

カラーチャートを用いたイチジク‘栴井ドーフィン’の熟度評価

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Evaluating the Degree of Ripeness in ‘Masui Dauphine’ Figs (*Ficus carica* L.) using an Improved Color Chart

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The aim of this study was to update the color chart that is currently used (NCC) to identify the optimal harvest stage for figs. ‘Masui Dauphine’ figs were harvested from August to October in 2014 and classified by experts into five levels of ripeness, from slightly immature to overripe. Their appearance was assessed using the NCC, and their ingredients such as total soluble solids, and characteristics such as breaking stress were also analyzed. During the harvesting period, as the coloration of the pericarp progressed, the fruit continued to ripen, the total soluble solids increased, the titratable acidity decreased, and the fruit softened. Fruits with progressed ripeness and high total soluble solids content received high-evaluations in the sensory, however, as the ripening progressed further the freshness retention period decreased. The quality and freshness retention period of the fruit could be evaluated using the pericarp coloration, consequently, the new improved color chart (improved CC) that was developed incorporated photographs of the equatorial sections of the fruit as color chips to evaluate the complex color patterns on the pericarp. This improved CC system was further validated by testing fruits from production plots. We have demonstrated that the improved CC is a practical and effective tool for the classification of high-quality fruits throughout the entire harvest season.

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Key words : fig, color chart, degree of ripeness, sensory evaluation, pericarp
イチジク, カラーチャート, 熟度, 官能評価, 果皮

Approximately 12,000 tons of fig (*Ficus carica* L.) are harvested each year in Japan, and more than one million tons are harvested globally. Figs are grown commercially in most Mediterranean countries as well as California, and the majority are used for dried fig production, as fresh figs are highly perishable. However, in recent years, the shipment of fresh figs and research into their postharvest storage has increased^{1)~3)}.

Figs mature from the lower to the upper nodes of the plant during the harvest period, and they rapidly change color and soften in the last few days of the fruit ripening process. As the fruits are incredibly soft, their freshness retention period after harvesting is only approximately 1 to 3 days at room temperature. Consequently, in Japan, figs are

harvested daily from August to November.

Consumers prefer figs that are fresher, sweeter, and more colored^{4), 5)} and they expect the fruits to be fully ripened. However, as the fruit ripens quickly during the harvest period, it is important to determine the optimal maturity of high-quality fruits for shipping. Growers usually determine ripeness using the skin color of the fruit. This means that the growers' varying skill levels for assessing maturity and farming experiences can lead to differences in the quality of the harvested fruit.

A technique for non-destructive discrimination using degree of ripeness judging equipment has been tested in persimmons⁶⁾. In practice, a unified index is usually formulated using the pericarp color of the target fruit, and the growers harvest the

fruit by referring to this index; such color charts have been developed and used for most major fruit trees^{7),8)}. The pericarp color of fruits and vegetables varies depending on their variety and growing conditions. Therefore, a color chart may not match the actual color of some pericarps because of the growing conditions or cultivar. Recently, new color charts for several kinds of fruits were developed to accommodate the new⁹⁾ and major varieties that are grown in each production areas¹⁰⁾ and to help facilitate harvesting¹¹⁾.

The color chart that is currently used (NCC) was developed and evaluated at the National Institute of Fruit Tree Science of the Ministry of Agriculture, Forestry and Fisheries¹²⁾. However, verification of the NCC was insufficient, as figs were only evaluated once, after the harvest peak. The pericarp color and fig color pattern changes from the immature to the overripe stage in only a few days. Therefore, to create a color chart that helps determine the optimal harvest stage, the color chips must correspond to this rapid coloring on the pericarp. However, as each color chip of the NCC is a single color, it is difficult to determine the ripeness of the figs that have patterned pericarps. Consequently, the NCC has not been used in production areas and its effectiveness is unknown.

An effective color chart to determine the optimal harvest stage of fruits must consider numerous factors related to the harvest (taste, storage, shipping, and regionality etc.). As consumers prefer fully ripe figs, growers have started to ship fruit at a more advanced stage of ripeness. Therefore, determining a harvest time for fully-ripe fruit that is also suitable for storage is required, and any newly developed color chart should meet this requirement. There have only been a few previous studies on the relationship between pericarp color and maturity in fig fruits, and their storability^{13)~15)}. However, fruit at more advanced stages of ripeness were not included in the analyses of those studies. Thus, the aim of this investigation was to establish a technique based on the pericarp color of the figs, by which to determine an optimum harvest stage for both quality and storability during the long harvest season. We first clarified the effect of the pericarp color of 'Masui Dauphine' figs on fruit quality and storage stability and evaluated the effectiveness of the NCC during the fig harvest season. We then improved upon the design of the

NCC and developed a practical new color chart suitable for real-world fig harvesting.

Materials and methods

1. Evaluation of the pericarp color using the NCC and fruit quality at each ripeness level (Exp. 1)

'Masui Dauphine' figs were harvested from mature trees planted in conventional and non-woven fabric mulching cultivations at the research orchard of Hyogo Prefectural Agriculture, Forestry, and Fisheries Technology Center from late August to late October in 2014. The ripeness of the fig fruits was classified into 5 levels according to the degree of coloration on the pericarp. The five criteria for ripeness classification were as follows: slightly unripe, not harvested because unripe in most production areas; optimal harvest stage (OHS) 1, ripe enough to be harvested but judged to be unripe in some production areas; OHS2, ripeness suitable for harvest in all production areas; OHS3, suitable ripeness in some areas but judged to be overripe in some production areas; and overripe, overly ripe and usually not shipped.

Early in the harvest season, the fruit ripeness standards were determined with the help of stakeholders such as agricultural cooperatives (JA) and agricultural improvement and extension center staff. As a rough guide to judge the maturity, the following standards were agreed upon: fruits colored red on 40%–50% of the surface area on the sun-exposed side of the pericarp were considered slightly unripe, 60%–70% coverage indicated OHS1, 80%–90% coverage indicated OHS 2, almost completely colored indicated OHS3, and fruits softer and darker than OHS3 were classified as overripe.

Five to seven medium-sized fruits at each ripeness level from each harvest periods were analyzed. The selected fruits were immediately weighed, and the pericarp color was evaluated using the NCC. The NCC consists of eight color tips, G1 to G3 and R1 to R5, and is used to classify immature to overripe fruits. The pericarp color was evaluated using the method of Matsuura and Araki¹⁶⁾. The NCC G1 to G3 color chips were labelled NCC1–3, and the R1 to R5 color chips were labelled NCC4–8 for simplicity. An intermediate color tone between each color chip was evaluated in 0.5 increments.

To evaluate the hardness of each fruit, we measured the breaking stress with a creep meter

(Rheometer, Fudoh Co., Ltd.). A cylindrical plunger (3 mm in diameter) pierced the equatorial section of the fruits at 1mm/s and stopped at 90% of the sample thickness. The maximum stress at the break was defined as the breaking stress. After the breaking stress measurement, the edible part of the fig was crushed in a blender (4090-BL-040A, Oster) and the sugar content and titratable acidity were measured. The total soluble solids content was measured with a digital saccharimeter (PR-101 α , Atago Co., Ltd.). Twenty grams of fruit was crushed with a 4 times volume of 80% (v/v) hot ethanol, and extraction was performed three times. The extract was filtered, concentrated, and diluted with distilled water to 100ml. Soluble sugars were analyzed using high-performance liquid chromatograph (LC 10 AD / VP, Shimadzu Corporation, Column : CAPCELL PAK UG80 NH₂, Osaka Soda Co., Ltd.) under the following conditions (mobile phase, acetonitrile:methanol:water 75:10:15 (v/v/v) ; flow rate, 1.0 ml / min ; column temperature 40 °C ; detector, RI). Fructose, glucose, and sucrose were identified and quantified by comparison with the retention times and peak areas of the external standards. Titratable acidity was measured using the 0.1 N sodium hydroxide neutralization titration method and converted to the malic acid content.

2. Effect of fruit ripeness on sensory evaluation (Exp. 2)

The effect of fruit ripeness on the sensory evaluations was also investigated. The 'Masui Dauphine' figs were harvested in early October in 2014, when they were predominately classified as OHS 2 to OHS 3 from the mature trees grown in the conventional cultivation fig garden of the Hyogo Prefectural Agriculture, Forestry and Fisheries Technology Center. The fig fruits were classified into three categories according to ripeness: OHS 1, OHS 2, and OHS 3 using the same method as described in Exp. 1. Six fruits (each $\geq$ 80 g) for each maturity stage were used for the sensory evaluations. The classified fruits were peeled and divided into eight equal parts from the fruit apex to the peduncle. The eating quality of the figs was evaluated by 14 panelists from the staff at the Hyogo Prefectural Agriculture, Forestry, and Fisheries Technology Center. Panelists evaluated four parameters (appearance, sweetness, hardness, and overall quality) on a five-point scale from -2 to +2, for which the score was evaluated relative

to a reference sample (OHS 2 figs). Total soluble solids content was measured using a portion of the fruit from the sensory evaluation by the same method described in Exp. 1.

3. Freshness retention period for each degree of ripeness (Exp. 3)

To determine the optimal ripeness while also considering the maintenance of freshness during distribution, the quality of the fruits at each ripeness level were evaluated during storage. Fruits were harvested in early September, the peak of the harvest, and classified into five ripeness levels as described in Exp. 1. Nine fruits (each 80–120 g) were used for each ripeness level. Immediately after harvesting, figs were placed in a special container for transport (Yurika-go, Oishi Sangyo Co., Ltd.) and stored at 25°C, which was the average temperature in Kobe City in September 2013. The quality of the fruit's appearance was evaluated after storage for 24, 48, and 72 h by 3 staff members. Appearance quality was scored with reference to the evaluation index of YOZA *et.al*¹⁷⁾ as follows; (4) Freshness within about 3h after harvest (freshness immediately after harvest) ; (3) slight loss of freshness, such as the loss of the glossy pericarp (limit of shipment) ; (2) slight discoloration, such as yellowing of the green part of the peduncle and slight darkening on the apex (limit of merchantability) ; (1) softening, darkening, and wrinkling of the pericarp (limit of edibility) ; and (0) decay or significant quality deterioration. An intermediate level of quality between stages was evaluated in 0.5 increments.

4. Evaluation of pericarp color at each ripeness level (Exp. 4)

To examine the degree of color unevenness on the pericarp, figs were harvested in early September in 2014, the peak harvest time, and classified into the same five ripeness levels as described in Exp. 1. Five to seven fruits (each $\geq$ 80 g) were measured for each ripeness level. The color tone at the equatorial section of the sun-exposed side of the pericarp, which is the part used for judging ripeness, was measured with a color difference meter (SE-2000, Nippon Denshoku Industries Co., Ltd.). The color tones of the dark-colored fruit veins (i.e., the dark-colored part) and the uncolored parts between the fruit veins (the light-colored parts) in the pericarps of the figs from each ripeness level were investigated. The lightness (L*) and

chromaticity (a^* , b^*) within a 5-mm diameter of the light- and dark-colored parts were measured with reference to a standard white board. The color tone of the dark- and light-colored parts were evaluated using the CIEDE 2000 color difference formula (ΔE_{00})¹⁸⁾.

5. Development and verification of an improved color chart (Exp. 5)

The NCC, which is composed of eight single-color chips, was improved, and then validated in this experiment. The color chips of the new improved color chart (improved CC), consisted of photographs of the fig pericarp at each ripeness level (Fig. 1).

First, we selected photographs of the sun-exposed side of the equatorial section of the fig pericarp that corresponded to the NCC color chip no. 4–8. In addition, as some production areas can ship fruits with a ripeness level equivalent to NCC no. 8, a photograph of a more highly colored pericarp was added as a chip to the improved CC (chip 9 in Fig. 1). To incorporate the rapid changes in the pericarp, we also selected photographs corresponding to intermediate stages of ripeness (i.e., half steps) for the NCC5–8 color chips (chips 5.5, 6.5, and 7.5 in Fig. 1). Therefore, the improved CC was composed of nine color chips. In addition, the characteristics of the pericarp ripeness were described for each color chip on the chart. In 2016, we verified the practicality of the improved CC on ‘Masui Dauphine’ figs harvested from the production fields

of Kobe City (three locations) and Awaji City (one location), which are the top two production areas in Hyogo Prefecture. Fruits of each ripeness level were harvested from each orchard once a month from August to October in 2016, and approximately 20–40 fruits per location were analyzed. Fruit ripeness was evaluated with the improved CC in the same way as it was with the NCC in Exp. 1. Total soluble solids content, titratable acidity, and breaking stress were also measured using the same methods described in Exp. 1.

6. Statistical analysis

Statistical analysis was performed using one-way analysis of variance followed by the Tukey-Kramer test. Sensory evaluation (Exp. 2) was performed using the Steel-Dwass test and an evaluation of pericarp color (Exp. 4) was performed using Welch’s t-test. P-values less than 0.05 were considered statistically significant. All statistical analyses were performed with R (R Core Team, 2020 <http://R-project.org>).

Results

1. Evaluation of pericarp color using the NCC and fruit quality at each ripeness level (Exp. 1)

The ripeness classification by the experts and the NCC color value of the pericarp and quality of the figs in each harvested period are shown in Table 1. The NCC value increased continuously as the fruit ripened. Regardless of the harvest period, OHS 1

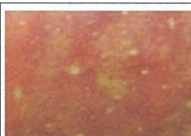
					
Color chip No.	4	5	5.5	6	6.5
Feature	Red line appears clearly on the green ground color	Green ground color remains between the red veins	Slight amount of green ground color remains between the veins	Ground green color between the veins disappears	Veins begin to disappear
					
Color chip No.	7	7.5	8	9	
Feature	Purple becomes darker and yellow dots are clear	Yellow dots disappear	Entire pericarp darkens	Less redness	

Fig. 1 Improved color chart for ‘Masui Dauphine’ figs

The color chip number corresponds to the NCC number.

Table 1 Quality of fig fruits at different harvest stages and degrees of ripeness

Harvest time	Degree of ripeness ²	NCC ³	Fruit weight (g)	Total soluble solids content (°Brix)	Sugar content				Titratable acidity (g/100g FW)	Breaking stress (N)
					Fructose (g/100g FW)	Glucose (g/100g FW)	Sucrose (g/100g FW)	Total (g/100g FW)		
Late Aug.	Slightly immature	5.2 a [*]	84.5 a	12.7 a	5.17	6.47	0.06	11.7 a	0.30 a	1.24 a
	OHS 1	5.9 b	87.8 a	13.6 ab	5.72	7.08	0.03	12.7 b	0.24 a	0.96 b
	OHS 2	6.9 c	89.9 a	14.4 bc	5.99	7.37	0.03	13.4 bc	0.22 bc	0.60 c
	OHS 3	7.4 d	90.5 a	15.1 c	6.27	7.73	0.04	14.0 c	0.21 bc	0.46 c
	Overripe	8.0 e	90.2 a	14.9 c	6.28	7.77	0.02	14.1 c	0.17 c	0.23 d
Early Sep.	Slightly immature	5.3 a	82.3 a	12.9 a	5.47	6.46	0.09	12.0 a	0.34 a	1.39 a
	OHS 1	6.1 b	85.4 ab	15.2 b	6.50	7.75	0.11	14.3 b	0.25 b	0.92 b
	OHS 2	6.9 c	89.0 ab	15.7 bc	6.89	8.15	0.09	15.2 b	0.24 b	0.66 c
	OHS 3	7.6 d	89.9 ab	16.5 c	7.02	8.18	0.11	15.3 b	0.22 b	0.43 cd
	Overripe	8.0 d	92.0 b	16.1 c	6.87	8.07	0.15	15.1 b	0.21 b	0.32 d
Late Sep.	Slightly immature	5.1 a	81.7 a	12.1 a	4.95	5.93	0.10	10.9 a	0.26 a	1.91 a
	OHS 1	6.0 b	80.3 a	12.6 b	5.61	6.68	0.12	12.4 b	0.19 b	1.06 b
	OHS 2	6.9 c	82.4 a	14.2 c	6.02	7.21	0.11	13.3 b	0.21 b	0.73 c
	OHS 3	7.5 d	84.3 a	14.9 c	6.05	7.26	0.12	13.4 b	0.18 b	0.33 d
	Overripe	8.0 e	85.5 a	14.5 c	5.93	7.11	0.12	13.3 b	0.16 b	0.28 d
Early Oct.	Slightly immature	5.3 a	69.2 a	13.1 a	5.28	6.38	0.19	11.9 a	0.31 a	2.33 a
	OHS 1	6.1 b	73.1 ab	13.6 b	5.51	6.54	0.27	12.3 a	0.30 a	1.24 b
	OHS 2	6.9 c	76.6 ab	14.3 bc	5.72	6.85	0.26	12.8 ab	0.22 b	0.73 c
	OHS 3	7.6 d	78.9 b	15.1 c	6.33	7.45	0.25	14.0 b	0.18 bc	0.34 d
	Overripe	8.0 e	78.5 b	14.7 c	6.10	7.27	0.23	13.6 b	0.16 c	0.26 d
Late Oct.	Slightly immature	5.3 a	67.2 a	15.3 a	6.47	7.81	0.64	14.9 a	0.44 a	2.66 a
	OHS 1	6.1 b	70.8 a	16.7 b	7.02	8.49	0.65	16.1 b	0.39 ab	1.06 b
	OHS 2	7.1 c	72.4 a	17.6 bc	7.18	8.72	0.65	16.6 bc	0.34 bc	0.72 c
	OHS 3	7.8 d	72.2 a	18.3 c	7.61	9.22	0.69	17.5 c	0.32 c	0.51 cd
	Overripe	8.0 d	73.4 a	18.1 c	7.39	9.01	0.67	17.3 c	0.31 c	0.32 d
Whole period	Slightly immature	5.3 a	77.0 a	13.2 a	5.47	6.61	0.22	12.3 a	0.33 a	1.91 a
	OHS 1	6.1 b	79.5 a	14.3 b	6.07	7.31	0.24	13.6 b	0.28 ab	1.05 b
	OHS 2	7.0 c	82.1 a	15.2 c	6.36	7.66	0.23	14.3 bc	0.24 bc	0.69 c
	OHS 3	7.6 cd	83.2 a	16.0 c	6.66	7.97	0.24	14.9 c	0.22 c	0.41 cd
	Overripe	8.0 d	83.9 a	15.7 c	6.51	7.85	0.24	14.6 c	0.20 c	0.28 d

The values are represented as mean (n = 5-7)

² Ripeness was classified into levels according to the degree of coloration of the pericarp and hardness.

³ Evaluated using the fig fruit color chart prototyped at the Fruit Tree Station of the Ministry of Agriculture, Forestry, and Fisheries (NCC).

^{*} Values within a column followed by the same letter are not significantly different from one another ($P < 0.05$; Tukey-Kramer test).

was identified approximately as NCC6, OHS2 was NCC7, and OHS3 was NCC7.5. Similarly, overripe was evaluated as NCC 8 at each harvest stage. The differences between the NCC values for OHS3 and the overripe category were small, and there was no significant difference between these NCC values in early September and late October. However, the average NCC value of OHS3 was smaller than that of the overripe. Overall, these results indicate that fig maturity when judged using the NCC is the same as the expert evaluations in all harvest periods.

Throughout all harvest periods, the total soluble solids content increased as the fruits ripened and was highest in OHS2-3 fruit. Glucose was the largest sugar component, followed by fructose and sucrose. Although the sucrose content was less than 1 g/100 g fresh weight (FW) in all harvest periods, it increased with the later harvest times. Total sugar content increased as the maturity progressed, reaching its maximum at OHS3. Titratable acidity was highest at the slightly immature stage of growth in all harvest periods and decreased as ripeness progressed. Breaking stress was also

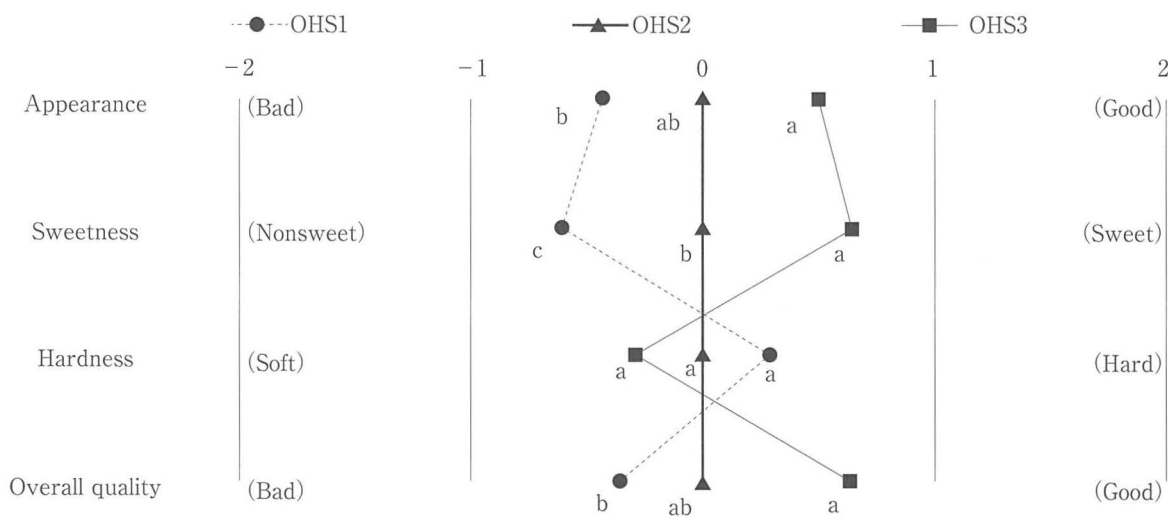


Fig. 2 Sensory evaluation of figs with different degrees of ripeness at harvest

Control: OHS2. Data are based on a scoring method evaluated by 14 panelists as described in the text (Exp. 2). Total soluble solids content in the sample: OHS1, 14.5 °Brix; OHS2, 15.8 °Brix; OHS3, 17.6 °Brix. Means with the same letter are not significantly different from one another (Steel-Dwass test, $P < 0.05$).

highest at the slightly immature stage of growth and decreased remarkably as ripeness progressed. The breaking stress of the overripe fruit was less than 20% of that of the slightly immature fruit. While the breaking stress at OHS1 in all harvest seasons was approximately 1 N. Overall, total soluble solids, acid content, and breaking strength were observed to consistently be related to maturity and the corresponding NCC values.

2. Effect of fruit ripeness on sensory evaluation (Exp. 2)

The average total soluble solids content of the fruits used in the sensory evaluation was 14.5 °Brix at OHS 1, 15.8 °Brix at OHS2, and 17.6 °Brix at OHS3. The results of the sensory evaluation are shown in Fig. 2. There was no significant difference in the evaluation of hardness at each degree of ripeness. However, as the fruit ripened from OHS 1 to OHS 3, the appearance evaluation, degree of sweetness, and overall evaluation were all significantly increased (Fig. 2).

3. Freshness retention period for each degree of ripeness (Exp. 3)

The freshness retention period at 25 °C was investigated for each degree of ripeness. There was little progression in the coloring of the fruit, even after 48 hours, but the appearance of the fruit changed, as the pericarp darkened and the black spots on the surface became enlarged (Fig. 3). The quality of the fruit's appearance deteriorated with

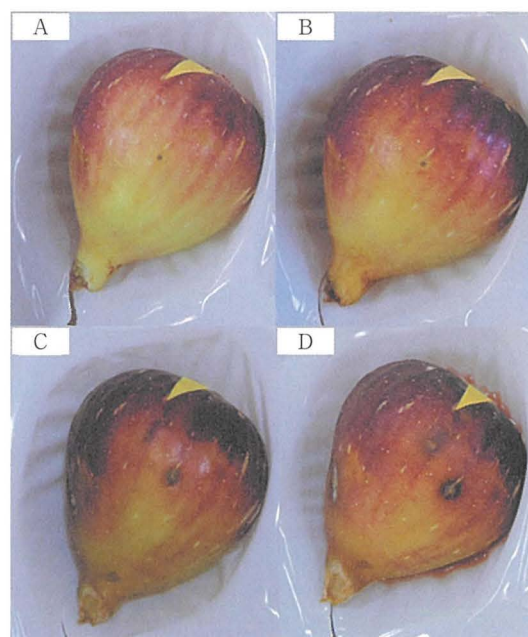


Fig. 3 Appearance of fig fruits during storage at 25 °C (relative humidity approximately 65%)

A: Immediately after harvest; B: after 24 h; C: after 48 h;

D: after 72 h. The appearance of the area indicated by the yellow mark was evaluated.

the passage of time and was below 2.0 (the limit of merchantability) after 72 h (Fig. 4). The freshness retention period differed, depending on the degree of ripeness of the fruit. Forty-eight hours after harvesting, fruits at the slightly immature OHS1 and OHS2 levels had maintained a higher quality (2.

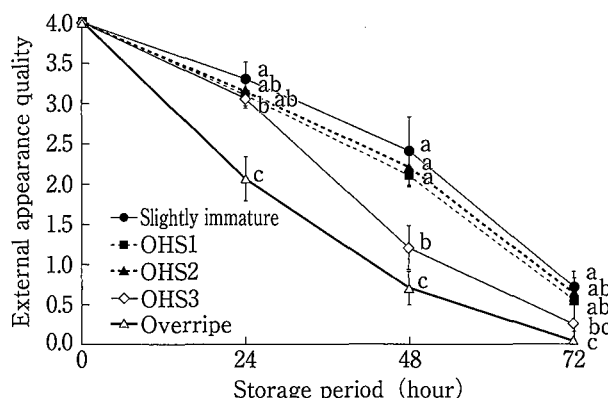


Fig. 4 Effect of the degree of ripeness at harvest on the changes in appearance during storage at 25 °C (relative humidity approximately 65%)

External appearance quality was rated as (4) freshness immediately after harvest; (3) limited shipment; (2) limited merchantability; (1) limited edibility; and (0) decay or significant quality deterioration. See text for complete definitions (Exp. 4). Means with the same letter are not significantly different from one another ($P < 0.05$; Tukey-Kramer test). Data points and vertical bars represent the mean $\pm$ standard deviation ($n = 9$).

0 or more in the appearance quality evaluation), and there was no difference in their storage stability (Fig. 4). After 24 h, the appearance quality of the OHS3 fruits could not be differentiated from the OHS1 and OHS2, but after this point the freshness decreased, and after 48 h, the appearance quality was below 2.0. Overripe fruit dipped below 2.0 after only 24 h.

4. Evaluation of pericarp color at each degree of ripeness (Exp. 4)

The mean lightness and chromaticity values of the pericarp at each degree of fruit ripeness in early September is shown in Table 2. During the ripening of the figs, the fruit veins first turned purplish red from the ground color of the pericarp. The space between the fruit veins then became a purplish red, so that the uneven color of the pericarp disappeared, and finally the whole fruit became a darker purple color. During the period when the fruit changed color, a complex pattern appeared on the pericarp. The brightness (L^*) value of the dark- and light-colored parts of the pericarp decreased as the ripeness progressed. In addition, the L^* value of the dark-colored part was

Table 2 Color features of the fig pericarp at each level of ripeness

Degree of ripeness	Part ^z	L^*	a^*	b^*	ΔE_{00}^y
Slightly immature	Dark-colored part ^x	34.3 $\pm$ 5.6	7.5 $\pm$ 2.5	11.0 $\pm$ 3.6	
	Light-colored part ^w	44.1 $\pm$ 7.2	3.6 $\pm$ 3.4	14.7 $\pm$ 4.2	10.3 $\pm$ 4.5
OHS 1	Significance ^v	*	*	NS	
	Dark-colored part	29.9 $\pm$ 2.6	8.2 $\pm$ 2.4	10.5 $\pm$ 4.0	
	Light-colored part	37.8 $\pm$ 3.6	4.5 $\pm$ 2.9	14.5 $\pm$ 3.5	8.6 $\pm$ 2.6
OHS 2	Significance	**	*	NS	
	dark-colored part	26.9 $\pm$ 2.4	10.2 $\pm$ 2.4	7.6 $\pm$ 2.0	
	Light-colored part	34.8 $\pm$ 5.4	8.5 $\pm$ 1.1	9.2 $\pm$ 2.5	6.6 $\pm$ 2.3
OHS 3	Significance	*	NS	NS	
	Dark-colored part	24.4 $\pm$ 2.7	8.2 $\pm$ 1.6	4.2 $\pm$ 3.0	
	Light-colored part	28.2 $\pm$ 1.2	8.0 $\pm$ 4.1	7.2 $\pm$ 1.4	4.0 $\pm$ 1.4
Overripe	Significance	*	NS	NS	
	Dark-colored part	22.5 $\pm$ 1.1	6.1 $\pm$ 2.0	1.9 $\pm$ 1.2	
	Light-colored part	24.0 $\pm$ 1.3	8.2 $\pm$ 1.3	3.6 $\pm$ 1.3	2.7 $\pm$ 1.3
Overripe	Significance	NS	NS	NS	

The values are represented as mean $\pm$ standard deviation ($n = 5-7$)

^z Sun-exposed side at the equatorial region of the fig fruit

^y Color difference between the dark- and light-colored parts on the pericarp of the same fruits (ΔE_{00}^* : CIEDE2000, Luo *et al.*, 2001)

^x Colored fruit veins

^w Uncolored parts between the fruit veins

^v NS, no significant difference; * $P < 0.05$, or ** $P < 0.01$ (t -test)

significantly lower than that of the light-colored part for all stages, except the overripe stage. In the slightly immature to OHS1 levels, the a^* value of the dark-colored part of the pericarp was significantly higher than that of the light-colored part. However, as ripeness progressed, the a^* value of the light-colored part increased, and there was no difference after OHS2. As ripeness progressed, the b^* values of the dark and light-colored parts decreased. The color difference value (ΔE_{00}) between the dark- and light-colored parts on the pericarp of the slightly immature fruit was the largest. The difference in ΔE_{00} values between the dark- and light-colored parts decreased as the fruits ripened, but the values ranged from approximately 4–9, even for OHS1–3.

5. Development and verification of the improved color chart (Exp. 5)

The quality of the figs harvested from the fields in the two main production areas in Hyogo Prefecture were investigated using the improved CC. The total soluble solids content increased as the pericarps became more colored, regardless of the production district or harvest season. Fruits identified as having a value of 6 or more with the improved CC had a total soluble solids content of at least 13 °Brix, and fruits with a value of 7 or more had a total soluble solids content of at least 14 °Brix (Fig. 5). Regardless of the production district or harvest season, the titratable acidity of the fruit

decreased as the pericarps became more colored. The titratable acidity of the fruits evaluated with a CC value of 6 or higher was less than 0.3% (Fig. 6). In addition, breaking stress decreased as the pericarps became more colored, regardless of the production district or harvest season. The breaking stress of the fruits was evaluated to be 6 or higher on the improved CC was 1 N or less (Fig. 7).

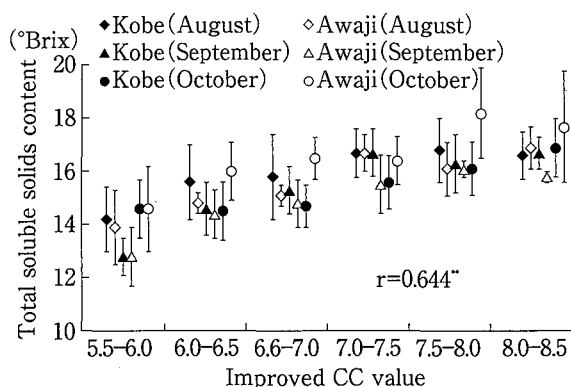


Fig. 5 Relationship between the improved color chart (CC) values and the mean total soluble solids content of the figs harvested each month in the main fig production area in Hyogo Prefecture

Data points and vertical bars represent the mean $\pm$ standard deviation ($n=3-26$ /each improved CC value, total 126 samples). **: Significant correlation according to Pearson's test at $P < 0.01$

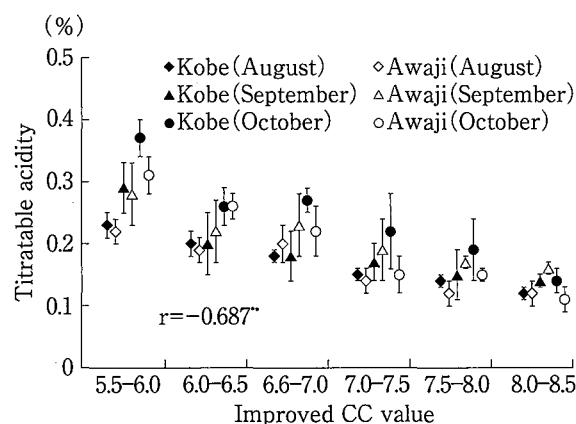


Fig. 6 Relationship between the improved color chart (CC) values and the mean titratable acidity of the figs harvested each month in the main fig production area of Hyogo Prefecture

Data points and vertical bars represent the mean $\pm$ standard deviation ($n=3-26$ /each improved CC value, total 126 samples). **: Significant correlation according to Pearson's test at $P < 0.01$

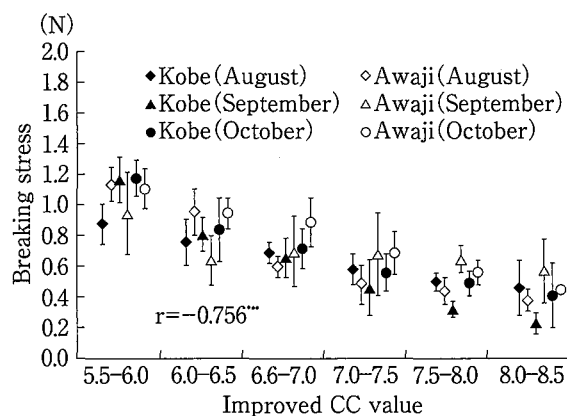


Fig. 7 Relationship between the improved color chart (CC) values and the mean breaking stress of the figs harvested each month in the main fig production area of Hyogo Prefecture

Data points and vertical bars represent the mean $\pm$ standard deviation ($n=3-26$ /each improved CC value, total 126 samples). ***: Significant correlation according to Pearson's test at $P < 0.001$

Discussion

1. Effectiveness of the original color chart

Figs mature from the lower nodes to the upper nodes of the tree during the harvest period, which means that the harvest period is relatively long, as for example, the normal cultivation of the main variety, 'Masui Dauphine', is from mid-August to late October each year in Japan. There may be differences in the pericarp color at the same optimal harvest stage depending on the time of year, so it is necessary to consider the entire harvest period when creating a color chart with harvesting criteria.

Overall, the results of this study indicate that fig maturity when assessed using the NCC, is the same as that evaluated by experts at all harvest stages. In addition, total soluble solids content, acid content, and breaking stress were also observed to consistently be related to maturity and the corresponding NCC values. Therefore, it was clarified that the optimal harvest stage of the figs could be determined by using the NCC throughout the harvest period. Although the proportion of sucrose in the sugar content increases later in the harvest season, there is no qualitative change from the slightly immature to overripe stages within a single harvest. ITO *et al.*¹⁹⁾ reported that figs with a higher total soluble solids content (total soluble solids content ranges from 12.0 to 15.0 °Brix) received a higher evaluation. As the purpose of this test was to enable the shipment of high-quality fruits, sensory evaluation testing was performed by using fruits with a total soluble solids content that was at least 2% higher than that of the fruits used in the survey by ITO *et al.*¹⁹⁾. The sensory evaluation showed that, even among figs with a high total soluble solids content, riper fruit with a higher sugar content received higher evaluations. Therefore, it is presumed that riper and sweeter figs are preferred and that shipping fruits with a high sugar content enhances the consumers' appreciation of the production area. In August, figs change from a slightly immature to overripe condition in just a few days^{20), 21)}. The total soluble solids content was found to increase rapidly with increasing ripeness (Table 1). In addition, the total sugar content of figs does not increase or decrease significantly after harvest²²⁾. Therefore, to ship high-quality fruits, it is necessary to harvest those with a high total soluble

solids content.

Conversely, the freshness of figs deteriorates very quickly after harvest. Fruits at OHS1 and OHS2 can be sold for approximately 48h after harvest, while fruits at OHS3 can only be sold for approximately 24h. It is therefore necessary to determine the optimal harvest stage by considering not only the total soluble solids content the fruit, but also the deterioration in quality and freshness. The results showed that the optimal harvest stage determined using the color of the pericarp with the NCC was consistent with that judged by an expert.

2. Development of an improved color chart

Color charts are often used to manage colors in industrial products to confirm that the difference between the product color and the reference color is within an acceptable range. In the case of agricultural products, the purpose is to select agricultural products that fall within an acceptable quality range. The coloring of the pericarp in Japanese pear progresses by one color chart chip over a 7-to-10-day period, and the corresponding total soluble solids content increases by approximately 0.8 °Brix²³⁾. However, as the change in the coloration of the pericarp and the increase in the total soluble solids content in figs proceeds much faster than in Japanese pears²³⁾, it is necessary to use color chips that make it easier to distinguish differences in coloration when creating a color chart for figs. Especially, to determine the degree of ripeness using the color tone of the pericarps, it is necessary to accurately assess the degree of coloring between the fruit veins. As noted previously, the NCC is not used in production areas because the color chips are a single color that represents an average of the heterogeneous pericarp colors, and therefore they do not match the color tone of an actual pericarp. Some studies^{24), 25)} have used the NCC as an index of fruit appearance quality, but even then, the fruit was indirectly judged by a derivative version of the NCC that used fruit photographs of the degree of ripeness corresponding to each color chip. In this survey, the average color difference (ΔE_{00}) between the dark-colored and light-colored parts of the same fruit at each degree of ripeness was 6.44 (maximum 10.3, minimum 2.65). This color difference value is much larger than the average color difference value between each color chip in the background color chart of the 'Sansa' apple (average 3.60, maximum

4.97, minimum 2.52)²⁶⁾ and of the 'Chikusui' Japanese pear (average 4.88, maximum 7.04, minimum 4.04)²⁷⁾. Therefore, it is difficult to judge the degree of ripeness of the fruit when using a monochromatic color chip that averages the color tone on the fig pericarp. There have been cases in which fig varieties were classified using color differences of the pericarp²⁸⁾, but the fruit with the most uniformly colored pericarp was selected from many fig fruits and then used for comparison. Although each color chip in a color chart for fruit usually represents a single color, some recent color charts have used photographs of fruit peels as color chips²⁹⁾. We believe that this method is also appropriate for figs.

In most cases, a color chip corresponding to the optimal harvest stage has been placed in the center of the color chart^{8),26)}. However, in the NCC, the proportion of color chips corresponding to immature fruits was high (NCC 1–5) relative to the optimal and overripe fruits (NCC 6–8). Moreover, some retailers have requested the shipment of more mature fruits, so in some fig-producing areas, the fruits corresponding to NCC chip no. 8 are within the shipping standard. There is thus a need to evaluate the ripeness of NCC chip no. 8 or higher to avoid shipping overripe fruits. The improved CC was created to overcome these issues, as described in the methods. The NCC has been used for fruit quality evaluations for approximately 30 years, since it was created²⁴⁾, the same number (improved color chart No.4–8) was applied to the color chip corresponding to NNC.

Exceptionally, in the improved CC, fruits with a ripeness equivalent to no. 8.0 may be shipped, but it is usually appropriate to harvest and ship fruits from 5.5 to less than 8.0, mainly fruits corresponding to 7.0 (OHS2). In addition, the characteristics of the pericarp at each ripeness level are described in the improved CC to make it easier to distinguish the fruits. The effects of the improved CC were verified using fruits harvested in August, September, and October from two major production areas in Hyogo Prefecture, and the relationship between the improved CC and total soluble solids content, titratable acidity, and breaking stress was confirmed. By harvesting fruits with a ripeness of no. 6 or higher according to the improved CC, high-quality fruits with a total soluble solids content of 14 °Brix or higher and a breaking stress of 1 N or lower

can be harvested regardless of the region or harvest time.

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カラーチャートを用いたイチジク ‘榊井ドーフィン’の熟度評価

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イチジクの最適な収穫時期を判定するため、現行のカラーチャート(NCC)の有効性を検証し、その後、カラーチャートを改良した。2014年の8月から10月までの

収穫期間に‘榊井ドーフィン’果実を、熟練者がやや未熟から過熟までを熟度別に5段階に分類した。判別した果実について、NCCを用いた外観、糖度等の成分、官能評価、および鮮度保持期間を調査したところ、収穫期間を通し、果皮の着色が進むにつれ、熟度が進み、糖度が高くなり、滴定酸度は低下し、軟化した。また、熟度が進んだ高糖度の果実は官能評価において、総合評価は高かったが、鮮度保持期間は短くなった。果皮の着色程度で果実品質や保存期間が評価できることから、果皮の複雑な変化を評価できるように、果実赤道部の果皮写真を色票とし、新たにカラーチャートを開発した。この改良したカラーチャートを生産圃場で検証したところ、収穫時期を通して、高品質の果実を判別することができたことから実用性があると認められた。

(令和3年3月10日受付, 令和3年8月5日受理)