Agri. & Biosys. Eng. Vol. 1(1):43-48(2000)

Mechanical Properties of the Apple Flesh According to the Specimen Size

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Abstract: Mechanical properties of the apple flesh were tested with compression test apparatus constructed by this study. The computer program was developed for measuring mechanical properties, and analyzing data obtained from the study. Compression tests on the apple flesh were performed at four levels of specimen diameter, three levels of specimen length, and at constant loading rate(25mm/min). Five replications were made at each treatment combination. Effect of specimen size on the mechanical properties of the apple flesh was investigated.

Keywords: Mechanical Properties, Apple Flesh, Specimen Size

Introduction

Fruits are living, biological materials, where composition, moisture content and texture vary continuously after harvesting and even in the course of storage. During processing, handling and transportation, the fruit is generally subjected to various external forces that may cause damage in the form of bruises, punctures and cracks. Damage caused by external forces exerted on a fruit can be analyzed with knowledge of the mechanical properties of the material.

Therefore, to have a minimum degree of fruit damage and the highest quality, the behavior of fruit when subjected to external forces usually in compressive form must be understood. The mechanisms of damage of the fruit by the compressive forces are not fully known yet, but a study of force-deformation behavior of fruits in their natural state has been an attempt to provide some possible criteria or comparisons of the relative strength of the various materials. The force-deformation relationship can be used most frequently in determining the mechanical properties of fruit, such as the bioyield point, the rupture point, the elastic modulus and some other properties.

A large amount of information is available on the mechanical properties of fruits and vegetables(Mohsenin et al., 1963; Fridley et al., 1968; Chappell and Hamann 1968; Wright and Splinter, 1968; Rao et al., 1974; Armstrong et al., 1990; Chen and De Baerdemaeker, 1993). These studies were concerned mostly with characterizing some basic mechanical properties without considering the size of the cylindrical specimen cut from the material.

Mohsenin(1986) reported that the difference between the elastic modulus of the flesh of the whole fruit found by the use of the Hertz theory in elasticity and by the parallel plate loading a cylindrical specimen taken from the flesh fruit is relatively small. This implies that the observations such as force-deformation behavior of fruits may be performed with material in their natural state or with specimens taken from them, and that in certain cases, the preparation of test specimens, with shapes reducing disturbing effect, may be of advantage.

Mohsenin(1986) and Sitkei(1986) reported that several requirement for uniaxial compression test of fruits and vegetables were applying a truly axial load to avoid the appearance of bendings, avoiding friction between the end surface of the specimen and the compression plate, and selecting a specimen with such length to diameter ratio that a proper degree of stability was obtained.

Kim et al.(1992) studied that effect of the test specimen taken from the different sampling positions (cavity shoulder, cheek, calyx end) on the mechanical pro- perties of the fruits. They reported that the values of the mechanical properties were shown the smallest ones at the specimen selected from the cheek section, because this section was the weakest section of the whole fruit and was more susceptible to mechanical damage than others. Abbott and Lu(1996) also found that mechanical properties of the apple were significantly influenced by specimen orientation, latitude and depth(from skin to core). Although some investigators have indicated the importance of specimen size when obtained force-deformation behavior of fruits and vegetables, they have not presented the results in detail sufficient to explain the effect of specimen size on the mechanical properties of fruits.

The objective of this study was to determine the effect of size of specimen taken from the apple flesh on the mechanical properties.

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Materials and Methods

1. Materials

Sample fruit was selected from Fuji cultivar of apples which is the most popular grown cultivar in Korea. The apples were harvested during the 1997 harvest season from the experimental orchard of Chungnam national university. The harvested apples were inspected to ensure uniform ripeness and size. After completing the inspection, the apples were stored at temperature of 0 ℃ and relative humidity of 90 % until tested. The apples were allowed to stabilize at experimental room temperature(15 ℃, R.H. 55 %) before tests were conducted. All specimen was taken from the cheek section as shown in fig. 1.

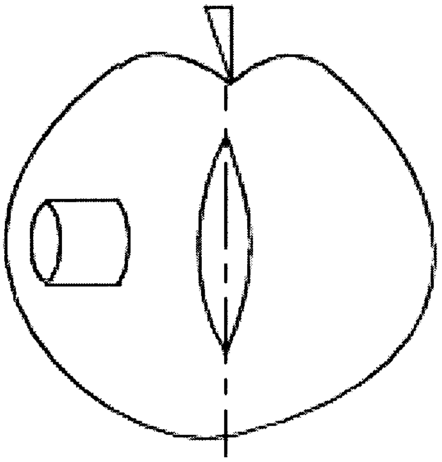


Fig. 1 Sampling position of the apple.

2. Experimental Apparatus and Methods

The experimental apparatus was constructed to measure mechanical properties of fruits and vegetables as shown in fig. 2. The apparatus was consisted of AC servo motor (MSD021A1X) and its interface board (STP-2M, CONTEC) to move crosshead in vertical direction with combination of ball screw and LM guide, A/D converter and signal amplifier integrated board(5508BG), load cell to detect the force applied to the specimen, and IBM compatible personal computer.

This compression test apparatus was constructed specially for measuring mechanical properties of fruits and vegetables, and its maximum load capacity was about 9800 N. The crosshead speed ranged from 0.5 to 30 mm/min. The vertical displacement of crosshead could be calculated on the basis of relationship between the number of pluses per revolution(2500 p/rev) of the servo motor and the lead per revolution(5 mm/rev) of the ball screw. And also this method was validated by LVDT measuring system.

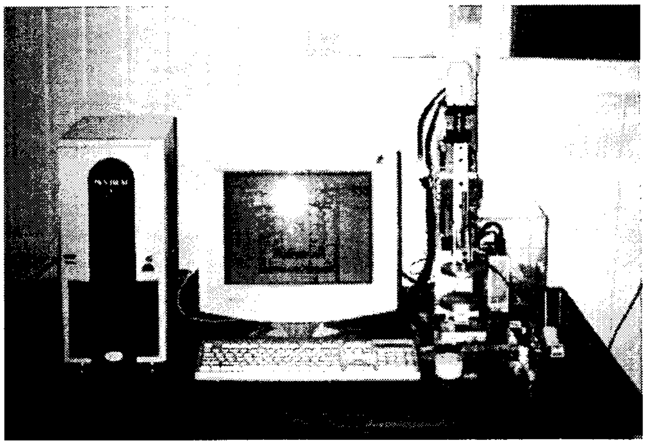
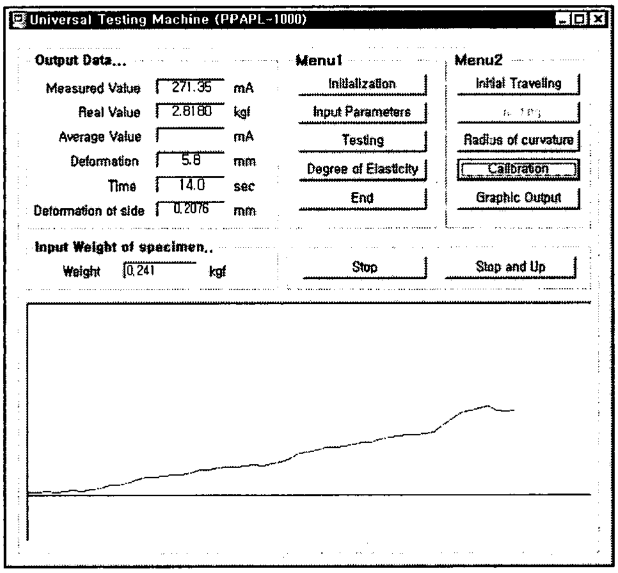


Fig. 2 General view of experimental apparatus for measuring mechanical properties.

The tests were conducted at four levels of specimen diameter(11.7, 14.9, 18.1, 21.2 mm) and three levels of specimen length(12, 16, 20 mm). Combination of all levels of diameter and length requires 12 specimen to complete one replication. Five replications were performed, so a total of 60 apples were needed and the only one specimen was taken from one apple.

Compression tests were conducted using the constructed experimental apparatus. The loading rate of the crosshead was fixed at 25 mm/min, which was within the range of loading rate (2.5 to 30 mm/min) specified by the ASAE S368.3 MAR95.

The force-deformation data was recorded by computer, and for controlling the measuring system and for processing the data, the computer program was developed in Microsoft Visual Basic(5.0) programming language. The developed program was illustrated in fig. 3, 4, and 5.



Universal Testing Machine (PPAPL-1000)

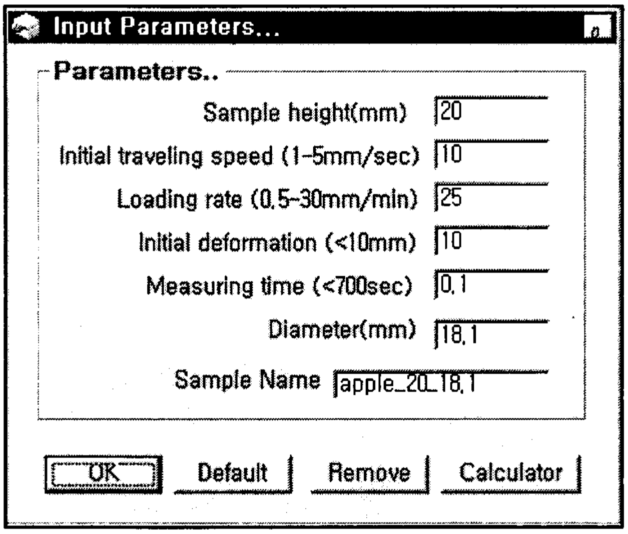
Output Data...

Measured Value 271.35 mA
Real Value 2.8180 kgf
Average Value mA
Deformation 5.8 mm
Time 14.0 sec
Deformation of side 0.2076 mm

Input Weight of specimen..

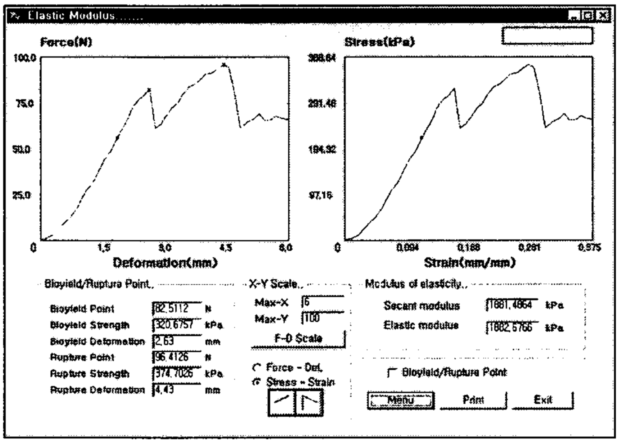
Weight 0.241 kgf

Fig. 3 Main menu window.



Sample height(mm) 20
Initial traveling speed (1-5mm/sec) 10
Loading rate (0.5-30mm/min) 25
Initial deformation (<10mm) 10
Measuring time (<700sec) 0.1
Diameter(mm) 18.1
Sample Name apple_20_18.1

Fig. 4 Input parameters window.



Bioyield Point 82.5112 N
Bioyield Strength 320.6757 kPa
Bioyield Deformation 2.63 mm
Rupture Point 96.4126 N
Rupture Strength 374.7026 kPa
Rupture Deformation 4.43 mm
Max-X 6
Max-Y 100
Secant modulus 1881.4864 kPa
Elastic modulus 1882.5766 kPa

Fig. 5 Test results output window.

Five mechanical properties, such as bioyield deformation, rupture deformation, bioyield strength, ultimate strength and apparent elastic modulus(Young's modulus) were analyzed in this study. the other mechanical properties except apparent elastic modulus were obtained and calculated from the force-deformation curves by the method specified in the ASAE Standard(ASAE S368.3 MAR95). The apparent elastic modulus was obtained by the different two methods in this study. One was secant modulus and the other method was calculated by taking the ratio of conventional stress to conventional strain as illustrated in fig. 6. Although these two modulus were not the same in practice, theoretically, these had to be the same.

$$E = (F/A)/(\Delta L/L)$$

Where E = Apparent elastic modulus(Pa)
F = Applied force(N)
A = Cross sectional area(m^2)
ΔL = Deformed length(m)
L = Original length(m)

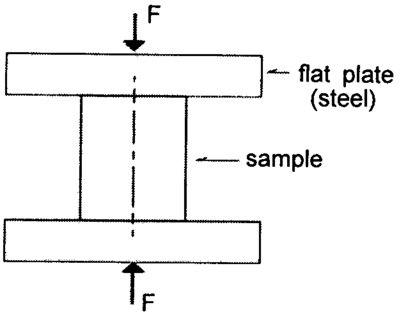


Fig. 6 Definition of elastic modulus for material.

Results and Discussion

1. Bioyield Deformation and Rupture Deformation

Bioyield deformation is defined as the horizontal distance from the beginning of force-deformation curve to bioyield point on the curve. And, rupture deformation is also the distance corresponding to rupture point as mentioned above. In order to measure bioyield deformation, bioyield point on the force-deformation curve must be found out, however it is very difficult or impossible to find out bioyield point at a certain biological material. Fortunately, the bioyield point of the apple flesh existed distinctly on the curve as shown in fig. 5.

As shown in table 1, the bioyield deformation of the apple flesh varied from 1.457 to 3.572 mm and the rupture deformation varied from 2.113 to 4.314 mm by the specimen size.

And also, it was found that bioyield deformation and rupture deformation increased with the increase of the specimen diameter and length.

Even though the similar data at the typical specimen size could be found in some other studies(Mohsenin, 1986; Park, 1993), it was nearly impossible to find out the research result considering effect of the specimen size

2. Bioyield Strength and Ultimate Strength

Bioyield strength and ultimate strength were calculated from the force-deformation data stored in the computer. Bioyield strength and ultimate strength of the specimen could be calculated by dividing bioyield point(force) and rupture point by its initial cross sectional area, respectively.

Bioyield strength and ultimate strength of the apple flesh were shown at table 2. Upon examination of the strength values from the table 2, it was found that the specimen size greatly affected the bioyield strength and the ultimate strength. These two strengths increased with the increase of the specimen diameter along the

Table 1 Bioyield deformation and rupture deformation of the apple flesh according to the specimen size

D(mm) / L(mm)	11.7		14.9		18.1		21.2	
	B.D*	R.D**	B.D	R.D	B.D	R.D	B.D	R.D
12	1.457	2.817	1.593	2.210	2.087	2.860	2.757	3.617
16	1.490	2.113	2.130	3.337	2.643	4.277	3.493	3.890
20	1.793	2.245	3.570	3.570	2.709	3.902	3.572	4.314

* B.D : Bioyield Deformation(mm) ** R.D : Rupture Deformation(mm)

Table 2 Bioyield strength and ultimate strength of the apple flesh according to the specimen size

D(mm) / L(mm)	11.7		14.9		18.1		21.2	
	B.S*	U.S**	B.S	U.S	B.S	U.S	B.S	U.S
12	151.1558	172.9932	250.0383	309.5453	320.1785	364.5482	644.7495	727.4587
16	154.4314	176.8830	222.3321	248.4005	376.6953	419.0053	682.4190	759.0075
20	112.4626	150.9511	212.3485	254.3840	315.2405	376.5080	653.1278	735.6924

* B.S : Bioyield Strength(kPa) ** U.S : Ultimate Strength(kPa)

specimen length up to 16 mm, and after that, those decreased with the increase of the specimen length at the same diameter level.

3. Effect of the specimen size on apparent elastic modulus

Secant modulus is well defined in the literature (Mohsenin, 1986), and this depends mostly upon the selected point on stress-strain curve. In this study, secant modulus was obtained from the stress-strain curve at the point a little below bioyield strength. The point needed to calculate secant modulus was selected in advance, on the force-deformation curve at approximately 50 % of rupture point. And by processing data stored in the computer, the stress-strain curve having the same selected point could be transformed automatically from the force-deformation curve through the developed computer program as shown in fig. 5. Also, the other modulus as illustrated in fig. 6 was calculated at the same point selected.

As shown in fig. 7, the apparent elastic modulus of the apple flesh decreased with the increase of the specimen diameter at the same length level. On the contrary, it increased with the increase of the specimen length at the same diameter level as shown in table 3.

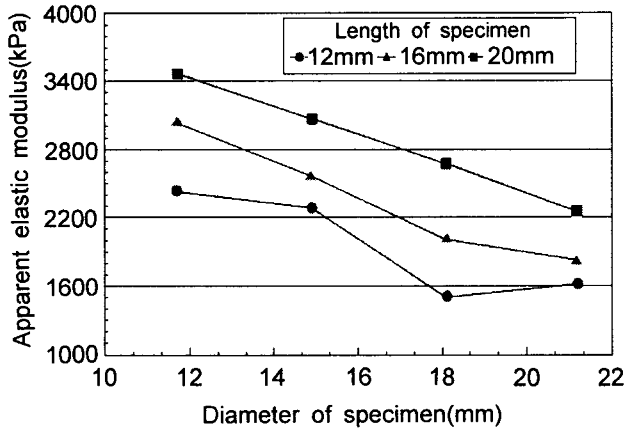


Fig. 7 Effect of the specimen diameter on the apparent elastic modulus of the apple flesh.

Comparing the apparent elastic modulus between these values and some others(Mohsenin, 1962; Park, 1993), the values obtained from this study was a little lower than others. It was believed that this difference between them was caused by different test method and different specimen size.

From investigation of the results as shown in fig. 7 and table 3, it was found that the specimen size was a significant factor on the apparent elastic modulus of the sample. To determine whether diameter and length of the specimen were significant at 1 % level,

Table 3 Effect of the specimen size on the apparent elastic modulus of the apple flesh

(kPa)

L(mm) \ D(mm)	11.7	14.9	18.1	21.2
12	2424.1261	2281.3859	1497.6729	1621.5980
16	3032.5669	2558.9458	2003.9084	1820.3809
20	3461.1382	3067.1575	2672.0580	2251.6833

Table 4 Analysis of variance of apparent elastic modulus for the apple flesh

Factors	DF	SS	MS	F-value
Diameter	3	6771071.00	2257023.75	32.29**
Length	2	4958642.00	2479321.00	35.47**
Interaction	6	327804.00	54634.00	0.78
Residual	24	1677763.00	69906.79	-
Total	35	13735280.00	-	-

analysis of variance(ANOVA) method was applied to the apparent elastic modulus of the apple flesh as shown in table 4. As expected, effects of the specimen diameter and length on the apparent elastic modulus of the sample were highly significant.

The results obtained from this study indicated that the specimen size as well as the loading rate and some other parameters related directly to the tests should be reported when determining the mechanical properties of fruits.

Conclusions

Bioyield deformation and rupture deformation for the apple flesh increased with the increasing of the specimen diameter and length.

Bioyield strength and ultimate strength for the apple flesh increased with the increase of the specimen diameter, but those strengths increased with increase of the specimen length up to 16mm, and after that, those decreased with the increase of the specimen length.

Apparent elastic modulus of the apple flesh decreased with increase of the specimen diameter, but it increased with the increase of specimen length.

From the results for analysis of variance applied to the apparent elastic modulus of the apple flesh, it was found that effects of the specimen diameter and length on the modulus were highly significant. These implied that the specimen size as well as the loading rate and some other parameters should be reported when determining the mechanical properties of fruits.

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