Development of Automatic Sorting System of Satsuma Mandarin by Light Reflectance

Kazuo Morita, Thoru Shiga* and Shôji Taharazako

(*Laboratory of Agricultural Systems Engineering*)

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Introduction

The grading process of Satsuma mandarin in the packinghouse line requires much amount of skilled laborers, because its manual grading mainly depends on the judgment of its surface color. Authors reported previously[2] that the surface color of Satsuma mandarin was found to be related with the peel chlorophyll content, and that the light reflectance property was highly correlated with it. Also, the relationship between the light reflectance property and acidity and total sugar content of the flesh was investigated in detail and it became evident that the spectral reflectance at 680nm wavelength could be applied for the quality evaluation of Satsuma mandarin by non-destructive method.

There have been many attempts[1,5,7,10] to develop non-destructive methods which offer basic improvements over manual methods, however, they involve a lot of problems which are still remained unsolved.

The purpose of our study was to obtain some basic data for the surface color evaluation of Satsuma mandarin at the moving state by the spectral reflectance at wavelength region of 680nm in order to apply it for the automatic sorting system.

An experimental equipment for easy practical application was designed in our present investigation and the grading accuracy was determined by using the optical measurement in the moving state.

Experimental Apparatus

The basic feature of the experimental apparatus is illustrated in Fig. 1. The optical system in the experimental apparatus was arranged on the principle of measurement based on previous study[8]. The experimental apparatus was consisted of the conveying, detecting and recording sections.

1. Conveying section

Several tests were carried on both the belt and the chain conveying systems. It was driven by the electric motor having a controlled speed device and was connected with the belt conveyer made up of hard black rubber of 10cm width by a pulley and rubber band, and the chain conveyer by a sprocket and roller chain. The chain conveyer was arranged by steel wires at an interval 2.3cm

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*: Faculty of Agriculture, Utsunomiya University. Utsunomiya.
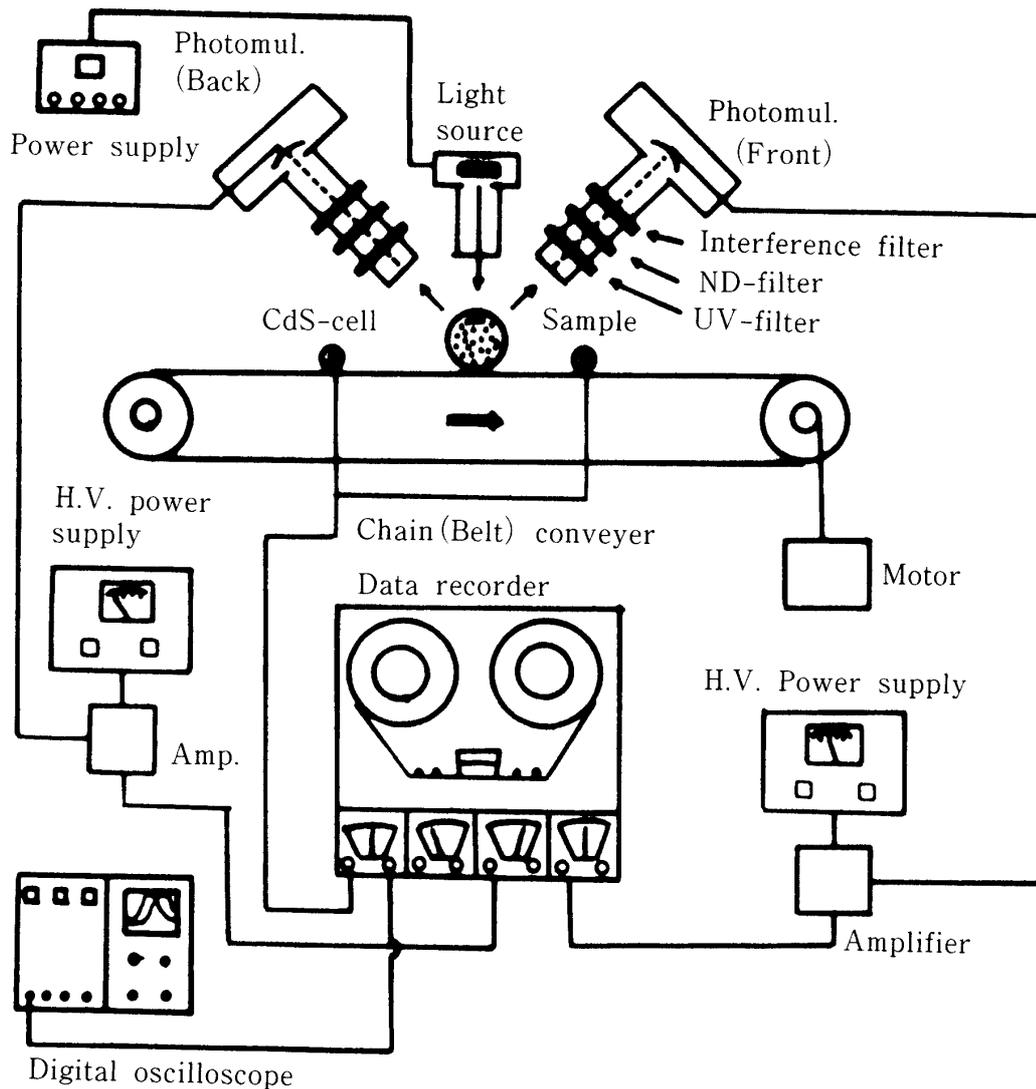
Fig. 1   Schematic diagram of experimental apparatus.

and were fixed at the top of a pair of parallel chains.

There was an advantage that the belt conveyer was to be easily applied for the present grading process, and on the other hand, the chain conveyer was characterized in such a way that the optical system was to be simplified due to the fact that the light reflectance property could be measured simultaneously at both sides of the blossom and stem ends.

The conveying speed was set up at 40cm/sec in both conveyers and it was decided on the condition that 100 tons of fruits might possibly be sorted out in a day, and the capacity of the system was compared to that of the present packinghouse.   Also, it was based on the assumption that the system should be consisted of ten sorting lines which were in operation during 8 hours and three fruits could be sorted out in a second.

2. Detecting section

Halogen lamp was used as a light source illuminating each Satsuma mandarin at moving state, and subsequent reflected light was allowed to pass through ultra-violet, neutral density and interference filters.   After that, it was detected by a pair of photomultiplier tubes (Hamamatsu, R-928, R-636).   The effect of stray light from the extra light source could be sorted out by using

cylindrical guide and closed filter box in front of the detector.   The scattering of the reflected light could be protected by painting the inside cylindrical guide with black color.

The halogen lamp provided extra energy at the wavelength region of 600nm.   The UV-filter (Toshiba, UV-39) intercepted the ultra-violet rays and the ND-filters (Kenko, ND-2, 4, 8) uniformly reduced the energy over the visible wavelengths.   The interference filter (Toshiba, KL-68) indicated maximum transmittance at 680nm wavelength, because of the chlorophyll absorption band.   The wavelength of 680nm was indentified as the color index of Satsuma mandarin[2].

The interference filter characteristics are described as follows.

Main transmittance wavelength: 678.0nm

Maximum transmittance ratio: 38.0%

The photomultiplier tubes indicated almost constant response over the wavelength region of 400 to 800nm.   The viewing area of the fruit was kept constant by the adjusting of its focusing. The new method was adopted in stead of using the sample port, and the spot illuminating size of about 19.6cm^2 (50mm diameter) was chosen.

3. Recording Section

The reflected light in photomultiplier tubes was converted into an electric current and it was amplified by direct current amplifier, and was recorded by a data recorder (TEAC, R-410).
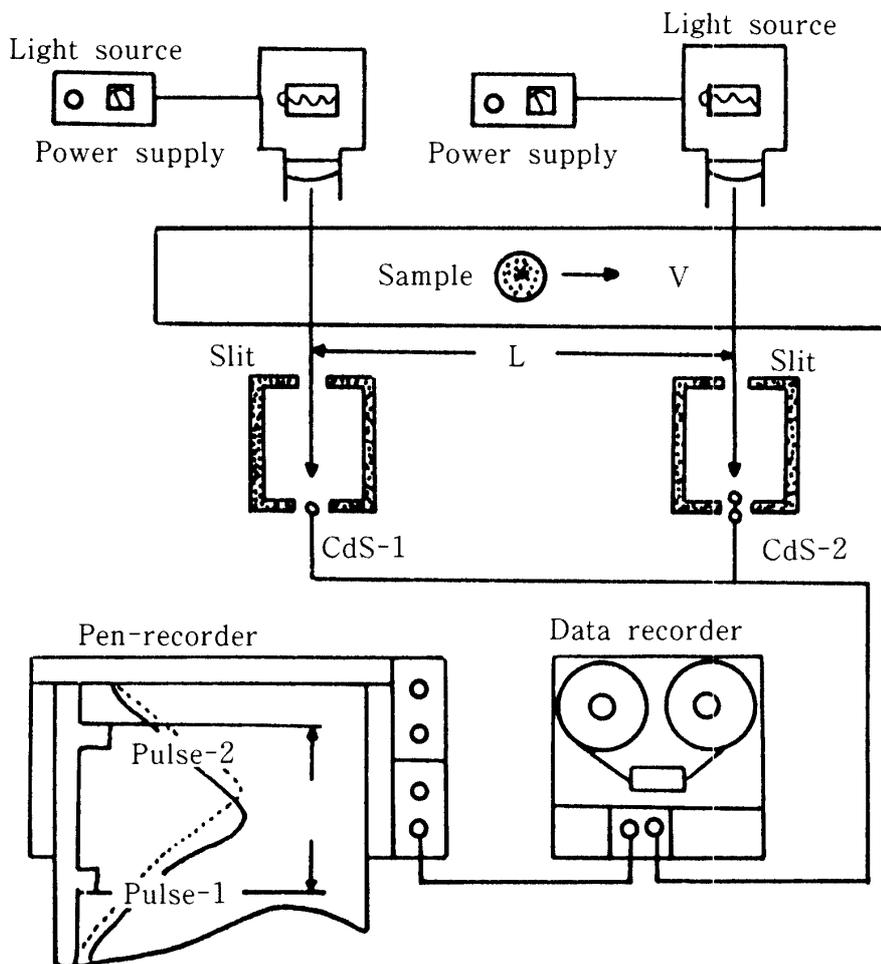

Fig. 2 Schematic diagram of trigger system.

The basic features of the measuring system to detect precise location of Satsuma mandarin on the conveyer at moving state have been illustrated in Fig. 2. The precise location of Satsuma mandarin on the conveyer was measured by CdS-cell sensor which was set along to the conveyer and the obtained data of the location were, simultaneously, recorded with the data of reflected light to the recorder.

Materials and Methods

1. Materials

The harvested Satsuma mandarin at the farmer's orchard in Fukuoka (Maebaru-cho, Itoshima District) were used for conducting our experiment. The fruits immediately after harvesting, were visually selected to be approximately same in size but different in color. The measurement of light reflectance properties was carried out immediately after the visual grading process.

2. Measurement of the light reflectance properties

The light reflectance properties of sound fruits with different colors were measured at both stationary and moving states. The measurement was carried out at blossom and stem ends of the fruits located just at the center of the illuminance spot. The reflected intensity of the standard, which was made of a painted white glass ball, was measured before and after fixing the reflected intensities of the fruits. The glass ball was approximately of the same size as that of samples.

The spectral reflectance at 680nm wavelength of each fruit was computed as a ratio of the
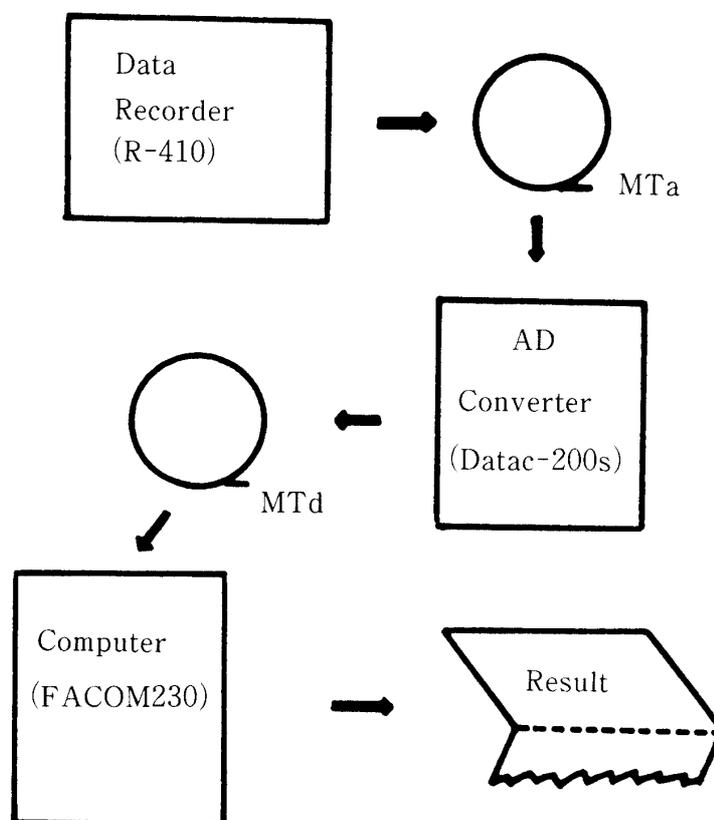
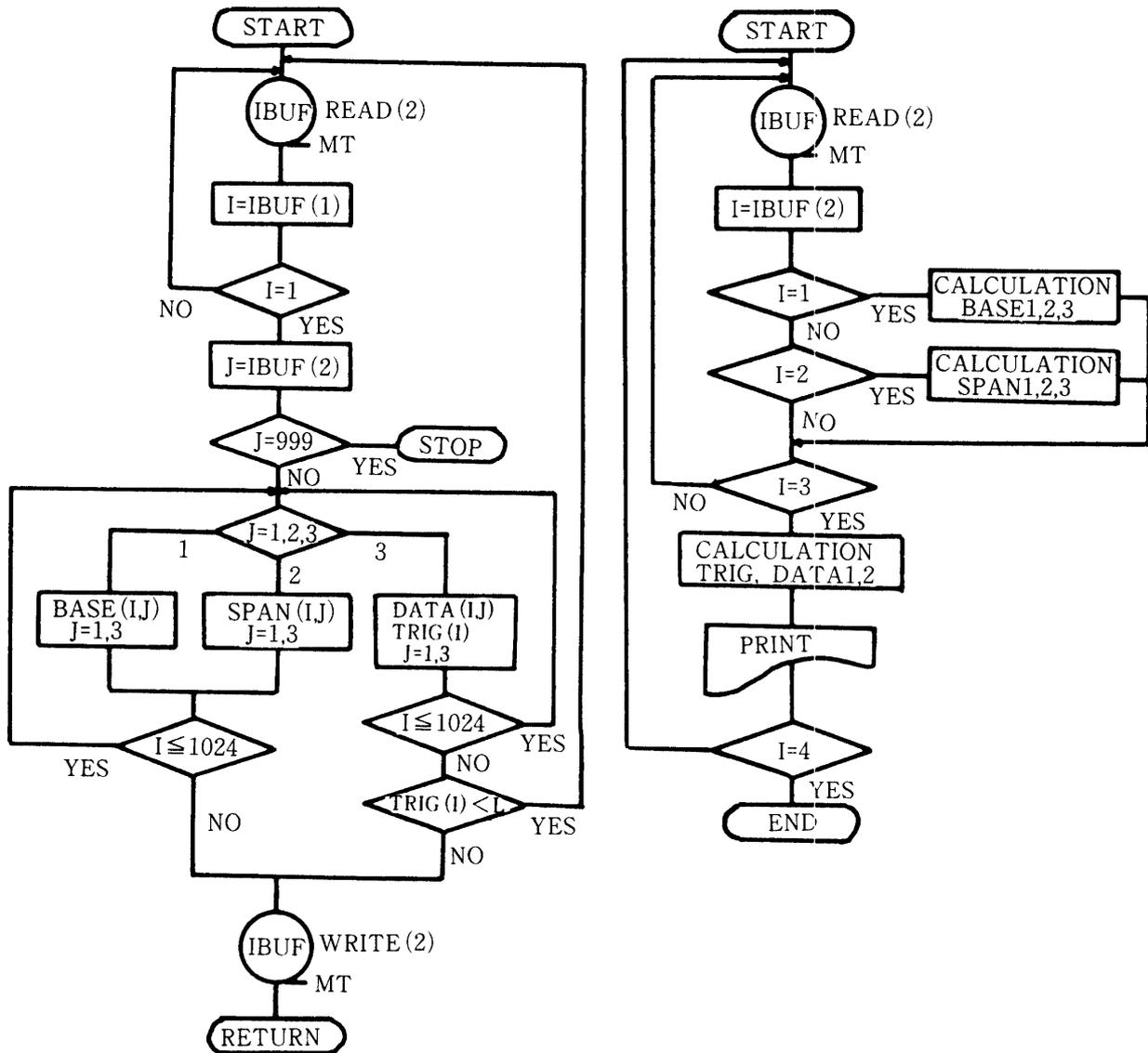Fig. 3   Block diagram of computer analyzing system.

Fig. 4   Flow chart for computing light reflectance of Satsuma mandarin on moving state.

reflected intensity of the sample to that of the white standard.   The stray light from other source was affected by 1% less than that of the total specular intensity, however, it was negligible.

The CdS-cell sensor was used for triggering to detect the precise location of fruits on conveyer, as the incident light illuminated a fixed area on the conveyer at all the time.   The collected data were transformed from analog into digital data after the experiment at the sampling time of 1000Hz by A/D transformer (FACOM, DATAC-2000S) and it was analyzed by mini-computer (FACOM230).   The block diagram of computer analyzing system and the flow chart for computing the spectral reflectance at 680nm wavelength of Satsuma mandarin in the moving state have been shown in Fig. 3 and 4, respectively.

3.   Measurement of the sample location

It was very important to detect the precise location of the fruit on the conveyer, as the reflected intensity of Satsuma mandarin was measured at moving state.   Moreover, as the conveying speed was considerably high at 40cm/sec of rate, the accidental error for one millisecond of the

measurement caused an error of 0.4mm for locating the sample on the conveyer. Therefore, the obtained data were fixed to show a wrong result by computing the analysis. The CdS-cell sensor was adopted for finding out the tolerance error in the experiment, and it became possible to control the measuring error at less than three milliseconds.

Consequently, the location of the sample on the conveyer could be measured at tolerance limit within 1.4cm or even less than that, which enabled this method to be applied in our experiment.

4. Evaluation of the surface color

The surface color of Satsuma mandarin was observed at both blossom and stem ends by differential colorimeter (Nippon Denshoku, ND-544AA). The surface color was represented at UCS value consisting of Hunter (L, a, b)[4]. The UCS was an improvement over the CIE $(X, Y, Z,$ or $x, y, Y)$ which was based on Grassman's law and color simulated observation. The Hunter was described by an expression to the space of L-a-b, and the relationships were illustrated in Fig. 5.

Spot illuminated
area: 19.6 (cm^2)
Sample: White Standard

Reflected intensity (V)
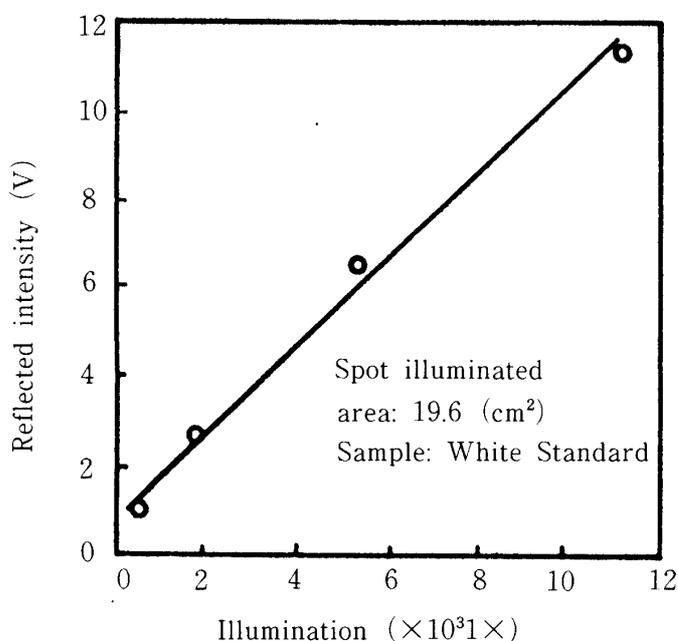
Illumination $(\times 10^3 1 \times)$

Fig. 5 Effect of illumination on reflected intensity of white standard at 680nm.

The physical characteristics of Hunter;
Lightness: L
Chroma: $\tan^{-1} (a/b)$
Hue: $\sqrt{a^2 + b^2}$

The measurement of surface color by the differential colorimeter was carried out having an area of 3.14cm^2 at both blossom and stem ends, which was a part of the area measured by the spectral reflectance.

Results and Discussion

1. Effect of illuminance

Effect of illuminance on the reflected intensity at the wavelength of 680nm is shown in Fig. 6. The standard used a white glass ball having 64mm of diameter, and was placed at the center of
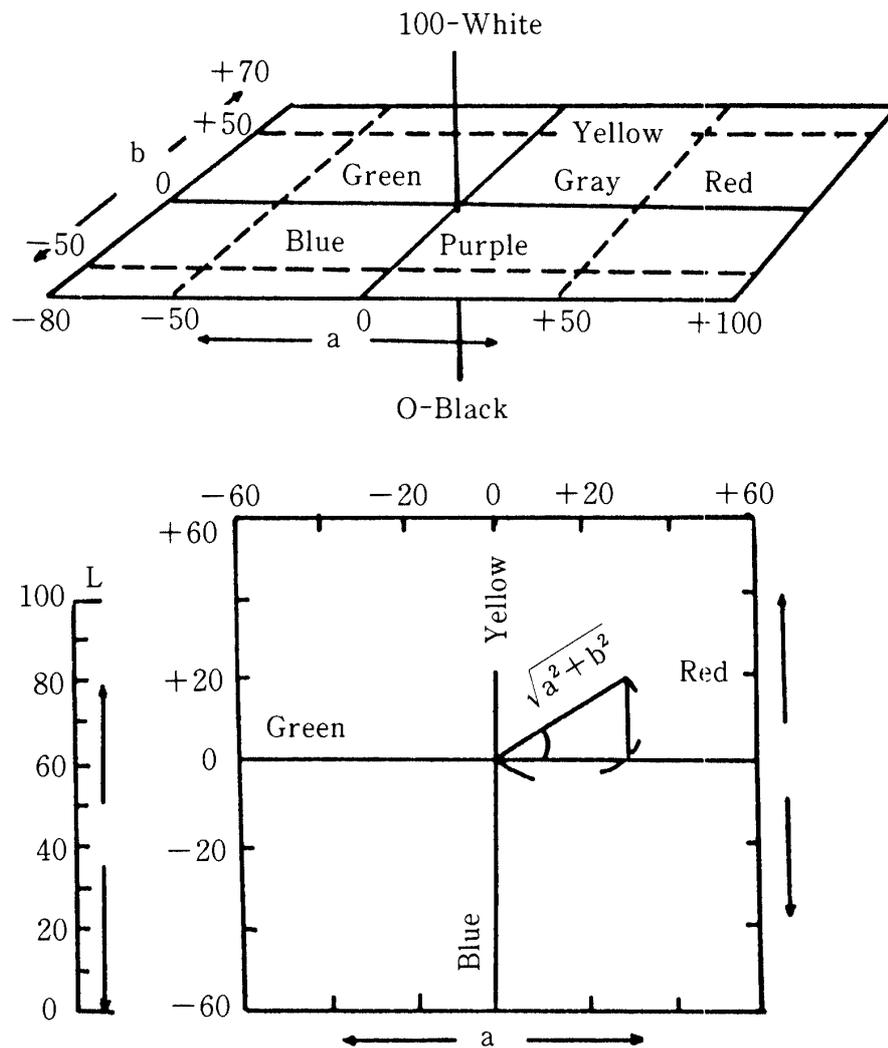
Fig. 6   Schematic diagram of Hunter L-a-b chromaticity.

illuminating area on the conveyer at stationary state.   Incident illumination was adjusted by regulating the voltage of the light source.   The reflected intensity increased linearly with the increasing of illumination.   It was assumed that the response of the filter containing sensors had a linear relationship, so the further tests were conducted with an illumination of 1.14×10^4 lx.

2. Effect of sample size

Effect of sample size on the reflected intensity at the wavelength of 680nm was investigated. Twenty fruits classified for four different sizes (2L, L, M, S), were selected to be of approximately the same color.   Fig. 7 shows the reflected intensity on blossom end at each size, using the average value and standard deviation.   Sample size, excluding S size, had little effect on the reflected intensity at 680nm.   The optional arrangement with the sample port could be used to remove sample size effects including S size[3].   In order to investigate the different results, correlation coefficients among sample size and the reflected intensities on blossom end at 680nm, were calculated for all sizes including and excludings S size.   It was evident that the height of the sample was affected by the reflected intensity.   Especially, the height of S size sample extremely decreased with the decreasing of its diameter.   Therefore, the viewing area could not be kept
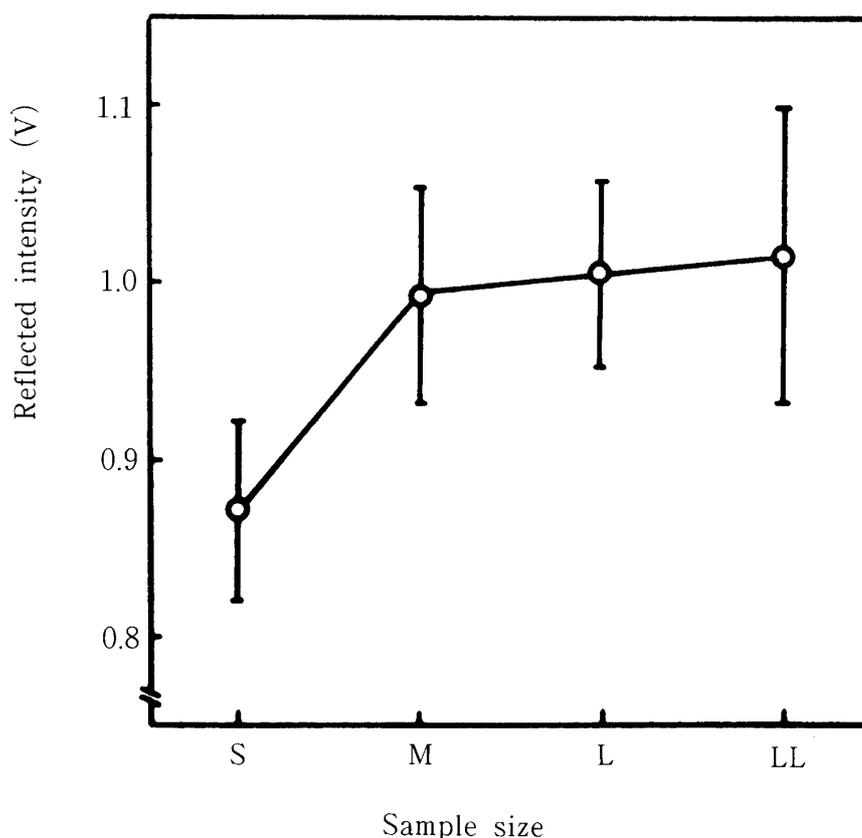
Fig. 7   Effect of sample size on reflected intensity on blossom end at 680nm.

constant by the new method using spot illumination.   It would be necessary for the measuring method to modify the reflected intensity in case of S size of Satsuma mandarin.   In our experiment, all the used samples were made to be of the same size (M size) for eliminating the effect of sample size.

3.   Effect of displacement on conveyer

The displacements of a sample on conveyer were illustrated in Fig. 8.   The sample laid on the center of illuminating area was used as standard, and the sample on the conveyer was moved at an interval of 5mm to rectangular direction and its maximum displacement was 15mm.   Fig. 9 shows the effect of the displacement of the sample on the reflected intensity.   The reflected intensity decreased symmetrically with the increased displacement in a crossing direction on conveyer (Fig. 9, Left).   The reflected intensity diminished by about 5% at 5mm displacement, and the diminishing ratio of the reflected intensity increased with the advancing increase of the displacement in the crossing direction on conveyer.   In practical application, the displacement in the crossing direction should be assumed to be within the limit of 5mm from the center of illuminating area, judging from the difference in the reflected intensities.

The reflected intensity, on the other hand, strongly decreased with the increasing of the front displacement in a moving direction on conveyer, but it was hardly changed by the increasing of the back displacement in the moving direction on conveyer (Fig. 9, Right).   The pair of detectors were set up in the moving direction on conveyer (Fig. 8).   Therefore, the characteristic curves were assumed to be resulted from the back detector and the result from the front one would be attributed to the opposite tendency.   The displacement in the moving direction was measured by CdS-cell
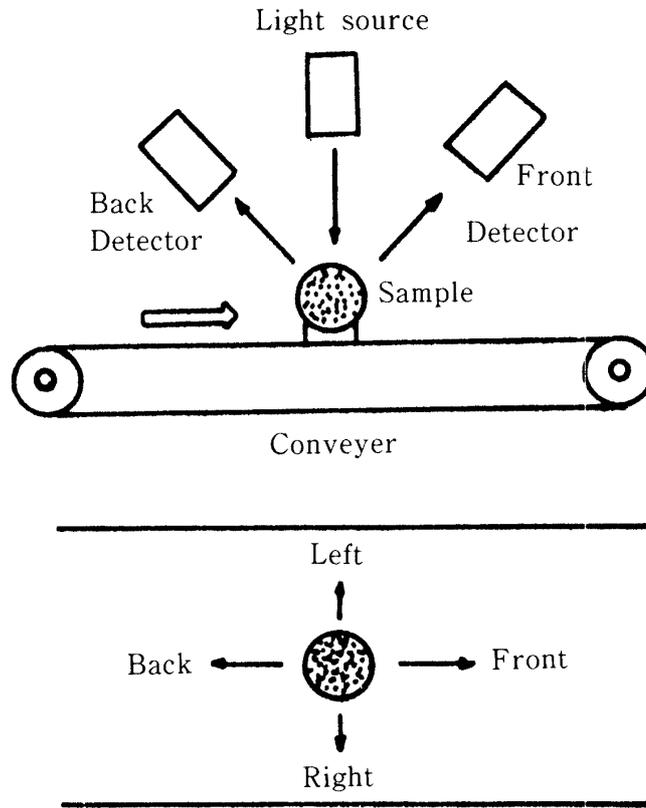
Fig. 8   Schematic diagram of the displacement of sample on conveyer.   Reflected intensity (V)
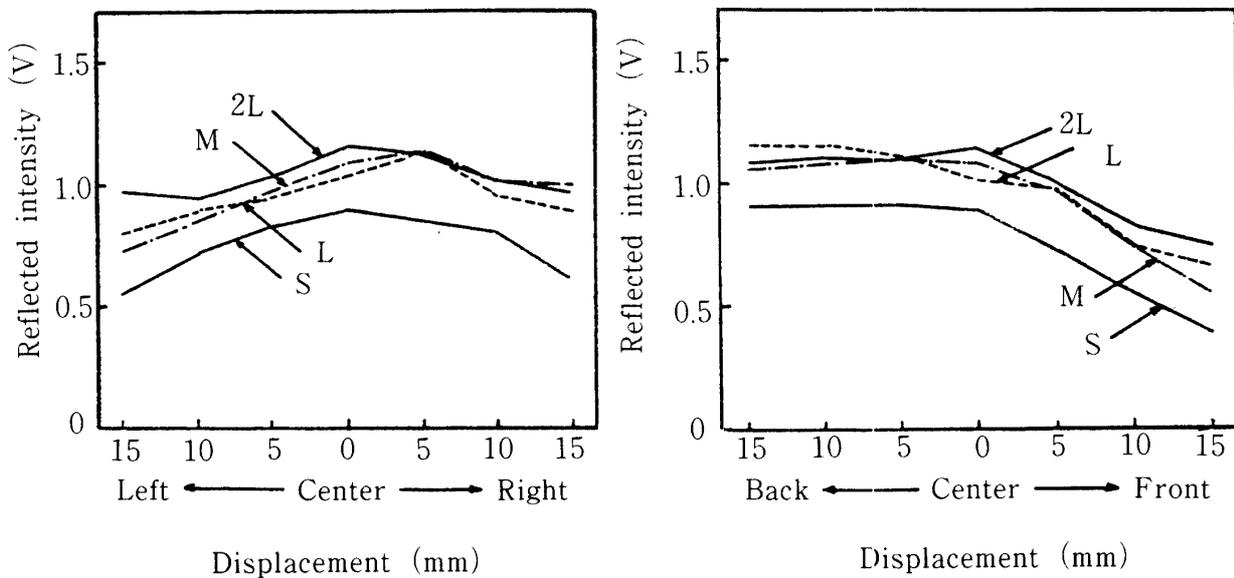

Fig. 9   Effect of the displacement of sample on reflected intensity at 680nm wavelength (Left: Crossing direction on conveyer, right: moving direction on conveyer).

sensor with computing system, therefore, the error could be kept within 1.4mm from the center of illuminating area.   The reflected intensities of the samples including S size, showed the same tendency but its reflected intensity was constantly lower than the other reflected intensities.   It

was assumed that the height of the sample was affected by the reflected intensity.

Consequently, it became evident that the displacement of the sample on conveyer was very important for measuring the reflected intensity. The displacement of the sample in the crossing direction should not be allowed to exceed 5mm from the center of illuminating area, so that, the manual singulation on conveyer of each sample was to be carried out strictly to keep it free from the effect on the reflected intensity in our experiment. Also, the displacement of the sample in the moving direction could be kept constantly within 1.4mm from the center of illuminating area on conveyer by the CdS-cell sensor.

4. UCS value vs. visual grading index

The relationship between the UCS value of surface color and visual color classification of Satsuma mandarin was investigated on both blossom and stem ends. The 24 samples (M size) containing different stages of maturinty, were classified into six different color stages by visula judgment, and visual grading index was counted up to 6th stage, so that the color levels of Satsuma mandarin approached to the full color. Fig. 10 shows the relationship between the Lightness (L), Chroma ($\sqrt{a^2+b^2}$), Hue (a/b) values and the visual grading index, using with the average value and standard deviation. The Lightness value on the both ends slightly increased with the increasing of the visual grading index. The Chroma value on the both ends strongly increased with the increasing of the visual grading index, especially between 2nd and 5th stages. The Hue value on the both ends extensively increased with the increasing of the visual grading index, but the increasing of the Hue value tended to be different between blossom and stem ends. The Hue value of stem end increased until it reached the final stage of visual grading index. It seems to be caused by the surface color of stem end and was delayed to become full coloration, compared with the surface color of the blossom end. It was also noted that the UCS value of blossom end was entirely higher than that of stem end. This was attributed to the stem scar which was more "woody".

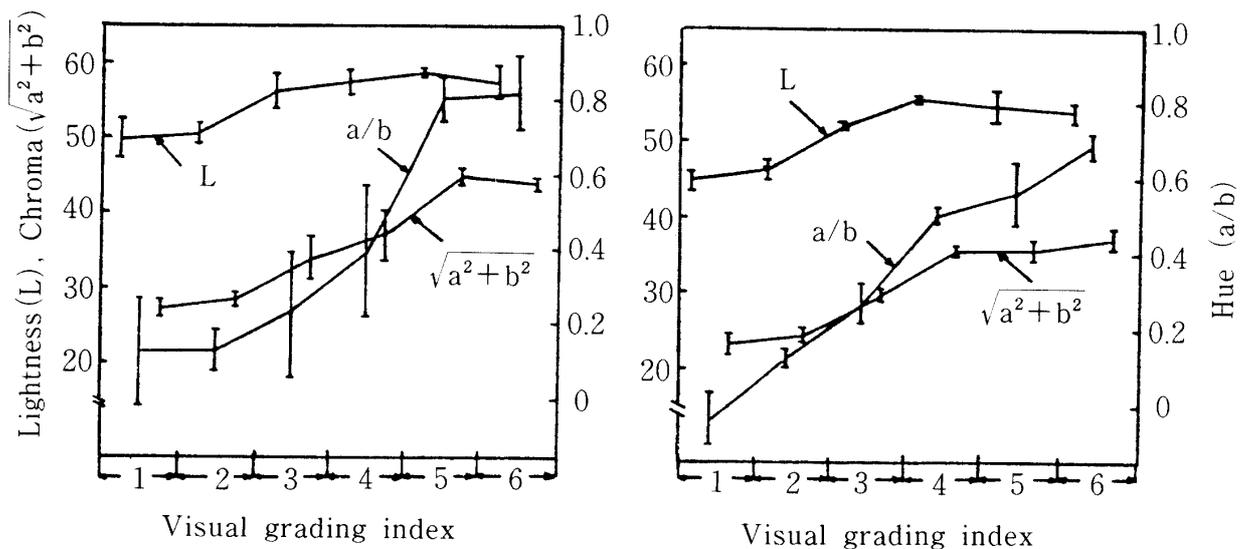Consequently, the UCS value increased with the increasing of the visual grading index and the

Fig. 10   Relationship between UCS value and visual grading index of Satsuma mandarin (left: blossom end, right: stem end).
Hue (a/b)

characteristic curves were similar to those of the both ends in shape.   The results indicated that visual grading index was mainly judged by the change of the Hue value and that the Lightness and Chroma values of surface color were secondary factors in the color judgement.

5. UCS value vs. light reflectance properties

As the visual grading index was judged by the Hue value of surface color, the relationship between the spectral reflectance at 680nm and the Hue value was investigated.   The measurement of spectral reflectance at 680nm was carried out at stationary and moving states at the both ends of 44 different color samples.   Fig. 11 shows relationship between the spectral reflectance at 680nm and the Hue value on stem end of Satsuma mandarin at stationary and moving states.   The Hue value changed from -0.15 to 0.74 with the changing of the spectral reflectance at 680nm from 15 to 70% at stationary state and from 20 to 90% at moving state.   The relationship between the spectral reflectance at 680nm and the Hue value was linearly correlated at the both states.   The linear regressions and their coefficients were as follows.
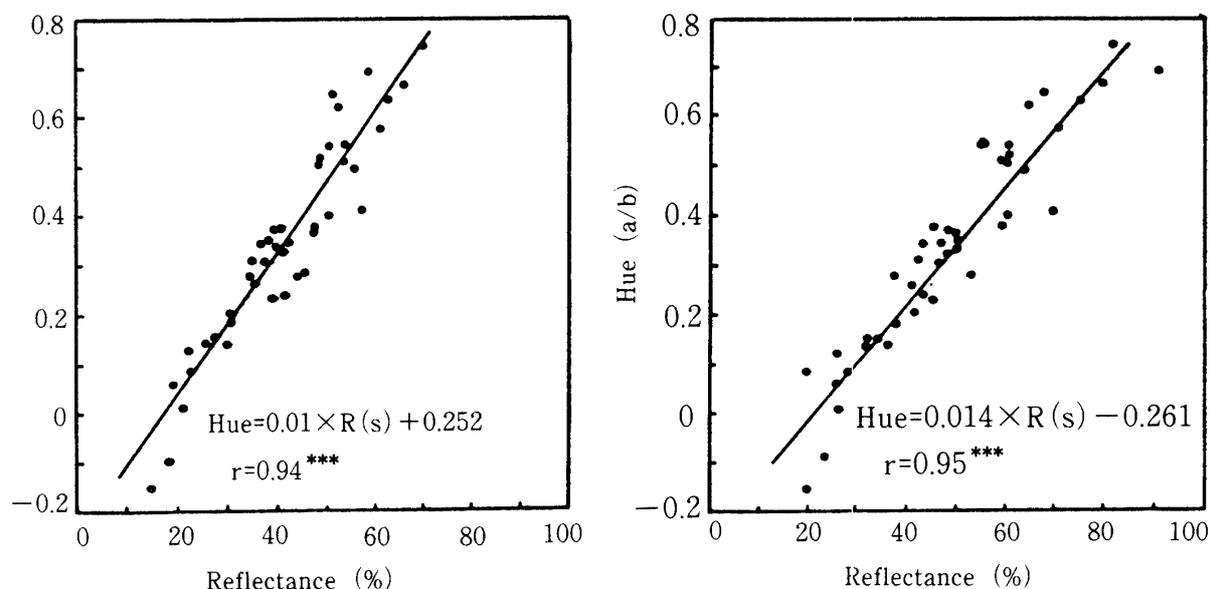

Fig. 11   Relationship between spectral reflectance of 680nm and Hue value at stem end of Satsuma mandarin (left: stationary state, right: moving state).

Stationary state,

$$HUE(S) = 0.014 \times R(S) - 0.261$$
$$(15 < R(S) < 70)$$
$$r = 0.95^{***}$$

Moving state,

$$HUE'(S) = 0.012 \times R'(S) - 0.251$$
$$(20 < R(S) < 90)$$
$$r = 0.94^{***}$$

The correlations had significant at 99.9% confidence level for the both states.   The high correlation between the spectral reflectance at 680nm and the Hue value was considered to be valid for automatic grading.   The correlation coefficients among the UCS value and the spectral

reflectance at 680nm on the both states were presented in Table 1. The R1 and R2 were the spectral reflectance at 680nm on the blossom end, and the R3 and R4 were those of stem end. Also, the R1 and R3 were the spectral reflectance at 680nm from the front detector, and the R2 and R4 were those of back detector. The Lightness and Chroma values were highly correlated to the spectral reflectance at 680nm but their coefficients of variation were lower than that of the Hue value. Therefore, it was assumed to be necessary to obtain more intensive data that the spectral reflectance at 680nm could be evaluated for the indices of Lightness and Chroma values.

It was also noted that the UCS value of either the blossom end or stem end was correlated with the spectral reflectance at 680nm on the opposite end. The correlation coefficients decreased while the relationship was not direct, but those were having the significance at 99.9% confidence level. Thus, it seems probable that the UCS value of the whole fruit could be estimated from a single measurement of spectral reflectance at 680nm by one detector. On the other hand, the single measurement of spectral reflectance at 680nm must further be considered in the direction of Satsuma mandarin on account of the fact the standard value of spectral reflectance at 680nm was different between the blossom and stem ends. Therefore, the index of spectral reflectance at 680nm without considering the direction of one fruit was developed. The spectral reflectance RA and RB in one fruit were obtained from the four detectors and the evaluation of the UCS value was tried to investigate the indices of RA and RB. The spectral reflectances RA and RB were calculated as follows.

(A)   Addition of spectral reflectances for all the directions
$$RA=R1+R2+R3+R4$$
(B)   Multiple of spectral reflectances for all the directions
$$RB=R1 \times R2 \times R3 \times R4$$

Where, the RA is to be fixed as the index of total surface color and the RB as that of unequal distribution and discoloration of surface color. Iwamoto et al.[6] measured the spectral reflectances of tomato with non-uniform color in three directions and the total color of the fruit was judged by the combination of the spectral reflectances. The correlation coefficients between the spectral reflectances RA, RB and the UCS values slightly decreased, compared with a single spectral reflectance (Table 1), but these were kept to be highly correlated with the UCS value. The evaluation of total surface color in one fruit could be accomplished by using these indices without considering its direction. To get the more accurate evaluation of surface color, it would be necessary that the surface color of Satsuma mandarin is to be judged for each index of spectral reflectance at 680nm. These indices were supposed surely to be valid for color grading in practical application, assuming them to be combined according to the varieties and the aim of grading.

6.   Spectral reflectance vs. visual grading index

In order to investigate the relationship between the spectral reflectance at 680nm and visula grading index evaluated by color judgment, the measurement of spectral reflectance of 680nm was carried out at moving state on the chain conveyer. After the 120 samples of M size were randomly selected, the surface color of sample was put under ranking, counting from 1 to 120, by human grading. The ranking of the surface color was strictly realized on the only stem end without consiering the surface color of the blossom end. Table 2 showed these correlation coefficients by using Spearman's rank correlation,[9] and was added to the relation with the Chroma and Hue values as well. As the samples were harvested after an optimum term, almost all the surface color of the

Table 1. Correlation coefficients among UCS value and spectral reflectance of 680nm on stationary and moving states.

| | Reflectance on stationary state | | | | | | Reflectance on moving state | | | | | | Coefficient variation |
| | Blossom end | | Stem end | | Both ends | | Blossom end | | Stem end | | Both end | | |
	R1	R2	R3	R4	RA	RB	R1'	R2'	R3'	R4'	RA'	RB'	C.V.
Lightness (B)	0.589	0.788	0.549	0.673	0.793	0.559	0.702	0.708	0.642	0.592	0.786	0.547	0.067
Chroma (B)	0.855	0.959	0.737	0.769	0.967	0.813	0.963	0.945	0.782	0.756	0.972	0.829	0.168
Hue (B)	0.833	0.908	0.674	0.680	0.942	0.819	0.931	0.908	0.702	0.698	0.958	0.858	0.589
Lightness (S)	0.608	0.634	0.805	0.871	0.801	0.570	0.667	0.641	0.855	0.812	0.789	0.556	0.069
Chroma (S)	0.776	0.698	0.924	0.960	0.973	0.851	0.781	0.774	0.965	0.948	0.977	0.867	0.148
Hue (S)	0.787	0.706	0.875	0.946	0.889	0.872	0.795	0.791	0.948	0.944	0.912	0.924	0.610

All correlation coefficients have significance at 99.9% confidence level.

Table 2. Correlation coefficients among visual grading index, UCS value and Spectral reflectance of 680nm on moving state.

| | Reflectance | | | | Blossom end | | Stem end | |
| | Blossom end | | Stem end | | | | | |
	RF	RB	RF	RB	Chroma	Hue	Chroma	Hue
Visual grading index	0.60	0.62	0.87	0.85	0.56	0.60	0.68	0.83
Chroma value of UCS	0.74	0.77	0.83	0.84	—	—	—	—
Hue value of UCS	0.68	0.61	0.84	0.83	—	—	—	—

All correlation coefficients have significance at 99.9% confidence level.
RF: Reflectance at a front detector.
RB: Reflectance at a back detector.

blossom end was already fully colored.   Therefore, the rank correlation coefficient at the blossom end became lower than that of stem end, but the correlations were significant at 99.9% confidence level.   The low correlation between the visual grading index and the Chroma value was found to be caused by fact that visual grading was mainly judged by the change of the Hue value of the surface color and that the Chroma of surface color was regared as a secondary factor for visual grading. As the spectral reflectance of 680nm was highly correlated with the visual color grading index, the Hue and Chroma values, it seemed to be suitable for a color grading index.   The correlations of the Chroma value on blossom end were higher than any other correlations on blossom end.   It was considered to be evaluated that the spectral reflectance at 680nm was related to the change of the Chroma value, as the surfaces of samples were already fully colored.   Compared with the belt conveyer, the correlations were found to be low.   Considering the factors of sample numbers, sample quality, measuring condition and so on, it could not be concluded that the measuring system by belt conveyer is better than that of chain conveyer.

Consequently, the surface color grading of Satsuma mandarin using the spectral reflectance method was considered to be accomplishable in the practical conveying system.

summary

In order to measure the surface color of Satsuma mandarin in moving state, the experimental apparatus was developed and the grading index using the new reflectance method without a sample port was applied.   The spectral reflectance through special filters increased linearly with illumination and therefore, the spectral reflectance from samples could be determind directly. The spectral reflectance was found to be constant through all the fruit sizes excluding S size.   The spectral reflectance was affected by the displacement of moving sample from the center of conveyer. Therefore, for accurate measurements, the displacement or shift should not be allowed to exceed 5mm.   Change in UCS values of a peel was not consistent with grading index by human judgment. Especially, the change in Hue value of surface color increased significantly for higher grades.   The UCS values and spectral reflectance in moving on belt conveyer were highly correlated, but judging from correlation, variation and regression coefficients, the spectral reflectance was noted to be valid for Hue of surface color.   Alll correlations were significant at 99.9% confidence level for both stationary and moving states.   Moreover, spectral reflectance RA and RB, which were new indices, do not depend on sample directions, and were highly correlated with UCS values.   Evaluation of surface color of Satsuma mandarin by these indices of the spectral reflectance was, therefore, fixed to be possible.   The color index at the stem end, evaluated by the human grading, had high rank correlation with the spectral reflectance in moving on chain conveyer.   The color grading using the reflectance method was considered to be accomplishable by making use of the both conveying methods.

Acknowledgment

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