sec during which the DLE is detected by the photomultiplier tube. Fig. 3 shows the controlling circuit of the time of T1 and T2. IC-1 constitutes the delay and gate circuit and strike a signal of T2 sec duration after T1 milli-second.

The starting signal is transmitted into the IC-1 through the flipflop circuit to prevent chattering and the gate signal is emitted after T1 milli-second. This gate signal is amplified by a transister after passing through the IC-2 and photocoupler and becomes the shutter and trigger signal. The time of T1 and of T2 can be selected at random from the formula $T=R\times C\times 0.4$ by adjusting the variable resistance R1 and R2, and capacitance Cl and C2. In the present study, T1=100 msec and T2=5 sec were used.

MATERIALS AND PROCEDURE

1. Materials

Tomatoes of the variety "Kyoryoku Beiju" harvested at Kukinomura, Kumamoto Prefecture according to the degree of ripeness were brought in the laboratory by truck at normal temperature, and used for measurement within **24** hours. The average dimensions of the sample were shown in Table 1.

Table 1. Average dimensions of tomatoes.

	Mean value	S.D.
Max. dia. (mm)	73. a	5. 3
Min. dia. (mm)	69.5	4. 4
Height (mm)	61. 1	3. 3
Weight (g)	173. a	28. 7

2. Measurement of DLE intensity

The sample was placed in position in the dark chamber and kept in darkness for the designated period. The flash excitation, opening and closing of the shutter and the DLE input into photomultiplier were operated automatically after turning on the start button. The DLE intensity for each decay period was read from the decay curve on the digital storage oscilloscope.

The method of experimentation on the effect of dark period before excitation and the effect of fruit temperature on DLE was the same as that expressed in the previous paper (Chuma and Ohura, 1982). However, the fruit was pre-illuminated with a flash light to make the uniform pre-exciting conditions before measurement.

3. Measurement of peel color

The coloration of the tomato was classified into 4 classes from green to red by visual classification by 2 persons. The peel color for each maturity stage and the number of tomatoes examined are shown in Table 2. As the products flow at random on the conveyor belt of the grading line, the DLE intensity emitted from different portion of the fruit should be determined. Therefore, the DLE intensity from the apex, stem end and two opposite sides of the cheek of the tomatoes were measured.

Table 2. Mature stage of tomatoes.

Mature stage	External color	Number
1: Green	Green, green to trace yellow	20
2: L. pink	Greenish yellow, light pink (Turning stage)	20
3: L. red	Orange, light red	20
4: Red	Red, deep red (Full ripe stage)	20

The peel color of the portions of DLE measurement was determined by color-difference meter (Nippon Denshoku: 504-AA), and expressed as Hunter L, a and *b* in the UCS (uniform chromaticity scale) color specification system.

RESULTS AND DISCUSSION

As the fundamental characteristics of the DLE of tomatoes under the continuing light excitation the effects of dark period, exciting light intensity, exciting time and fruit temperature on DLE have been reported (Chuma *et al.*, 1980b). In this experiment, the authors examined the effects of flash-light excitation on the DLE intensity.

1. Effect of dark period on DLE

The relationship between the DLE intensity and the length of dark period from 0 to 20 min just prior to excitation is shown in Fig. 4.

The DLE intensity increased until the longer dark period for the short decay period of 150 msec. The DLE was saturated when the tomatoes were under the dark period for 15 and 5 min for the decay period of 200 and 300 msec, respectively. A high and stable flash excitation is needed for obtaining the DLE to be used for sorting tomatoes. Since the DLE intensity is not stable under the dark period of short duration, DLE measurements should be made under the dark period of at least 5 min, and the decay period of 300 msec.

2. Effect of fruit temperature on DLE

Fig. 5 shows the relationship between DLE intensity and fruit temperature. The DLE intensity increased from 11 to 14°C from the initial decay period and reached a peak between 14 to 17°C. When the fruit temperature

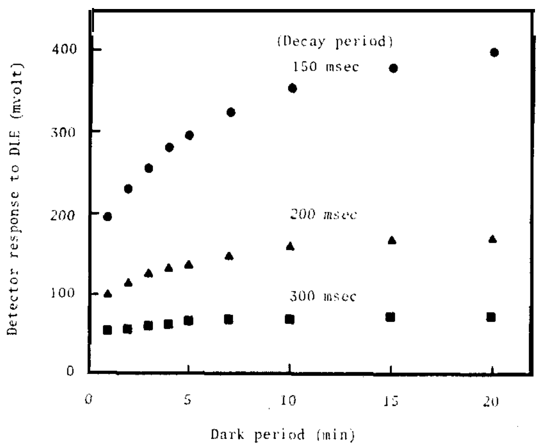

Fig. 4. Effect of dark period on DLE intensity of tomato.

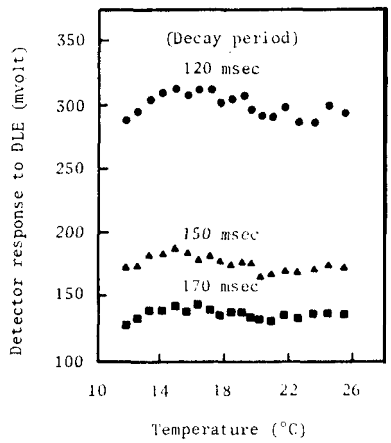

Fig. 5. Effect of fruit temperature on DLE intensity of tomato.

exceeded 17℃, the DLE intensity tended to decrease. For the decay period exceeding 200 msec, the DLE intensity was kept almost constant at a fruit temperature of 11 to 26℃, indicating a little temperature dependency. Thus, there is no need of controlling the temperature of tomatoes with respect to DLE measurement, which provide conveniences in making a measuring device.

3. **Relationship between DLE intensity and peel color**

As an index of peel color, the Hunter a-value in the UCS color specification system was used and the relationship between DLE intensity and peel color was examined. The relationship between DLE intensity and the a-value for the apex face of the tomatoes is shown in Fig. 6. The a-value for the rind color during this period changed from 15 to 35. The DLE intensity also de-

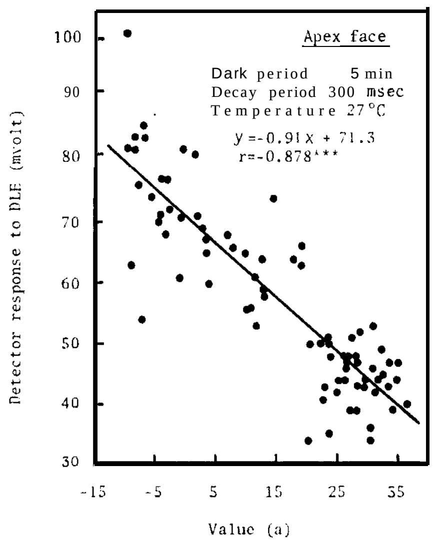

Fig. 6. Relationship between u-value and DLE intensity of tomatoes.

creased with the change in peel color from green to red, indicating a high correlation between the a-value and DLE intensity. A linear relationship was obtained as follows:

$$y = -0.91x + 71.3,$$

where y is the DLE intensity in milli volts and x is the Hunter a-value. The correlation coefficient between DLE and Hunter a-value was -0.878 and the formula was statistically significant at the 0. 1 percent level.

The relationship between the DLE intensity and the peel color of the position other than the apex was also investigated. The value of peel color of the cheek in the maturing stage was 2 or 3, which was composed of green and red peels, and high correlation was not obtained between DLE and peel color. At the stem end, the color of rind was not accurately identified because of the interruption of the green color of the stem.

4. **Effect of the measuring portion of tomato on the DLE intenisity**

The relationship between the DLE intensity and the coloration according to the measuring portion of the tomato is shown in Fig. 7.

The DLE intensity of tomatoes decreased with the increase in the coloration. The DLE intensity of cheek between the maturing stages of 2 and 3 differed much, but less in the difference between stages 1 and 2 or stages 3 and 4. At the stem end, there was no noticeable difference between neighbouring stages except for the difference between stages 1 and 4. On the other hand, the DLE intensity at the apex was different for each stage of coloration and tended to decrease with the increase in coloration.

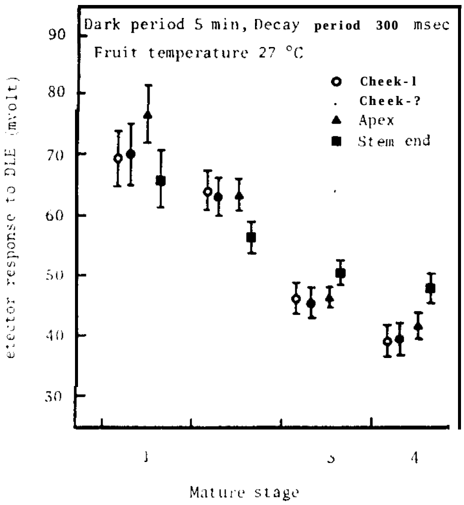

Fig. 7. Relationship between mature stage and DLE intensity of tomatoes

5. **Sorting accuracy of tomatoes by DLE**

Tomatoes sorted visually into 4 classes were used for the sorting test. Table 3 shows the sorting accuracy of tomatoes by DLE intensity. The sorting accuracy for maturing stages 1 and 2 were 78 percent and 75 percent, respectively, while that of the stages 3 and 4 was 60 percent. These results coincided with the sorting accuracy of tomatoes by the previous apparatus using continuous light excitation. The sorting accuracy of red tomatoes was low due to the little chlorophyll content, however, no green tomatoes were mixed into the matured tomatoes, suggesting the possibility of sorting by DLE.

Table 3. Sorting accuracy of mature stage of tomatoes by DLE intensity. DLE intensity was measured in 300msec decay period emitted from the apex face of tomatoes.

Mature stage	Range of DLE intensity	Number	1	2	3	4
			Sorting accuracy (%)			
	71 and over	18	78	22	0	0
	56-71	20	25	75	0	0
	45-56	21	5	5	62	28
4	below 45	21	0	0	33	67

CONCLUSION

DLE measuring apparatus using the flash light excitation was developed and proved to be durable for the high speed repeating operation.

DLE characteristics of tomatoes by flash light excitation were revealed. The DLE intensity and the peel color had a high correlation and was used as a maturity index of tomato. Green tomatoes mixed with matured red ones were sorted with permissible accuracy by the DLE intensity.

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