異なる温度及び湿度条件下に貯蔵したハッサク果実のこ斑症発生について

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Occurrence of Rind-Oil Spot of Hassaku (*Citrus hassaku* Hort. ex TANAKA) Fruits Stored under Different Temperatures and Relative Humidities

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Summary

The occurrence of rind-oil spot, a postharvest physiological disorder of Hassaku (*Citrus hassaku* Hort. ex Tanaka) fruits stored at 2°, 5°, 10°, 15° and 20°C uder low (75-80%) and high (90-95%) relative humidity for 3 months was investigated. In addition, color development ("a/b" value) of peel surface, weight loss, peel moisture, fruit temperature and fruit firmness were also determined. Rind-oil spot as regards surface pitting occurred mostly at the equatorial zone and the development of symptoms spread to the stylar end and rarely to the stem end of the fruits. The symptom was initially observed at the first inspection after 30 days in storage and became more evident after 60 days in storage and to the end of the storage period. When fruit was stored at temperatures above 10°C, surface pitting markedly occurred, whereas the symptoms appeared at lower temperatures (<10°C). The development of slight symptoms increased under low humidity as compared with high relative humidity.

Introduction

Evidence concerning a postharvest physiological disorder referred to as rind-oil spot of citrus fruits, as related to chilling temperature stress in storage or transit, has been reported by several workers(2, 3, 7, 8, 14, 15, 16, 17, 18, 19, 22). The disorder occurs as a commonly manifested visual symptom in the form of surface pitting or peel pitting and develops into a large brown pitted areas(4, 7, 8, 17) and results in reduced marketability of the fruits.

The development of pitting and its relationship with chilling temperature range and period of exposure(2, 4) have been generally observed. Different levels of sensitivity of citrus cultivars to chilling injury were evident during cold storage(2), and symptoms were often more pronounced after transferring to non-chilling temperature during shelf life(13, 17). Lemon and grapefruit developed chilling injury when exposed to temperatures below 10°C(2, 7, 11). In the case of Hassaku fruits, however, the occurrence of surface pitting occurred during storage at normally non-chilling temperatures(8, 14, 15, 22). Water loss during low temperature storage is also reported as a causal factor in the sensitivity to chilling injury of cucumber and pepper fruits (12), grapefruit(19) and Hassaku fruits(22). In addition, the distribution of pitting symptoms has been previously described as appearing randomly over the fruit surface, and variation in diffusive resistance was considered to explain the phenomenon of chill-injured grapefruit(18, 19).

Since the sensitivity of Hassaku to chilling injury is different from other citrus cultivars, the information on the occurrence and development of rind-oil spot of Hassaku and the causal factors concerned are limited. The present study was undertaken to evaluate the role of different temperatures under high and low relative humidity conditions during storage, on the occurrence of rind-oil spot of Hassaku. The developmental pattern of rind-oil spot of whole fruits and separated portions, stem end, equatorial zone and stylar end of

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fruit peel was also investigated.

Materials and Methods

Plant materials and treatments preparation

The *Citrus hassaku* Hort. ex Tanaka fruits used in this experiment were harvested at the citrus orchard of Hiroshima Fruit Tree Experiment Station, Citrus Branch, Mihara, Hiroshima Prefecture. The fruits were handled carefully to avoid bruising at ambient temperature, and placed in corrugated cardboard cartons with nominal capacity of 15 kgs (dimension, 28 cm in width x 30 cm in height x 45 cm in length and lined with sponge sheets). Fruit samples were transported directly by truck car to the laboratory of Pomology, Department of Horticulture, University of Tsukuba on December 15, 1985.

Only undamaged fruits free from apparent infection were chosen for the experiment. The samples were grouped randomly into each treatment consisting of 15 fruits, and then repacked in the same cardboard cartons as mentioned above. Storage conditions were controlled at temperatures of 2°, 5°, 10°, 15° and 20°C under 90–95% relative humidity (high RH) and 75–80% relative humidity (low RH) conditions for 3 months. After storage the fruits were transferred for shelf life which maintained a temperature of 20°C under the same relative humidity conditions for one month, to simulate market holding conditions.

The low RH condition was controlled by placing 10–15 g of drying crystal calcium chloride bags in the corrugated cardboard cartons ; humidity was periodically checked by digital humidity meter Model HN-K of CHINO, Ltd. The anhydrous calcium chloride bags were changed when they became saturated. The high RH condition was controlled by circulating humidifier air inside the corrugated cardboard cartons. In this case, relative humidity was no higher than 95%, to prevent condensation on fruit surfaces which might interfere with normal gas exchange. The temperature of fruit peel was measured by inserting a calibrated copper–constantan thermocouple into the peel at 3 mm in depth and connected to a digital thermometer (Model CPD-100, CHINO, Ltd.).

During storage, samples of fruits of each treatment were taken at monthly intervals to determine the fruit characteristics, including color development of peel surface, weight loss, peel moisture, fruit firmness and rind-oil spot symptoms which appeared on peel surfaces.

Color development

Peel surface color of fruits was dertermined by using a color difference meter (Model CR-100, MINOLTA CAMERA Co., Ltd.). The Hunter ("L", "a" and "b") color values for each fruit were measured initially and at monthly intervals throughout storage at 4 locations about half way between stem end and equatorial planes, in order to minimize variation between measurements. The results reported as "a/b" values agreed well with visual color observations.

Fruit firmness

Firmness of the fruits was determined with a Fudoh Rheometer type NKM-2002J (Fudoh Kogyo Co., Ltd.) using conical tip plunger of 3 mm diameter driven into the fruit peel at a speed of 6 cm/min under standard load 0–2 kgs. The data were recorded as 4 measured values obtained from the opposite paired sides of the equatorial zone of fruits.

Weight loss and peel moisture content

Individual fruits were weighed prior to storage and at monthly intervals during the storage period. The initial weight was recorded as 100% and succeeding data were expressed as percentage of initial weight.

Peel moisture was determined from the whole fruit peel and separated portions such as stem end, equatorial zone and stylar end of the fruits. Five grams of fresh peel tissue were cut into small pieces, placed in 10 ml of distilled water and crushed after floating for 6 hr at 60°C. The tissues were dried under a vacuum of 10 mm Hg for 48 h. Tee weight of dried samples was used to calculate the percentage of peel moisture.

Evaluation of rind-oil spot and decays

The degree and number of rind-oil spots and decays which occurred on surface of fruit peel were determined at monthly intervals throughout the storage and shelf life periods. Rind-oil spot (peel pitting) was rated on a scale of 0–3 such that scale 0 (none) = 0 spots, scale 1 (slight) = 1–3 tiny spots (0–20 mm), scale 2 (moderate) = 4–6 spots (21–35 mm), scale 3 (severe) = 7 spots or more (over 35 mm). Stages in the development of the disorder were obtained by taking successive samples from individual fruits over a period of several days as pitting developed.

Results

During the storage period, the temperature of fruit peel was a little higher under low RH compared with that under high RH at the same temperature treatment.

Color development on surface of fruit peel

The color development of peel surface of Hassaku fruits stored at different temperatures under low (75-80%) and high (90-95%) RH conditions is shown in Fig. 1. The "a" and "b" values were recorded and the "a/b" value (yellow-red color scales) was calculated to present overall color of fruit peel. The "a/b" value is negative for green fruit, appoximately zero for yellow fruit, and positive for orange and red. The "a/b" value of fruit peel color reached its maximum peak from 30 to 60 days in storage under low RH (Fig. 1 a). Under high RH condition, however, the "a/b" value increased over a longer period of time (Fig. 1 b). At storage temperatures above 10°C, the surface of fruit peel developed orange color better than at lower temperatures. The maximum "a/b" value varied among different storage temperatures under low and high RH conditions. It was also noticed that the yellow color (positive "b" value) developed faster than red color (positive "a" value) in both low and high RH conditions (unpublished data). Moreover, the color development under high RH condition at all temperatures continued throughout 90 days in storage.

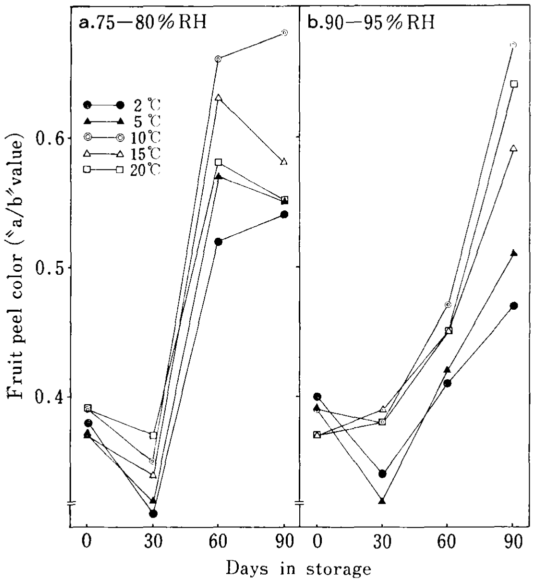

Fig. 1. Color development, "a/b" value, by used of Hunter's colorimeter on Hassaku fruit peel during storage at 2°, 5°, 10°, 15° and 20°C under low (75-80%) and high (90-95%) relative humidity.

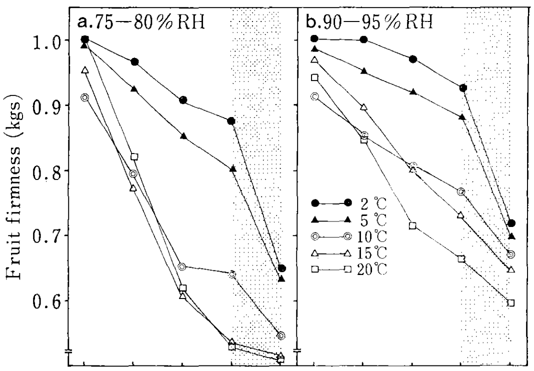

Fig. 2. Changes in fruit firmness of Hassaku fruit stored at 2°, 5°, 10°, 15° and 20°C under low (75-80%) and high (90-95%) relative humidity (unshaded area), and after 90 days in storage transferred for shelf life at 20°C (shaded area).

Fruit firmness

The effect of temperatures and RH conditions on fruit firmness is shown in Fig. 2. Under both high and low RH conditions, fruits stored at 2° and 5°C were firmer than those stored at 10°, 15° and 20°C. However, fruits stored under the low RH condition had lower firmness values than those under the high RH condition at all temperature treatments. After 30 days in storage, the firmness value of fruits markedly declined throughout the storage period. Furthermore, during shelf life period, firmness still continuously decreased, especially after fruits were stored at 2° and 5°C.

Weight loss and peel moisture content

Fig. 3. shows the cumulative weight loss of Hassaku fruits under different temperatures and relative humidity conditions. At the same temperature, fruits stored under low RH had a higher percentage of weight loss than those

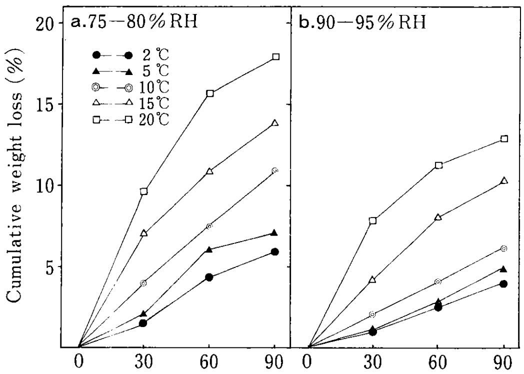

Fig. 3. Cumulative weight loss of Hassaku fruit during storage at 2°, 5°, 10°, 15° and 20℃ under low (75-80%) and high (90-95%) relative humidity.

under high RH. During 30 to 60 days in storage, weight loss of all fruits was markedly increased, especially under low RH. The effects of temperature and RH on peel moisture of whole fruits and separated peel parts are shown in Fig. 4. Peel moisture of whole fruits decreased with longer storage periods in all treatments. This could be related to the cumulative weight loss shown in Fig. 3. At the termination of storage, percentage of peel moisture at the stem end was higher than at equatorial zone and stylar end, in all treatment conditions. Furthermore, peel moisture content was lower under low RH than under high RH condition at the same temperature treatments.

The occurrence of rind-oil spot on the fruit surface

In this experiment, rind-oil spot symptoms appeared on the fruit surface in the form of

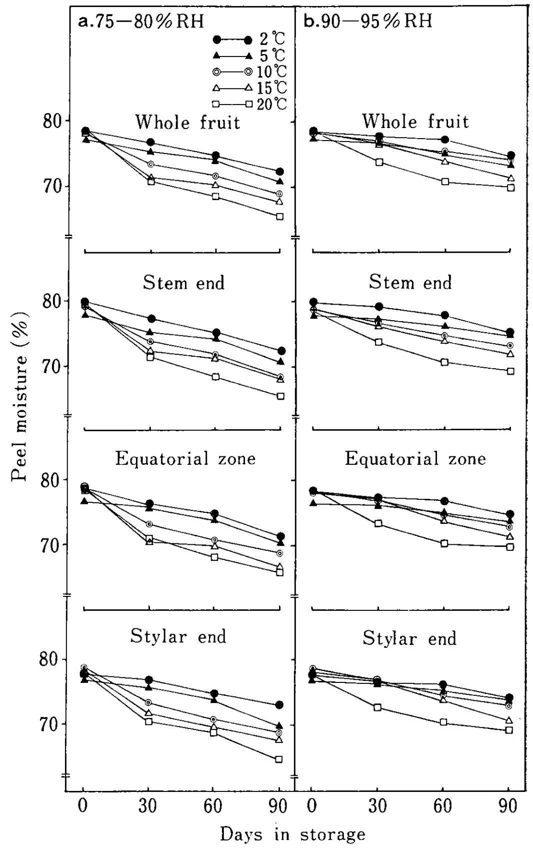

Fig. 4. Changes in peel moisture content of whole fruits and separated prats of peel; stem end, equatorial zone and stylar end of Hassaku fruits stored at 2°, 5°, 10°, 15° and 20℃ under low (75-80%) and high (90-95%) relative humidity.

"pitting", in which discrete areas of peel collapse, causing brown sunken lesions which tend to coalesce to form irregular shapes. The pitting symptoms and development were clas-

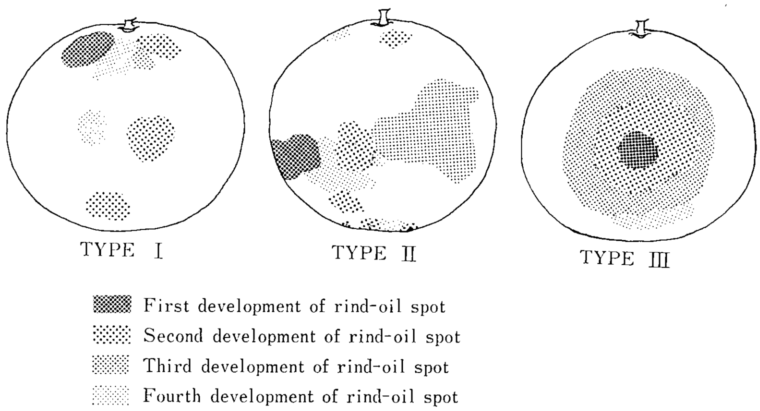

Fig. 5. Three types of the development of rind-oil spot of Hassaku fruits.

sified into three types as shown in Fig. 5. Type I: the visual symptom was initiated as a small area at the stem end and spread to the equatorial zone and stylar end of the fruit. Type II: the symptom was initiated mostly at the equatorial zone and thereafter spread to the stylar end and stem end. Type III : the symptom was also initiated at the equatorial zone and developed like a concentric circle around the original symptom point.

The effects of temperature and RH on the number of rind-oil spots which appeared on fruit peel are shown in Fig. 6. When the fruit was held under low RH, the physiological disorder of rind-oil spot, expressed on a number-of-fruit basis, markedly occurred in fruits stored at 10°C, followed by 15° and 20°C, whereas at 2° and 5°C it appeared only slightly. In separated portions of fruits, rind-oil spot mostly occurred at the equatorial zone, followed by stylar end and stem end (Fig. 6 a).

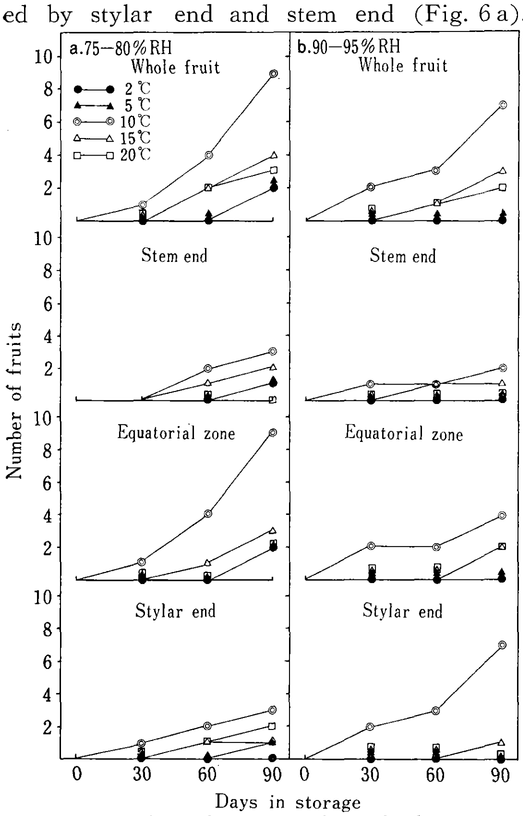

Fig. 6. Number of fruits with rind-oil spot on whole fruits and their separated parts of peel surface; stem end, equatorial zone and stylar end of Hassaku fruits stored at 2°, 5°, 10°, 15° and 20℃ under low (75-80%) and high (90-95%) relative humidity.

With fruits held under high RH, rind-oil spot occurred substantially in fruits stored at 10°C, followed by 15° and 20°C, and not at 2° and 5°C. In separated portions of fruit, rind-oil spot occurred mostly at the equatorial zone and stylar end, however it occurred slightly found at the stem end (Fig. 6 b).

In addition, the disorder of rind-oil spot appeared as tiny pitting at the first inspection after 30 days in storage at 10°C. The pitting symptom became more evident after 60 days in storage and increased towards the end of storage period. Thereafter, the degree of rind-oil spot increased with a longer postharvest period and sometimes occurred together with decay, due to infection by molds and other microorganisms.

The degree of developing rind-oil spot expressed as number of pittings per fruit is

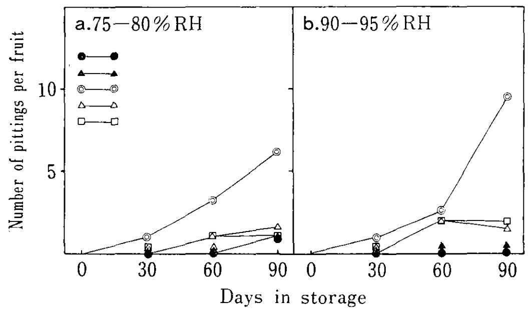

Fig. 7. Number of pittings per fruit appearing as rind-oil spots on peel of Hassaku fruit stored at 2°, 5°, 10°, 15° and 20℃ under low (75-80%) and high (90-95%) relative humidity.

Table 1. Development of rind-oil spot area on peel surfaces of Hassaku fruit stored at 2°, 5°, 10°, 15° and 20℃ under low (75-80%) and high (90-95%) relative humidity.

Temperature of storage	Total area of rind-oil spots (mm^2)/fruit			
	Days in storage			
	0	30	60	90
	Under low (75-80%) RH			
2℃	—	—	—	9.81
5℃	—	—	—	13.35
10℃	—	78.50	1,277.89	1,300.11
15℃	—	—	95.77	206.65
20℃	—	—	104.15	157.53
	Under high (90-95%) RH			
2℃	—	—	—	—
5℃	—	—	—	—
10℃	—	13.63	391.72	563.80
15℃	—	—	29.05	85.45
20℃	—	—	113.04	195.00

shown in Fig. 7. The number of pittings became progressively more pronounced at temperature of 10°C, was less at 15° and 20°C, was almost no at 2° and 5°C and increased more distinctly under high RH than under low RH. On the other hand the data from Table 1 indicated that the area of pitting is larger in fruits exposed to low RH than in those under high RH.

Discussion

The temperature and RH of the atmosphere are generally known to be important for the postharvest life of fruits and vegetables. In this investigation, Hassaku fruits stored under high RH minimized weight loss, and fruit firmness still remained; however, color development of peel surface was apparently retarded compared with lower RH at all temperature treatments. These data suggested that the favorable effects of high RH moidified physical deterioration of peel(6, 20) and were important factors in extending postharvest storage life. On the other hand, Ben-Yehoshua(1) repotred that low RH accelerated senescence processes, including peel desiccation, decrease in firmness and softening of fruits. The data on weight loss (Fig. 3), peel moisture (Fig. 4) and fruit firmness (Fig. 2) showed the effect of low RH on water loss in the storage period. Furthermore, fruits stored at 10°C and above developed peel color better than those at 2° and 5°C, which did not develop full color. Lemon fruits also exhibited similar effects(3).

This investigation showed that the occurrence of rind-oil spot of Hassaku fruits was related to high temperature and low RH in storage. This agrees with the results of several workers(8, 14, 15, 22). Yamashita(22) suggested that temperature seems to be more dominant on the incidence of rind-oil spot than does RH. In addition, water loss due to low RH surrounding fruits is considered as the important factor in chilling injury of many plants (5, 12, 19).

In this study, the occurrence of rind-oil spot of Hassaku fruits became progressively worse at 10°C and above, and symptoms increased under low RH. Conversely, the rind-oil spotting was minimized by storing the fruit under high RH. Moreover, the occurrence of rind-oil spots on fruit transferred from low temperature to room temperature (20°C) was greater, particularly after 90 days in storage at 2° and 5°C (data not shown). Therefore, the occurrence of rind-oil spot of Hassaku fruits closely involved water loss due to low RH with intermediate temperatures above 10°C.

One interesting observation is that rind-oil spot mostly began as small pitting in the equatorial zone of sometimes in other parts of fruit peel and developed into larger brown, irregular-shaped areas. This disorder had a tendency to develop or distribute pitting symptoms at the equatorial zone or stylar end of peel surfaces. However, pitting of grapefruit appeared randomly on fruit surfaces(18). The variation in sensitive parts of Hassaku fruit on the occurrence, development and contribution of this disorder suggested that peel moisture at those two parts is slightly lower in concentration and desiccation of peel easily occurs. The data from Table 1 also suggested that the severe development of the disorder was stimulated by low RH. Purvis(19) also reported that water loss as an effect of stomatal and cuticular transpiration was not uniform over entire fruit surfaces.

The induction of chilling injury in chilling-sensitive plants as related to low temperature stress (around 10°-12°C but above the freezing point of their tissues) induced changes in the molecular ordering of membrane lipids(21). The phase of trasition membrane lipids has been associated with discontinuities in Arrhenius plots of temperature(9, 10). Murata(14) demon strated that break point temperature in Arrhenius plots of Hassaku was about 10° to 12°C, which corresponded closely with the critical temperature of chilling injury. Ben-Yehoshua(1) indicated that water loss from transpiration causes shrinkage, drying and softness leading to accelerated deterioration of fruit, such as in membrane integrity. This information may indicate that Hassaku fruits were sensitive to chilling stress, resulting in rind-oil spot at the critical temperature above 10°C and associated with water stress affecting membrane alteration, which reflects the primary reponse phase of chilling injury. Further investigation is undertaken, however, regarding biochemical and physiological changes in relation to rind-oil spot of Hassaku fruits.

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異なる温度及び湿度条件下に貯蔵したハッサク果実のこ斑症発生について

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摘　要

ハッサク果実の貯蔵中のこ斑症発生と，貯蔵環境，とくに温度と関係湿度とのかかわりを明らかにするために本研究を行った.

果実は低湿度（75～80% RH）及び高湿度 90～95% RH）条件下で，それぞれ 2，5，10，15，20℃ の温度で，3か月間貯蔵した．こ斑症は貯蔵 30 日から主に貯蔵果実の赤道部に発現し，その後果頂部及び果梗部へ発達した．その発生程度は，貯蔵 60 日以降急激に増加した．貯蔵温度の違いについて，10℃以上ではこ斑症発生が多く，それより低温域では発生が抑えられた．低湿度条件は，こ斑症発生を助長した．また，それぞれの貯蔵環境における果皮色の進み(a/b 値)，果重減少率，果皮水分，果実湿度，果実硬度の変化についても言及した.