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Quality Evaluation of Agricultural Products by Infrared Imaging Method

III. Maturity Evaluation of Fruits and Vegetables

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Introduction

Hitherto the grade of maturity of fruits and vegetables has been evaluated by the visual inspections, such as comparison with the samples and the color grade table. However, this method is quite time-consuming, and human fatigue frequently influences the results. Recently, automatic and non-destructive methods for the maturity evaluation of fruits and vegetables have been investigated. Massie, D. R. and Norries, K. H. reported a rapid method for measuring a large number of samples to determine the relationships between the optical density and the quality of certain agricultural products[5]. Chuma, Y. et al. also studied optical properties of fruits and vegetables and reported the delayed light emission could be used as a means for automatic selection of tomatoes and oranges[1,2].

Infrared imaging method can be applied to evaluate the grade of maturity of fruits and vegetables. Most of the successful applications capitalize on the ability of infrared imaging devices, to measure the surface temperatures of samples without contact. Since the heat generated in metabolic processes of fruits and vegetables influences surface temperatures of the samples, an equipment that may be capable of sensing these temperature changes is considered to be useful in the maturity evaluation.

The thermal imaging device which has been applied to the grading of fruits for bruise and to the discrimination of hatching eggs during the incubation period, as reported in the previous papers[3,4], appears to have been established as one of the more reliable methods available. The same device can be applied to maturity evaluation. Preliminary results on the maturity evaluation of some kinds of fruits and vegetables were discussed in the present paper.

Experimental Procedures

1. Fruits and Vegetables Tested

Fruits of Japanese persimmon (*Disopyros kaki* L., cv. Hiratanenashi), fruits of Japanese pear (*Pyrus serotina* Rehder var. *culta* Rehder, cv. Nijisseiki) and fruits of tomato (*Lycopersicon esculentum* Mill, cv. Yūyake B-go) were selected. Fruits of Japanese persimmon were picked from Toso Orchard, University Farm, Faculty of Agriculture, Kagoshima University, the others were purchased from the producers. Dimensions and weights of those samples and their grade of maturity are listed in Table 1. The grade of maturity of fruits and vegetables is to be divided into three, i.e. immaturity, maturity and over-ripe, depending on their color, firmness, and sugar content.

The firmness of fruits and vegetables was measured by a universal hardness-meter. The sugar content of samples was determined from the Brix of the juice which was expressed from the fruits and vegetables. Titratable acidity specified for citric acid was also measured. These values are also listed in Table 1. Ripening stage of tomatoes was evaluated, using the color grade table traditionally used.

Table 1. Average dimensions and weights of fruits and their grades of maturity

Kind of fruits	Grade of maturity	Number of fruits	Average dimensions Diameter (mm)	Average dimensions Height (mm)	Average weight (g)	Hardness (kg)	Sugar content (Brix)	Acidity (%)
Tomato	Immaturity	14	71.7	60.2	171.3	1.37	4.31	0.827
(cv. Yūyake	Maturity	14	70.7	60.4	169.6	1.24	4.25	0.706
B-go)	Over-ripe	14	70.5	59.8	163.0	1.04	4.34	0.635
Japanese	Immaturity	10	69.3	48.6	138.8	2.67	15.74	—
persimmon	Maturity	10	68.6	47.3	136.8	2.21	16.32	—
(cv. Hira-tanenashi)	Over-ripe	14	63.2	46.7	114.4	0.48	14.07	—
Japanese pear	Immaturity	12	76.1	70.4	240.1	2.08	9.28	0.141
(cv. Niji-sseiki)	Maturity	12	75.9	71.1	237.9	1.89	9.98	0.148

2. Thermal Imaging Device

A Fujitsu Infra-Eye 102 A, a medical thermography, was used in the present experiment. The details of the apparatus were reported in the previous paper[3].

Fig. 1 shows a block diagram of the experimental arrangement. Samples were placed in a shielding box. Infrared radiation emitted from the sample was collected by an infrared vidicon camera, and the signals received were transmitted to the Infra-Eye 102 A. Thermal images were produced by a black and white T. V. monitor, and color T. V. monitor, respectively. While, temperature-curves were represented by temperatures on a single scanning line passing through the sample at a given elevation.

3. Measurement of Surface Temperature and Temperature-Curve

Surface temperature of fruits and vegetables was generated on a thermal image taken by the infrared camera, in much the same way as in a television picture, in a black and white T. V. monitor. The measuring-temperature range was indicated by a glace-scale divided into 5 parts between white and black, and the 5 divisions of the glace-scale were shown at the lower part of the picture. The thermal image was taken by a 35 mm camera attached to the T. V. monitor.

The temperature-curve was also shown in the T. V. monitor, independently. It can also be taken by a 35 mm camera attached to the T. V. monitor under the same conditions of the photograph of the thermal image.

4. Storage Conditions

Temperature changes in the surface of fruits and vegetables caused by the grade of maturity

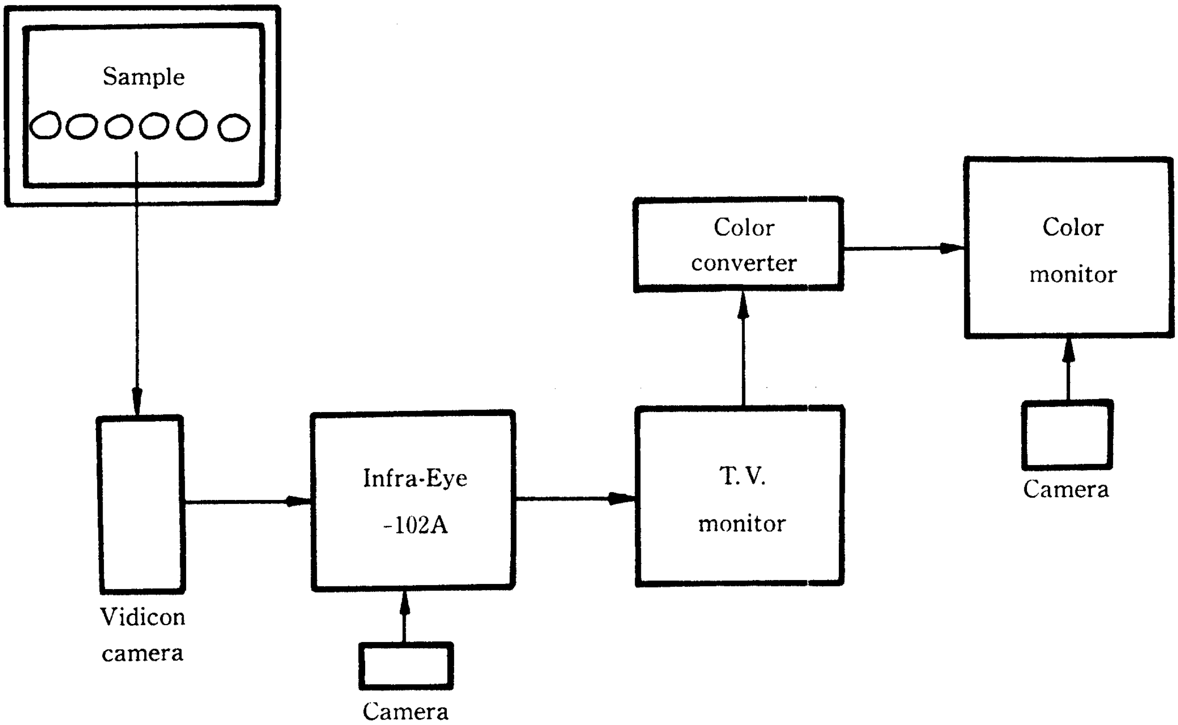

Fig. 1. Block diagram of experimental arrangement of the infrared measurement.

are usually very samll under normal conditions. Therefore, it is of great importance to determine suitable conditions for the infrared measurement. One of the suitable conditions is the one in which the samples were kept at a constant temperature for more than 24 hours before measurement, and the constant temperature was selected to be slightly higher, or slightly lower, than room temperature.

Thermo-regulated rooms were used for the storage of samples. For the higher temperature storage, temperature of the room was regulated at 30°C, and for the lower one it was regulated at 5°C.

At the infrared measurement, there are some temperature differences between the samples and room temperature. The surface temperature of the samples gradually approaches to room temperature in accordance with the time elapsed. Relationship between changes in the surface temperature and the grade of maturity of samples was investiagted.

Results and Discussions

The infrared measurements of fruits and vegetables were made at room temperature immediately after having brought them out from the thermo-regulated room. Since there were some temperature differences between the surface temperature of samples and room temperature, surface temperature of samples varied from time to time. A series of measurements was made as a function of the time measured.

1. Maturity Evaluation of Fruits of Tomatoes

Fig. 2 shows the thermal images (Fig. 2–a) and the temperature-curves (Fig. 2–b) for fruits of tomatoes (cv. Yūyake B-go) stored for one day at lower temperature after harvesting. Since the shape of tomato is not a perfect sphere, there is some heterogeneity in the temperature distribution between the upper part and the lower part of the thermal image. On the other hand, the tem-

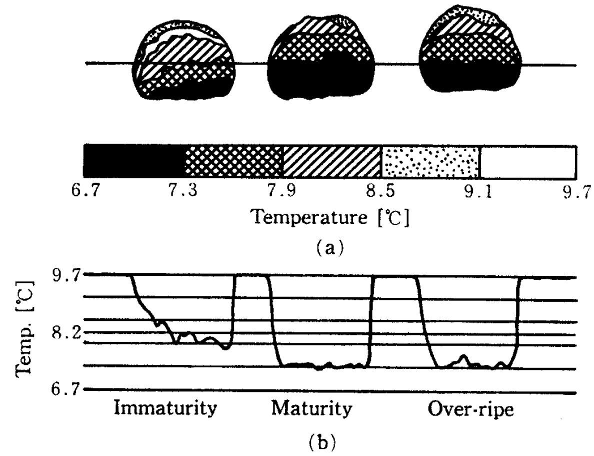

Fig. 2. Thermal images and temperature-curves for fruits of tomatoes (cv. Yūyake B-go).
(a): Thermal images, (b): Temperature-curves

perature-curve passing through the center of tomato indicates rather monotonous variation. Therefore, it is assumed that the surface temperature of the sample was represented by the mean value of the temperature-curve.

Fig. 3 shows the thermal images and temperature-curves for tomatoes (cv. Yūyake B-go) stored for one day (Fig. 3–a) and for 2 days (Fig. 3–b) at the lower temperature. As seen in Fig. 3, the surface temperature of the immatured tomato is slighly higher than those of the matured and the over-riped ones.

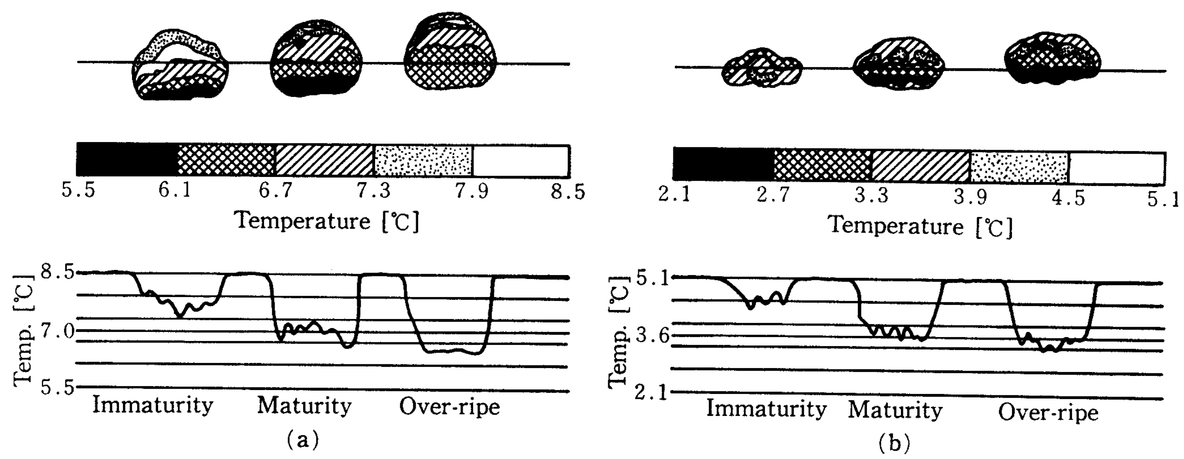

Fig. 3. Thermal images and temperature-curves of tomatoes (cv. Yūyake B-go).
(a): Stored for one day, (b): Stored for 2 days at lower tempeature

Fig. 4 shows the time dependency of the surface temperature of tomatoes (cv. Yūyake B-go) immediately after their removal from the thermo-regulated room. These tomatoes were stored for 2 days at lower temperature. The surface temperature of the immatured tomato was 0.5°C higher than those of the matured and the over-riped ones at the beginning of measurement. Temperature difference between them gradually increased in accordance with the time measured. While, temperature difference between the surface temperature of the matured tomato and that of the over-riped one was very small at the beginning, then became gradually apparent after 10 minutes elapsed.

In order to observe the thermal images for tomatoes stored at a temperature slightly higher than room temperature, tomatoes (cv. Yūyake B-go) were stored at lower temperature for 2 days, and then were stored at higher temperature for several hours before measurement. Fig. 5 shows the temperature-curves for the tomatoes stored at the above conditions. The surface temperature of the over-riped tomato is higher than those of the matured and the immatured ones. From these results, the tendency observed at the higher temperature stored condition is just opposite to the tendency observed at the lower temperature stored condition.

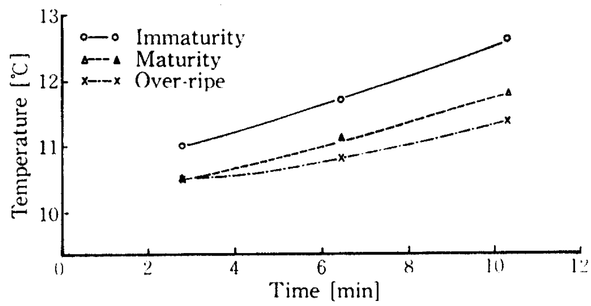

Fig. 4. Relationship between surface temperature of tomatoes (cv. Yūyake B-go) and the time measured.

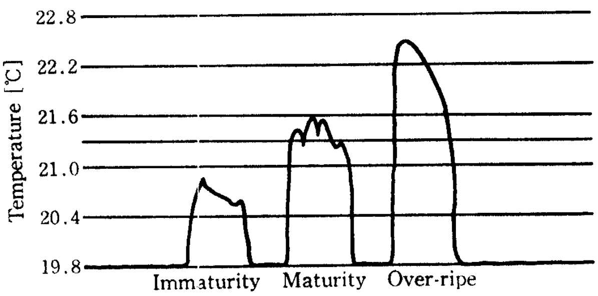

Fig. 5. Temperature-curves for fruits of tomatoes (cv. Yūyake B-go) stored at lower temperature for 2 days, then stored at higher temperature for several hours.

Fig. 6 shows changes in the surface temperature of tomatoes in three grades of maturity, stored at higher temperature before measurement, as a function of the time measured. Differences between surface temperatures of tomatoes in three maturity grades are obvious at the beginning. The surface temperature of the over-riped tomato is the highest, and those of the matured and immatured ones are the middle and the lowerst, respectively. The order of the surface temperature difference is held even after 30 minutes elapsed.

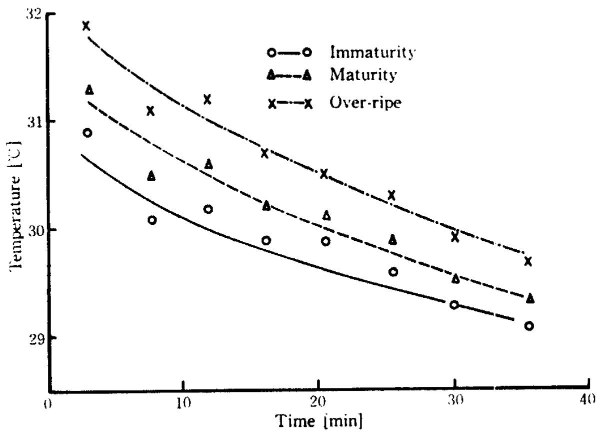

Fig. 6. Relationship between surface temperature of tomatoes (cv. Yūyake B-go) and the time measured.

2. Maurity Evaluation of Fruits of Japanese Persimmon

Fig. 7 shows the thermal images and temperature-curves for fruits of Japanese persimmon (cv. Hiratanenashi) stored for one day (Fig. 7–a) and for 4 days (Fig. 7–b) at lower temperature after harvesting. As seen in Fig. 7, surface temperature of the immatured persimmon is slightly

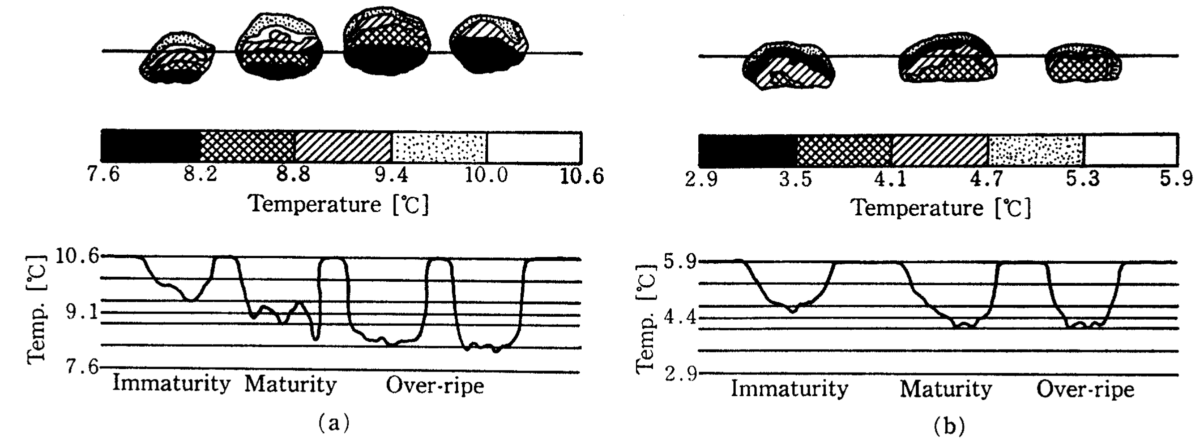

Fig. 7. Thermal images and temperature-curves for Japanese persimmon (cv. Hiratanenashi). (a): Stored for one day, (b): Stored for 4 days at lower temperature

higher than those of the matured and the over-riped ones.

Fig. 8 and Fig. 9 show changes in the surface temperature of persimmons in the three grades of maturity, stored at lower temperature for one day (Fig. 8) and stored for 4 days (Fig. 9), as a function of the time measured. As seen in Fig. 8, the surface temperature of the immatured persimmon is obviously higher than those of the matured and the over-riped ones, because the measurement was made one day after harvesting.

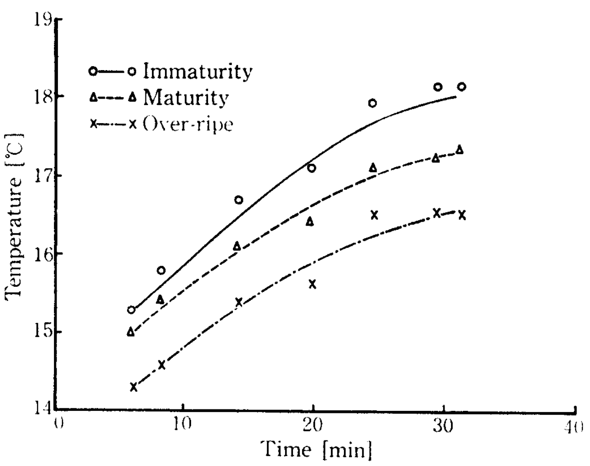

Fig. 8. Relationship between surface temperature of Japanese persimmon (cv. Hiratanenashi) and the time measured.

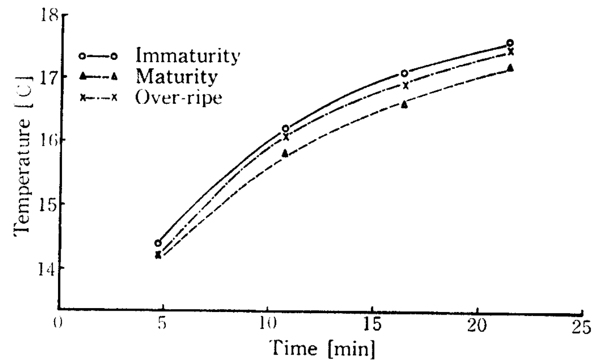

Fig. 9. Relationship between surface temperature of Japanese persimmon (cv. Hiratanenashi) and the time measured.

On the other hand, as seen in Fig. 9, differences between surface temperatures of persimmon in the three grades of maturity are not so obvious at the beginning, but became gradually apparent after 10 minutes elaspsed, because the measurement was made 4 days after harvesting.

From these results, maturity evaluation of persimmon carried out one day after harvesting is more effective than that carried out after 4 days elapsed. It may be explained that maturation of persimmon was progressed during the storage even at lower temperature, and that the difference between the surface temperature of persimmons in the three grades of maturity became very small.

3. Maturity Evaluation of Fruits of Japanese Pear

Fig. 10 shows the thermal images and temperature-curves for fruits of Japanese pears (cv. Nijisseiki) stored for 3 days (Fig. 10–a) and for 6 days (Fig. 10–b) at lower temperature. As seen in Fig. 10, surface temperature of the immatured pears is slightly higher than that of the matured one, but the difference between them is not so clear.

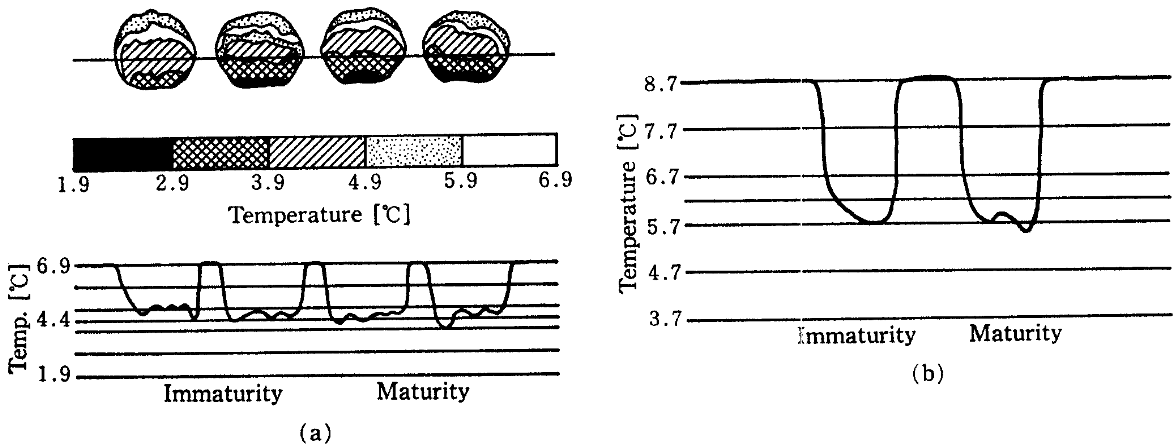

Fig. 10. Thermal images and temperature-curves for Japanese pear (cv. Nijisseki).
(a): Stored for 3 days, (b): Stored for 6 days at lower temperature

In order to observe the thermal images for pears stored at relatively higher temperature, pears (cv. Nijisseiki) were stored at lower temperature for several days, and then stored at higher temperature for several hours before measurement. Fig. 11 shows the temperature-curves for pears stored for 6 days at lower temperature, and then stored at higher temperature for several hours (Fig. 11–a), and that stored for 3 days at lower temperature and then stored at higher temperature for several hours (Fig. 11–b) before measurement, respectively.

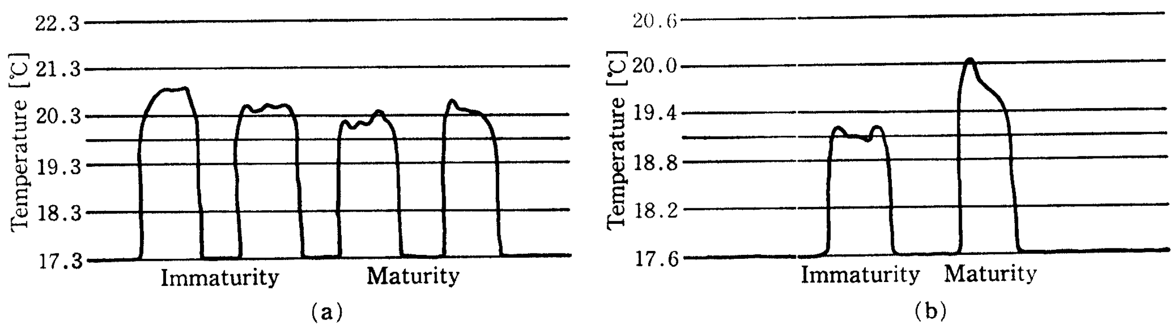

Fig. 11. Temperature-curves for Japanese pear (cv. Nijisseki).
(a): Stored for 6 days, (b): Stored for 3 days at lower temperature, then stored for several hours at higher temperature before measurement, respectively

As in the case of tomatoes stored at higher temperature before measurement, the surface temperature of the immatured pear is slightly lower than that of the matured one stored at higher temperature.

Conclusion

The infrared imaging method was investigated to examine the possibility of maturity evaluation of fruits and vegetables. Changes in surface temperatures of fruits and vegetables in different grades of maturity are very small. In order to estimate small temperature changes in the surface of samples, suitable conditions for the infrared measurement were established by varying the storage temperature of the sample before measurement.

The maturity evaluation of fruits and vegetables by the infrared imaging method shows the following conclusions.

1) The surface temperature of the immatured fruits and vegetables, stored at lower temperature before measurement, is slightly higher than those of the matured and the over-riped ones.
2) The surface temperature of the immatured fruits and vegetables, stored at higher temperature before measurement, is slightly lower than those of the matured and the over-riped ones.
3) Since the grade of maturity of fruits and vegetables is progressed during the storage even at the lower temperature, further experiments are to be necessary to determine the relationship between the temperature of the samples and the grade of maturity.

Summary

An infrared imaging method was investigated for the purpose of examining the possibility of maturity evaluation of fruits and vegetables. By this method, the surface temperatures of the the samples could be measured without contact.

Fruits and vegetables tested in the present experiment were fruits of Japanese persimmon, Japanese pear, and tomato, in the different grade of maturity. Surface temperatures of the sample were estimated from the thermal images and the temperature-curves obtained by this method.

Suitable conditions for the infrared measurement were established by varying the storage temperature of fruits and vegetables before measurement. A relationship between the surface temperature of the samples and the grade of maturity was investigated.

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