JARQ 28, 36–43 (1994)

Development of Device for Nondestructive Evaluation of Fruit Firmness

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Abstract
To evaluate the firmness of fruits and vegetables, the amount of deformation of a certain compressive force can be obtained within the elastic range, and the firmness can then be evaluated in a nondestructive manner. When the basic testing device (HIT-Counter I) was designed on an experimental basis and used in kiwifruits to evaluate fruit firmness, a high correlation with the conventional destructive fruit tester was observed and firmness evaluation without destruction could be achieved. Furthermore, the possibility of using this device for evaluation of ripeness, prime eating condition, quality control in shipping, quality evaluation during storage was confirmed. Therefore, a device for practical use (HIT-Counter II), which does not require any technical skill and easy to handle and operate was developed. Results of tests in several laboratories, showed that the firmness of fruits could be evaluated in a nondestructive manner. The device was produced on a commercial basis, and laboratories are beginning to use it.

Discipline: Agricultural engineering / Horticulture
Additional key words: fruit tester, kiwifruit, melon

Introduction

The quality of fruits is determined not only by the appearance and the taste, but also by the firmness of the flesh. To evaluate the firmness, fruit firmness tester such as Mugness-Tayler fruit pressure tester and push-pull testing instrument with a cone and plunger can be used[3,4]. The fruit firmness tester enables to evaluate a maximum load through the spring when a plunger penetrates into the object. This device is often used because it is simple and easy to handle but it is not suitable for the evaluation of the firmness which requires precision due to the influence on the measurements of the support mechanism and the penetrating speed. Evaluation by the push-pull testing instrument is highly accurate because the penetration force can be measured accurately by a load cell and it is also possible to control the penetration speed of the plunger. However, it is difficult to use it because some skill is required for the operation of the instrument and data analysis. Moreover, it is difficult to carry out sequential individual evaluations and frequent inspections because these methods are all destructive and other information must be estimated from the data of extracted sample. Moreover, fruits can not be handled like industrial products because the fruits display wide individual differences. Therefore it is important to develop a simple nondestructive device for the evaluation of the firmness that can be used by laboratories and fruit-sorting factories.

The purpose of this study is to develop a nondestructive device for the evaluation of the firmness that can be easily handled and enables to obtain comparable evaluations to those by using the conventional fruit firmness tester and push-pull testing instrument. In the beginning, a prototype was designed based on the use of deformation and force within the range of elasticity. Firmness of kiwifruit and melon was measured by the nondestructive method. The relation between the firmness measurements of kiwifruit with this device and the sugar and acid contents was studied. We developed thereafter a more practical firmness evaluation device based on tests using the prototype. The device developed here was commercialized in 1989 and is used for various tests[1,5].

Devices and methods of evaluating firmness

To evaluate the firmness of fruit by nondestructive methods, we applied a compressive force within the range of elasticity and used the deformation as an index. As shown in Fig. 1, the forces Fa, Fb ($Fa<Fb$, $Fa>0$) which, within the range of elasticity, do not damage an object are set beforehand and the firmness is evaluated by the deformation (Db - Da). This evaluation method, by limiting the force and measuring range within the elastic deformation, enables to perform nondestructive measurements. It is necessary to set in advance the force which does not result in destruction and plastic deformation.

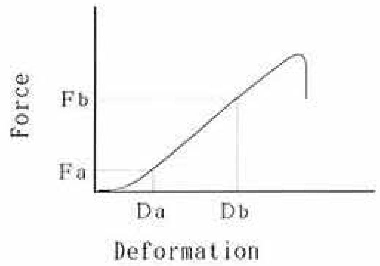

Fig. 1. Force - deformation curve

Based on this method, we developed a prototype that can measure a deformation against the preset force by compression with the plunger moving at a constant speed by combining a computer (Sharp MZ-80B) and the push-pull testing instrument (Rheodynacorder RDR-1500, Iio Denki) (Fig. 2). Compressing plunger can be adapted to the shape and the diameter can be adjusted to the object. Diameters are 3, 8 and 12 mm. It is possible to select a plunger velocity from 6 steps, 50, 100, 150, 200, 300 and 600 mm/min. Comparison force is put into the computer through A/D converter and load cell (maximum 196.1 N). The deformation by compression is determined by calculating the compression time required to change the force from Fa to Fb and the plunger velocity. Also the plunger can be raised when the force Fb is attained, so that the force does not

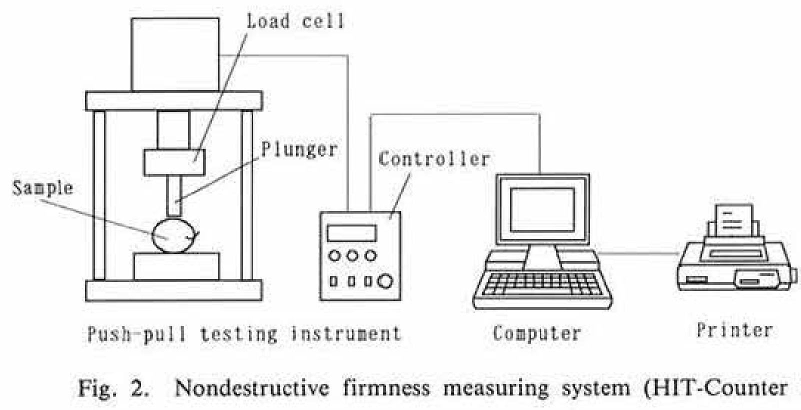

Fig. 2. Nondestructive firmness measuring system (HIT-Counter I)

exceed the preset force of the object. The relation between the force and deformation is displayed on the CRT and printed out. We designated this prototype as HIT-Counter I (HIT being the acronym of hardness, immaturity and texture).

The procedure for measurements using HIT-Counter I is as follows: first, the plunger compressing velocity and forces Fa, Fb within the range of elasticity should be set to be compatible with the firmness measurement of the object. Also, the force Fb must be measured to avoid plastic deformation or destruction of soft objects. The measurement can be started after, firstly, the levels of these parameters for testing conditions are selected and set on the instrument, and secondly, the object is fixed in a stable position. Provisions are made for the instrument to come into contact with the object at various sides. Then the plunger goes down and force data are put into the computer. The plunger going down at a constant speed comes into contact with the object. The compression time required to change the force from Fa to Fb is measured and the deformation is calculated based on the time and speed. The graph which indicates the force and deformation is output by the CRT and the printer.

The firmness in HIT-Counter I is evaluated by the deformation resulting from the switch from force Fa to Fb. The evaluation figure is replaced by integer because this device must be used in research laboratories and in fruit-sorting factories. Since the deformation equals the plunger velocity × compression time, which is required for the change from Fa to Fb. This figure is defined as HIT-Counter value which expresses the degree of firmness. Small HIT-Counter values indicate that the deformation is small and the consistency is hard, while larger values indicate a softer consistency. Since the HIT-Counter value is a time function, even if the deformation is identical, the value changes according to the plunger velocity. For example, if the HIT-Counter value is 100 when the deformation is 1.47 mm, the HIT-Counter value is 50 for a deformation of 1.47 mm provided that the plunger velocity is twice as high. The numerical value which evaluates the firmness can be changed by the plunger velocity for the measurements. In HIT-Counter I, the HIT-Counter value 1 corresponds to 14.7 μm when the plunger velocity for measurement is 50 mm/min.

As a result, since the measured HIT-Counter value changes with the diameter of the plunger, the velocity and the forces (Fa and Fb), the conditions of measurement must be defined precisely.

Test of prototype

Verification of nondestructive evaluation of firmness by HIT-Counter I and tests to define the measurement conditions were carried out for application for the determination of prime eating condition, internal quality such as sugar and acid contents, storage quality evaluation as well as dynamic firmness evaluation.

1) Methods

(1) Evaluation of kiwifruit firmness

The firmness of kiwifruit was measured by HIT-Counter I and the conventional fruit firmness tester and verification of the nondestructive evaluation by HIT-Counter I was carried out. Along with the progression of ripening, kiwifruit became soft, the sour taste was attenuated and the degree of sweetness increased. Nakanishi et al.[2] reported that there was a close relation between the kiwifruit firmness and the contents of total nitrogen, organic acid, soluble protein and free amino acids. The relation between the HIT-Counter value and the internal quality including sugar and acid contents was investigated. The nondestructive evaluation of the internal quality was examined.

Kiwifruits were obtained from Ehime Prefecture as test materials (62 fruits of cultivar Hayward, 7 days after harvest). To modify the firmness (additional ripening) of the fruit, three different temperatures, 5°, 13° and 20°C were used, respectively. Fruit pressure tester FT011 was used as conventional fruit firmness tester. Titratable acidity (as citric acid) was determined while the sugar content was measured by the refractive index. Conditions for the measurement with HIT-Counter I were as follows: plunger velocity was 50 mm/min, diameter of the plunger was 8 mm, and the set forces were Fa = 1.0 N, Fb = 3.9 N. The measurements were performed in the center of the fruit and average measurements of four points were computed.

(2) Evaluation of melon firmness

Melon needs additional ripening because the flesh immediately after harvest is hard. Usually, the evaluation of additional ripening is achieved by pushing the stylar scar of the fruit and the firmness is estimated empirically without numerical values. By measuring the firmness of melon based on the HIT-Counter value, the possibility of estimating the prime eating condition was examined. Also in the storage test of melon, attempts were made to evaluate the conditions for the maintenance of the quality using the HIT-Counter value.

As test materials 90 melons cultivated in a greenhouse (6 per box) were supplied directly by a farmer in Kagawa Prefecture. The test was carried out 4 days after harvest and the firmness was investigated for all the samples of each box. The firmness of the fruit before the storage test was determined. Samples with the same firmness were used for the storage test. For the storage test, four conditions were adopted (A: room storage, 15–18°C, B: low pressure storage, 12°C, 7–20 kPa, 12 hr, C: low pressure storage, 12°C, 13–40 kPa, 12 hr, D: low pressure storage, 6°C, 13–40 kPa, 12 hr). The firmness was determined after 10 days only with the taste test. Conditions for the measurement using HIT-Counter I were as follows: plunger velocity; 50 mm/min, plunger diameter; 12 mm, and forces; Fa = 1.0 N, Fb = 3.9 N. Measurements were performed at the center of the stylar scar.

2) Results and discussion

The measurement of kiwifruit firmness with HIT-Counter I was highly correlated with the conventional fruit firmness tester (Fig. 3). However, a scar due to the pressure was observed when the HIT-Counter values reached 100 and the deformation required for the nondestructive evaluation was about 1 mm. The evaluation of additional ripening was based on the presence of immaturity with hard flesh and high acidity with HIT-Counter values of 10–20. Softness and acidity suitable for consumption corresponded to a HIT-Counter value of 50. Also, four points per sample were measured and the differences among samples were less conspicuous in the case of firm fruits, while the differences were larger with softer fruits, presumably because additional ripening was not uniform. The correlation between the HIT-Counter value and the acidity was high and could be used as an index of the internal quality evaluation (Fig. 4). No clear relation was observed between the sugar content and HIT-Counter value.

The nondestructive measurement of melon firmness was possible at a compression value of about 2 mm. The evaluation of additional

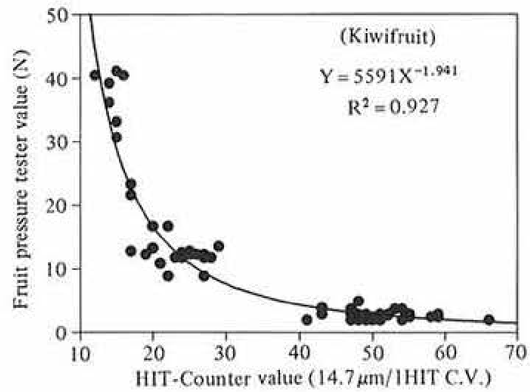

Fig. 3. Correlation between HIT-Counter value and fruit pressure tester value

ripening corresponded to the flesh collapse when the HIT-Counter value exceeded 100. The value for the prime eating condition was estimated at about 50. In the measurements performed 4 days after harvest, the HIT-Counter values showed wide variations from 18 to 75 (Fig. 5). These variations occurred despite the identical cultural conditions under which all the melons tested were grown. The observation suggested that the fruit firmness might have varied even at the time of harvest, and therefore, the experimental device could have been used for grading the produce before shipment, in order to secure the uniform quality of the merchandise.

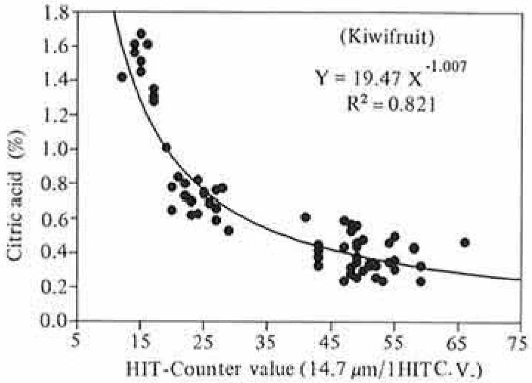

Fig. 4. Correlation between HIT-Counter value and titratable acidity (as citric acid)

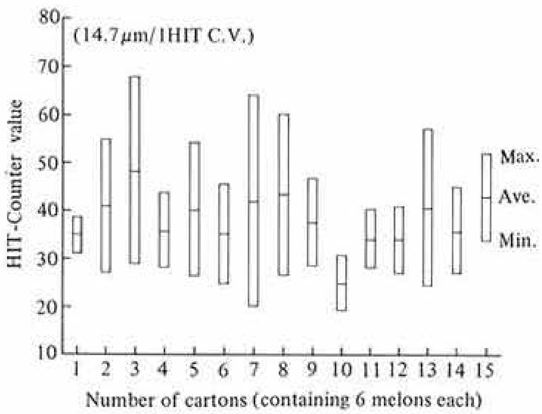

Fig. 5. Firmness of melon in every carton 4 days after harvest

The comparison indicated that the HIT-Counter I can be adopted as a device to provide a criterion for evaluating the quality change during storage (Fig. 6). Among the four test conditions, B with the smallest HIT-Counter value was found to have caused the least degree of postharvest additional ripening in the stored fruit. In storage experiments, all the samples can be tested repeatedly without physically affecting the quality of samples. Consequently, by applying the HIT-Counter in actual storage tests, the device can become an effective and useful tool for the determination of the optimum storage conditions. However, the genetical variations among different varieties of melon are too great to allow the interpretation of the results in conclusive and generalized terms, calling for the accumulation of additional data.

In these tests, it was confirmed that nondestructive evaluation using HIT-Counter I was possible for kiwifruit and melon. Also it was confirmed that HIT-Counter I could be used not only for the measurement of the physical firmness but also for quality control including storage and fruit sorting, evaluation for quality

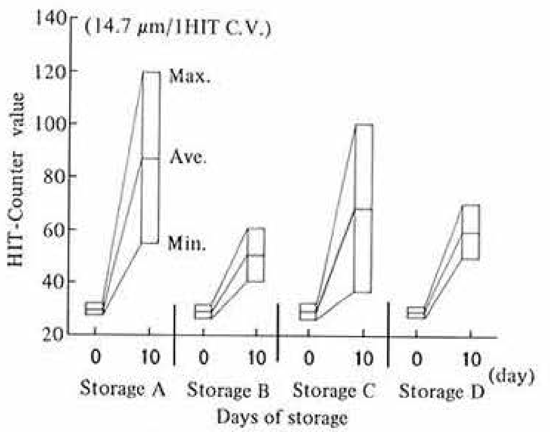

Fig. 6. Firmness of melon when storage test was performed

maintenance, additional ripening test, prime eating condition, etc.

For nondestructive firmness evaluation, the diameter of the plunger should be 8 and 12 mm for kiwifruit and melon, respectively. For the firmness evaluation of additional ripening in kiwifruit and melon, force values should be Fa = 1.0 N, Fb = 3.9 N and plunger velocity 50 mm/min.

Consideration about use of HIT-Counter II

Since HIT-Counter I is composed of various instruments such as a push-pull testing instrument, a compression tester and a computer, it cannot be handled easily for the measurements performed in various areas.

The device designed experimentally is basically identical with HIT-Counter I. For practical use, the three instruments were combined into a single device designated as HIT-Counter II with the board computer (280 CPU) being placed in the center (Fig. 7). If the compressive force is determined by a load cell, the plunger can compress at a certain speed by using a stepping motor. For the measurement of hardness, the HIT-Counter value and deformation could be determined based on the speed of the movement of the stepping motor (1 msec unit). The main improvements are as follows: (1) the parts are combined into a single measuring device with improved mobility, (2) measurements can be easily repeated by setting once the conditions until changes are made, (3) for the nondestructive measurement, evaluation based on the amount of deformation caused by the set compressive force and evaluation based on the compressive force against the set deformation amount are possible. Moreover, the conventional destructive measurement (maximum compressive force for destruction) is possible, (4) measured results can be read in the liquid crystal display and can be printed out, and (5) compressive force can be output by voltage and recorded.

Moreover, in HIT-Counter II, operations for

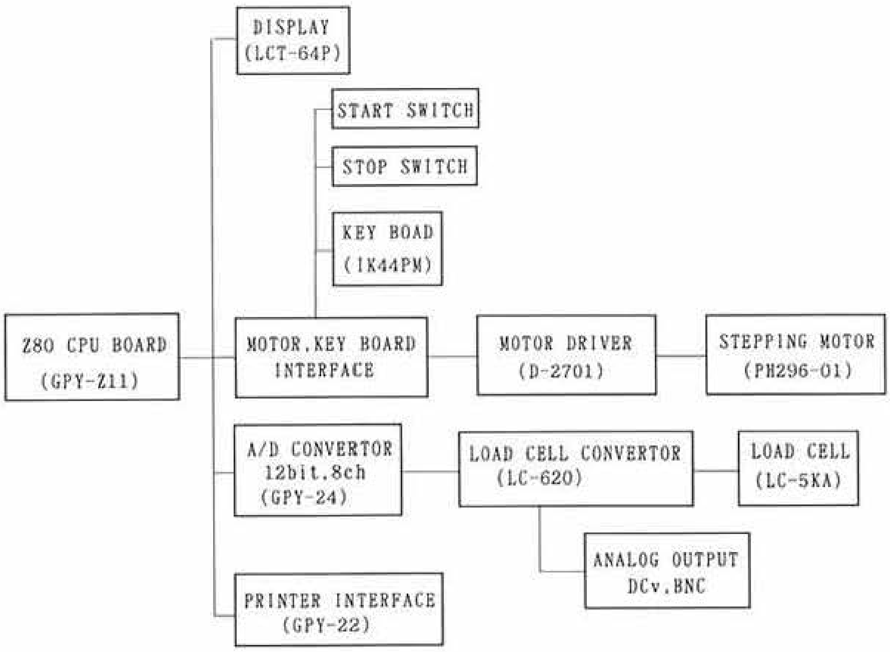

Fig. 7. Block diagram showing components of HIT-Counter II

the measurement are divided into 4 modes: (1) measurement, (2) condition setting, (3) calibration of compressive force, and (4) movement setting. When power is supplied, a mode selection menu appears and calibration and condition setting can be performed only when necessary. If unnecessary, the measurement can be performed immediately. Also, when the footing switch is installed in the measurement starting switch, operability for repeated measurements is improved. Flow diagram of firmness evaluation by HIT-Counter II is shown in Fig. 8. Specifications of HIT-Counter II are shown in Table 1 and the overall view is

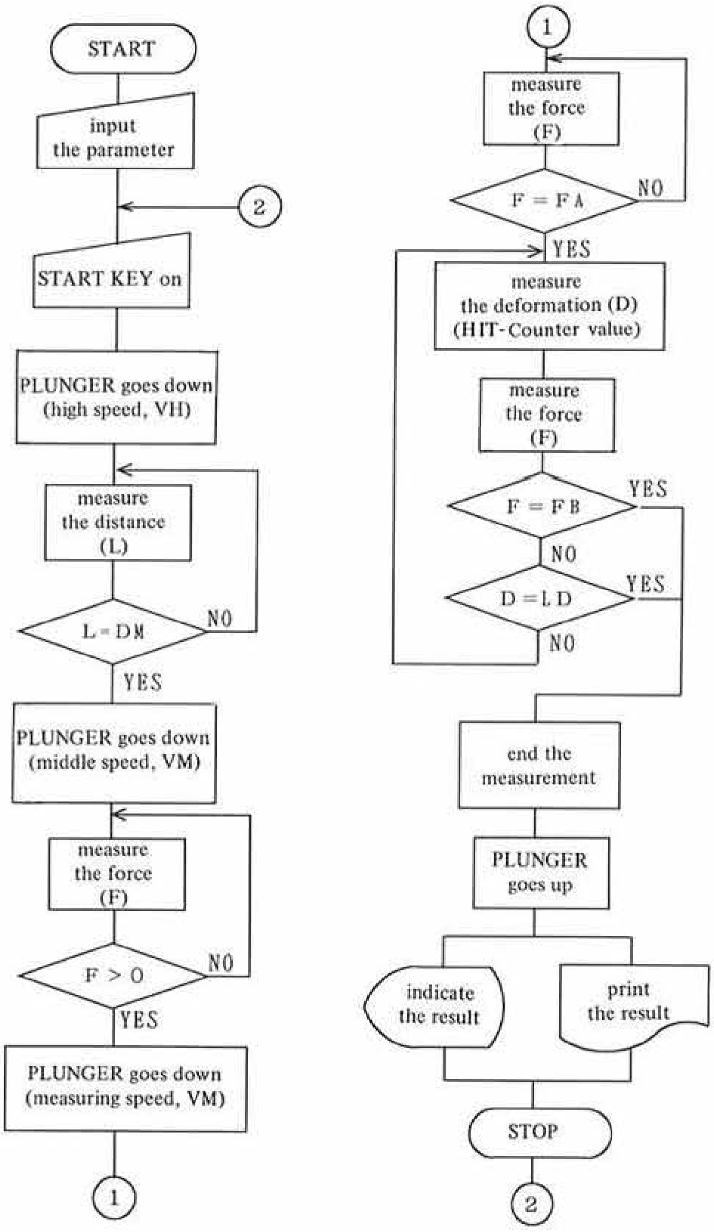

Fig. 8. Flow diagram of firmness evaluation

Table 1. Specifications of HIT-Counter II

1. Power supply: AC 100 V (50/60 Hz)
2. Size: 180(W) × 455(H) × 250(L) mm
3. Weight: 25.6 kg
4. Items of measurement:
   1) Deformation for preset force (HIT-Counter value)
   2) Maximum force for preset deformation
5. Range of measurements:
   1) Force; 0-29.4 N (0-3,000 gf)
   2) Deformation; 0-100.0 mm
   3) Plunger speed; 10-500 mm/min 20 steps
6. Output:
   1) Printer; parameter, results
   2) Voltage of force; DC 0-5 V

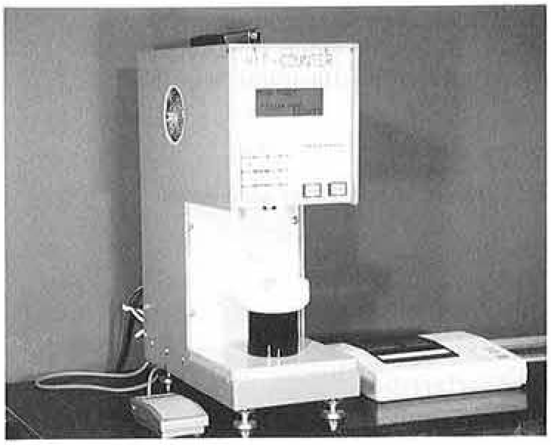

Plate 1. HIT-Counter II

shown in Plate 1.

To confirm the practicability of HIT-Counter II, tests were carried out at several laboratories. The results of the tests showed that nondestructive evaluation of firmness was possible for several kinds of fruits by using HIT-Counter II. However, though the test is nondestructive, it is necessary to touch and deform fruits. Therefore, it is important to determine the elastic deformation range and identify appropriate conditions for evaluation. Also, depending on the needs of users, measuring conditions should be unified to compare data.

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(Received for publication, June 1, 1993)