# PORTABLE INSTRUMENT FOR MEASURING FIRMNESS OF CHERRIES AND BERRIES

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**ABSTRACT.** *A portable data-acquisition instrument was designed and built to rapidly and automatically measure firmness of cherries and berries. The firmness is measured by slightly compressing the fruit between two parallel surfaces and recording the force versus deformation data. Tests were conducted on sweet and tart cherries, blueberries, and strawberries. Results show the system is capable of distinguishing between bruise treatments, harvest treatments, and fruit maturity levels. Mean chord stiffness (MCS) was the best indicator of fruit firmness. A description of the instrument is given along with the measurement techniques and results.* **Keywords.** *Berries, Cherry, Compression, Deformation, Firmness, Nondestructive.*

One of the physical properties of fruit that is frequently used as a measure of quality is the firmness of the fruit. With fresh fruit such as cherries, blueberries, and strawberries, a sensory judgment of firmness is commonly made by gently squeezing the product with the fingers. This subjective estimate of firmness is a measurement of the degree of deformation of the fruit under the influence of a compression force. Bourne (1967) has shown that determining firmness of a product varies among people and under repetitive tests the same person will obtain different results for the same product. For these reasons many instruments and methods have been developed over the years in an attempt to standardize and quantify fruit firmness.

Many of the instruments designed to detect firmness are for larger fruits such as apples, peaches, and pears and are not sensitive enough for small fruits such as cherries, blueberries, and strawberries. One common method used to measure firmness is the puncture principle in which a probe is forced into the fruit and the amount of force required to cause penetration is measured. Based upon this concept, Magness and Taylor (1925) developed a hand-held fruit pressure tester which is widely used for measuring firmness in many fruits such as apples, peaches, and pears.

Several techniques for measuring firmness of tart cherries were investigated by Parker et al. (1966). Some of the techniques included: measuring the time required for a cherry to roll a given distance on a sloped plane; dropping cherries on a sloped plane and measuring the distance they bounced; and stacking 10 cherries in a vertical tube, subjecting them to a load, and measuring the distance the cherries compressed. For a variety of reasons, none of the above methods provided satisfactory results which led to the development of the puncture-load (PL) meter. The PL meter measured tart cherry firmness by measuring the displacement of a rod into the flesh of the cherry for a period of 120 s under a given load. Parker et al. (1966) found that the displacement differences between bruised and unbruised cherries was consistently detected, however, the slow throughput of the instrument (20 to 30 cherries/h) limited the practicality of the device.

In an effort to automate the PL meter, Diener et al. (1969) developed the deformation-load (DL) instrument. As with the Parker et al. (1966) device, the DL instrument measured the displacement incurred by a fixed load when placed upon the cherry, with the added convenience of automatically graphing the displacement versus time curves. Diener et al. (1969) determined that within the first 0.25 s of the application of the load to the cherry, 85% of the final total displacement has occurred. The time to make a firmness measurement with the DL instrument compared to the PL meter was significantly reduced, however, the interpretation of the graphical results could result in operator bias.

Many other methods and instruments have been developed to measure firmness in small fruits: cherries (Bouyoucos and Marshall, 1950; Kenworthy and Silsby, 1974; Lustig and Bernstein, 1987); blueberries (Rohrbach, 1981; Wolfe et al., 1982; Slaughter and Rohrbach 1985); strawberries (Ourecky and Bourne, 1968).While all of these methods have been able to quantify fruit firmness,

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none have been adopted as a standard for any of the fruits listed above.

ASAE standard S368.2 provides the procedures to follow when testing the firmness of fruits and vegetables. The purpose of the standard is for determining mechanical attributes of food texture, resistance to mechanical injury as a result of static loading, and quasi-static force-deformation behavior of food materials of convex shape (ASAE, 1991). Use of this standard requires the production of a force-deformation curve, which is typically obtained with an Instron universal testing machine. From this curve a number of mechanical properties can be determined such as stiffness, modulus of elasticity, point of inflection, etc. Although this method is accepted as a standard for testing fruit and vegetables, it is quite slow, not portable and requires interpretation of the graphical results.

## OBJECTIVES

The ability to measure the firmness of fruit with a system that is relatively quick, objective, nondestructive, portable, able to measure a variety of cherries and small berries, and can provide instantaneous results would be of great benefit to researchers. The specific objectives of this study were to:

- Develop a portable system that could quickly and automatically measure the firmness of cherries and berries based upon the force exerted by the fruit when compressed between flat plates at precise increments.
- Determine what properties of the force-deformation curve best describes the firmness of a fruit with known bruise treatments, harvest treatments, and maturity levels.

- Recommend a specific testing procedure that gives the most consistent results for each of the fruits tested based upon the analysis of the data collected from each of the firmness experiments.

## MATERIAL AND METHODS
### FIRMNESS INSTRUMENT DESIGN

Our first attempt at developing a portable firmness measuring device for cherries and berries was completed in 1989. Although the device had a different design than our current one, the same principles were used. Since 1989 several improvements have been made in both the software and hardware design of the system, resulting in second and third generation systems. Our current system consists of a portable IBM-PC compatible, central processing unit that includes a microprocessor; memory storage, A/D converter, and a battery; and the firmness measuring device. The firmness measuring device is constructed from an aluminum Y-shaped frame on which is mounted a stepping motor (model STH-39D113 DC12V 0.16A 1.8DEG/STEP, Shinano Kenshi Co., Ltd., Japan), plunger, compression and load cell plates, load cell (Omega model LCL-454 full bridge thin beam, Omega Engineering, Inc., P. O. Box 2669, Stamford, CT 06906), and serial communication port (fig. 1). The load cell has a combined error of 0.25% full scale and a full-scale deflection of approximately 1.0 mm (0.04 in.).

### HARDWARE CONTROL AND DATA COLLECTION

A menu-driven software program within the PC controls both the collection, storage, and analysis of the firmness data. The firmness of the fruit was determined as detailed in figure 2. Using the PC-controlled stepping motor, the
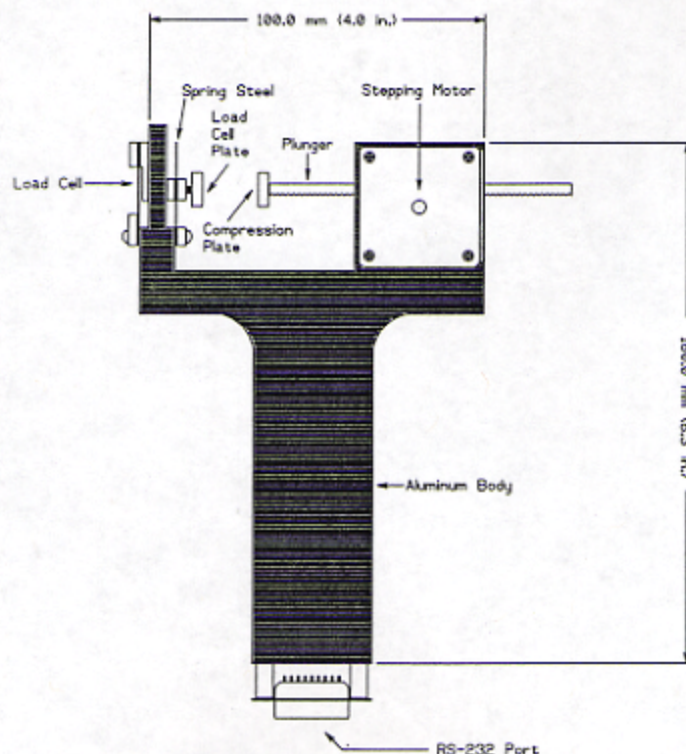


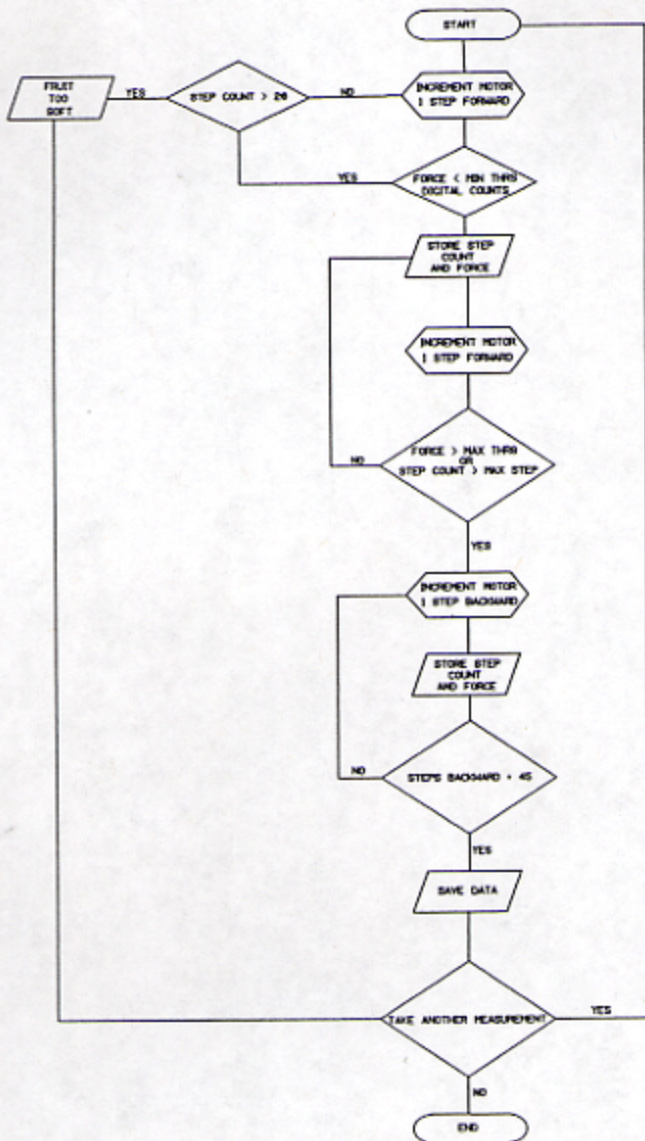Figure 1–Schematic drawing of firmness measuring device.

Figure 2–Flow chart for control sequence for the firmness measurement process.

conditions is met: 1) the force at the end of the step is greater or equal to the maximum cutoff force value; or 2) the step count is equal to a set maximum. When one of these conditions is met, the stepping motor is reversed and the relaxation force is recorded for each step in a manner similar to loading. The data collected is downloaded to the PC via the RS232 interface between the computer and the microprocessor. The force-deformation data is then analyzed using various mathematical firmness calculations.

## INSTRUMENT AND FRUIT EVALUATIONS
### TART CHERRY BRUISE TREATMENTS (INITIAL TESTS)

Our initial testing of the firmness device was used in a 1989 tart cherry bruising experiment. This experiment was conducted in order to test the design concept of the firmness instrument and to determine the best data analysis method. A sample of approximately 300 red tart cherries were carefully hand picked at the Michigan State University Experimental Research Station in Traverse City, Michigan. A subset of 100 cherries of average size, color, and void of defects were utilized for the firmness measurements.

Prior to the measurements, the cherries were placed in a bath of 12°C (54°F) water for 1 h to minimize initial temperature differences between the cherries. The 100 cherries were then divided into four groups of 25 cherries. Each group was given a bruise treatment ranging from zero to three drops from a height of 0.75 m (2.5 ft) onto a flat hard plastic surface [e.g. 0X, 1X, 2X, and 3X where 0, 1, 2, and 3 = number of drops and X = drop height of 0.75 m (2.5 ft)]. The cherries were positioned during the drop so that the cheek side of the fruit was impacted when it hit the surface. Fruit firmness was then measured on all 100 cherries. Each cherry was positioned so that the suture line of the cherry was parallel and midway between the faces of the load cell plate and compression plate. A maximum compressive force of 1.5 N (0.34 lbf)was used as the cutoff.

### STRAWBERRY MATURITY

In June of 1990, firmness measurements were taken on the same day, for 15 different fruit at each of five different maturity stages (visual colors) of 'Honeoye' strawberries. The five maturity stages were classified as: green (no redness); breaker (green with red blush); orange (past green, yellow to red); light red, and dark red. Three firmness measurement replications were taken at the base of the narrow diameter and three at the base of the wide diameter of each berry (i.e., just below the stem end). A maximum compressive force of 2.2 N (0.49 lbf) was used as a cutoff value.

### BLUEBERRY MATURITY

A blueberry maturity experiment was conducted in August of 1990. Firmness measurements were taken on the same day for 48 different fruit at each of three different maturity stages (visual colors) of 'Bluecrop' blueberries. The three maturity stages, using color as the determinant factor, were classified as immature (low blue), near mature (medium blue), and mature (high blue). Two firmness measurements were taken across the base of the berry

compression plate is opened or closed. The fruit is positioned between the compression plate and the load cell plate in such a way that the fruit is not initially in contact with either flat plate. The user then issues the PC command to start data collection. The stepping motor is incremented one step [0.1 mm (0.004 in.)] forward at a constant rate of 8.85 mm/s (0.35 in./s). The force exerted on the load cell at the end of the step is compared to a set minimum threshold. If the force is less than the minimum threshold, the motor is incremented another step. This process is repeated until the force is greater than the minimum threshold which allows the operator to "take the slack out of the system" without regard to the fruit's initial distance from the load cell. If the number of steps is greater than 20 and the force is less than the minimum threshold, the fruit is considered too soft for accurate measurement. When the force is greater than the minimum threshold, the stepping motor is incremented one step and the force at the end of the step and the step count are stored in memory. This process is repeated until one of the two following

(stem end up, blossom end down) with the second measurement rotated 90° from the first. A maximum compressive force of 2.2 N (0.49 lbf) was used as a cutoff value.

## SWEET CHERRY MATURITY

Since 1990, firmness measurements of sweet cherries have been made in conjunction with a sweet cherry quality project described in detail by Guyer et al. (1991). All orchards were located at and within the vicinity of the Northwest Horticultural Research Station in Traverse City, Michigan. Each harvest season, samples of fruit from several varieties of sweet cherries were carefully hand harvested over several weeks. The firmness measurements were taken across opposite cheeks of the cherries and a force of 3.0 N (0.67 lbf) was used as the maximum cutoff value.

## BLUEBERRY HARVEST TREATMENTS

In 1992, Bluecrop blueberries harvested using three commercial mechanical harvesters and a commercial hand picking crew were compared. The complete design of the experiment is detailed in Brown et al. (1993). Firmness measurements were taken across opposite cheeks on the same day for 100 fruit for each of the four harvest treatments. Initial berry firmness was taken prior to hand and mechanical harvesting. A maximum force of 1.5 N (0.34 lbf) was used as a cutoff value.

## RESULTS AND DISCUSSION
### TART CHERRY BRUISE TREATMENTS

A typical force versus deformation curve for a tart cherry is shown in figure 3. Note that only the portion of the curve with the positive slope represents the compression of the cherry (i.e., closing of the firmness device), whereas the negative sloped portion of the curve represents the opening of the firmness device.

The force versus deformation curves generated from testing the 100 cherries were analyzed for the purpose of finding various components of the curves that would discriminate between the bruise treatments. These various components included: integration of the force-deformation curve; integration of the compression portion of the curve;

integration of the decompression portion of the curve; slope of the best fitting line for the compression and decompression portions of the curve (MCS); the difference between the compression and decompression slopes; force at 2.00 mm (0.08 in.) of deformation; and deformation to peak force. Other variables such as bioyield point, modulus of elasticity, and inflection point were not calculated because they are based upon some type of tissue failure of the fruit. In our tests, fruit was only compressed a small amount and no tissue failure was observed.

A correlation matrix was developed for the variables listed above to determine which best describe cherry firmness in relation to the bruise treatments (table 1). The results show that the slope of the compression portion of the force-deformation curve (MCS) and deformation to peak force were highly correlated to the bruise treatment. Other research had shown that slope of the force-deformation curve was a consistent measure of fruit firmness (Ballinger et al., 1973; Slaughter and Rohrbach, 1985). We selected MCS as the basic measure of tart cherry firmness based upon the high correlation with the bruise treatment and previous flat plate compression research which also used MCS as a measure of their results.

The mean firmness of the 0X (control fruit, no drop) cherries was 489.1 N/m (33.5 lbf/ft) compared to 421.0 N/m (28.8 lbf/ft) for 1X, 345.6 N/m (23.7 lbf/ft) for 2X and 299.7 N/m (20.5 lbf/ft) for 3X (fig. 4). An analysis of variance for MCS for the four bruise treatments showed a significant effect at alpha = 0.05, (data not shown). Classifying each individual cherry based upon a linear regression analysis of the MCS and the corresponding bruise treatment produced a total misclassification rate of 30% for the 100 cherries. However, no cherry was ever misclassified by more than one bruise treatment, i.e., cherries dropped 0X were never classified as a 2X nor were 1X fruit classified as 3X and vice-versa. The data indicate that during a specific harvest season, mechanically harvested tart cherries could be sampled for firmness with this device and classified accordingly.
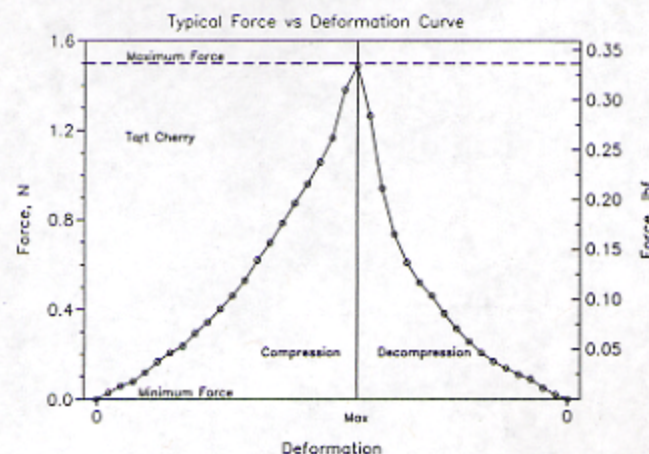


Figure 3–Typical force vs. deformation curve for a tart cherry.

Table 1. Correlation matrix of various variables used to describe firmness of a tart cherry bruise experiment, 1989

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.00 | | | | | | | | |
| 2 | 0.56 | 1.00 | | | | | | | |
| 3 | 0.43 | 0.94 | 1.00 | | | | | | |
| 4 | 0.61 | 0.83 | 0.61 | 1.00 | | | | | |
| 5 | −0.90 | −0.45 | −0.28 | −0.63 | 1.00 | | | | |
| 6 | 0.78 | 0.47 | 0.25 | 0.72 | −0.88 | 1.00 | | | |
| 7 | −0.86 | −0.48 | −0.27 | −0.70 | 0.96 | −0.97 | 1.00 | | |
| 8 | −0.86 | −0.57 | −0.38 | −0.73 | 0.95 | −0.86 | 0.93 | 1.00 | |
| 9 | 0.91 | 0.70 | 0.57 | 0.74 | −0.94 | 0.83 | −0.90 | −0.95 | 1.00 |

**Variable**
1 = Bruise Treatment
2 = Integration (Full Curve)
3 = Integration (Compression Curve)
4 = Integration (Decompression Curve)
5 = Slope (Compression Curve)
6 = Slope (Decompression Curve)
7 = Slope Difference (Compression - Decompression)
8 = Force at 2.0 mm of deformation
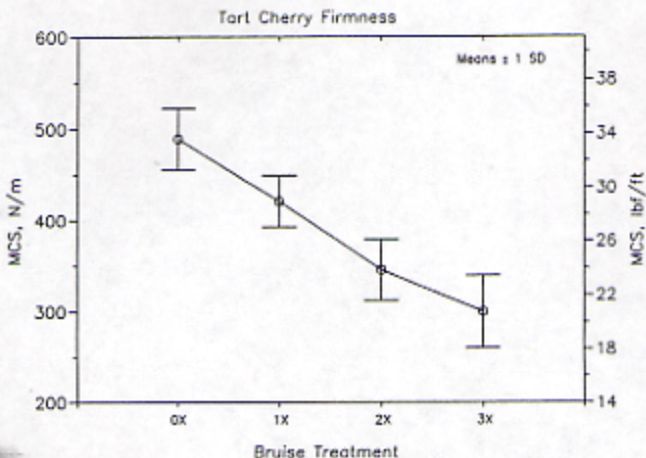9 = Deformation at Peak Force

**Figure 4**–Average tart cherry firmness ±1 SD vs. bruise treatment (e.g., each group received a bruise treatment ranging from zero to three drops from a height of 0.75 m (2.5 ft) onto a flat hard plastic surface, n = 25 for each group).

## Table 3. The MCS for 48 different fruits in each of three maturity stages of Bluecrop blueberries harvested on 14 August 1990 (rep. 1)

| Blueberry Maturity | Mean MCS* (N/m) | S.D. (N/m)† |
|---|---|---|
| Immature (low blue) | 943.4a | 70.6 |
| Near mature (medium blue) | 832.6b | 123.6 |
| Mature (high blue) | 741.4c | 73.5 |

\* Means in a column which are identified with the same letter are not significantly different (p = 0.05) by Duncan's Multiple Range Test.

† N/m × 0.069 = lbf/ft.

Calculation of the MCS for the second replication (data not shown) resulted in values which were considerably less *than the first replication indicating that the structure of the* blueberry was disrupted by the first measurement. A maximum cutoff threshold of 2.2 N (0.49 lbf) is too high for blueberries and should be in the range of 1.0 to 1.5 N (0.22 to 0.33 lbf).

## STRAWBERRY MATURITY

Calculations of the firmness data (data not shown) showed that the MCS was the most indicative of strawberry maturity. The general trend showed that as strawberries become more mature (gain red color) the firmness decreases similarly for both the narrow and wide diameters (table 2). Strawberries in the green and breaker maturity stages were significantly firmer than those in the orange, light, or dark red maturity stages (alpha = 0.05). The orange and light stages were significantly firmer than the dark stage.

Preliminary analysis showed that the data was inconsistent when strawberry firmness was measured in the second and third replications. This is probably due to the physical structure of the strawberry, which once compressed does not return to its original shape because of tissue damage, therefore repeated measurements of individual strawberries is unwarranted. Measurements taken across either diameter will define the firmness of the strawberry, but either the narrow or wide diameter must be consistently used.

## BLUEBERRY MATURITY

The Mean Chord Stiffness (MCS) was the best indicator of firmness for three stages of blueberry maturity. The results show that as the blueberries deepen in blue color, firmness decreased significantly for the three maturity stages (table 3).

## SWEET CHERRY MATURITY

The results for several years of sweet cherry firmness data are presented in table 4. Due to the amount of firmness data we have collected over a four-year period, only three varieties and two harvest seasons are presented. The 'Emperor Francis' and 'Hedelfingen' varieties both show that during the 1991 and 1993 harvest seasons, the firmness of the cherry decreases in each of the subsequent harvest dates. The 'Ulster' variety appears to follow no specific trend in the 1991 harvest season. During the 1993 harvest season, firmness for Ulster increased slightly from the first to second harvest, but decreased in each of the following harvest dates. In 1991, the difference in firmness between the first and last harvest of Emperor Francis and Hedelfingen was 27 and 21%, respectively, compared to only 5% for Ulster. The difference in firmness between the first and last harvest for Ulster in 1993 was 13% compared to 35 and 31%, respectively, for Emperor Francis and Hedelfingen.

## BLUEBERRY HARVEST TREATMENTS

The results of the blueberry harvest treatments are presented in table 5. Prior to harvesting, the initial berry firmness (control) was 1293.2 N/m (88.6 lbf/ft). After 10 days in cold storage [0°C (32°F), 95% RH] and 1 day ambient room temperature [24°C (76°F)], the average firmness for the three mechanical harvest treatments ranged from 486.2 to 528.3 N/m (33.3 to 36.2 lbf/ft) while the average for the hand harvest was 740.1 N/m

## Table 2. The MCS for 15 different fruits in each of five maturity stages of 'Honeoye' strawberries harvested on 18 June 1990 (rep. 1)

| Strawberry Maturity | Mean MCS (N/m)* Wide Dia. | Mean MCS (N/m)* Narrow Dia. | S.D. (N/m)† Wide Dia. | S.D. (N/m)† Narrow Dia. |
|---|---|---|---|---|
| Green | 1858.4a | 1698.5a | 261.8 | 290.2 |
| Breaker | 1707.4a | 1616.1a | 228.5 | 245.2 |
| Orange | 1432.8b | 1269.9b | 320.7 | 207.9 |
| Light Red | 1280.8b | 1301.4b | 190.3 | 196.1 |
| Dark Red | 1078.7c | 988.5c | 187.3 | 134.3 |

\* Means in a column which are identified with the same letter are not significantly different (p = 0.05) by Duncan's Multiple Range Test.

† N/m × 0.069 = lbf/ft.

## Table 4. The MCS for three varieties of sweet cherries for two different harvest seasons

| Har-vest Date | Variety Firmness Measurement, MCS (N/m)* Emperor Francis 1991 | Emperor Francis 1993 | Hedelfingen 1991 | Hedelfingen 1993 | Ulster 1991 | Ulster 1993 |
|---|---|---|---|---|---|---|
| 1 | 1715.2 | 2178.1 | 1653.4 | 1821.1 | 1591.6 | 1744.6 |
| 2 | 1476.9 | 2004.5 | 1446.5 | 1533.8 | 1527.9 | 1771.1 |
| 3 | 1419.0 | 1621.1 | 1358.2 | 1371.0 | 1599.5 | 1688.7 |
| 4 | 1249.3 | 1422.9 | 1307.2 | 1227.8 | 1510.2 | 1587.7 |
| 5 | na† | na | na | 1253.3 | na | 1473.9 |

\* N/m × 0.069 = lbf/ft.

† Only four harvest dates were tested in 1991 for all varieties and in 1993 for Emperor Francis.

**Table 5. Mean, maximum, minimum, and standard deviation firmness values for four blueberry harvest treatments and control, 1992**

| Harvest Treatment | MCS (N/m)[*] | | | |
| --- | --- | --- | --- | --- |
| | Mean | Maximum | Minimum | S.D. |
| Control | 1293.2 | 1884.7 | 902.0 | 179.5 |
| Hand | 740.1 | 1383.1 | 345.5 | 170.9 |
| Mechanical 1 | 519.3 | 967.2 | 179.5 | 151.9 |
| Mechanical 2 | 528.3 | 1120.0 | 290.1 | 161.1 |
| Mechanical 3 | 486.2 | 955.0 | 198.4 | 140.9 |

[*] N/m × 0.069 = lbf/ft.

(50.7 lbf/ft). This represents a 59 to 62% loss from the initial firmness for the mechanically harvested fruit and a 42% loss for hand harvested fruit.

For each harvest treatment a normal probability density function curve was calculated. The probability density function describes the distribution of probability for a continuous random variable for each set of firmness data. The curves were then plotted over the entire range of firmness values measured from the four harvest treatments and the control (fig. 5). Comparing the density curves shows that the mechanically harvested fruit have essentially the same distribution, as opposed to the hand harvested and control fruit. If the firmness measurements of the hand and mechanically harvested fruit had been taken immediately after harvest, the density curves would probably shift toward the control. However, it would probably still be possible to sample lots of fruit for firmness and classify them based on their distribution.

## SUMMARY

The portable instrument for measuring the firmness of cherries and berries was developed to provide a method that could rapidly and automatically quantify firmness. The current software is menu driven and allows the user to easily set variables such as the maximum compressive force. The current hardware is light and portable, and can easily be taken into the field to take measurements.

Tests conducted with the firmness instrument on tart cherries, sweet cherries, blueberries, and strawberries in
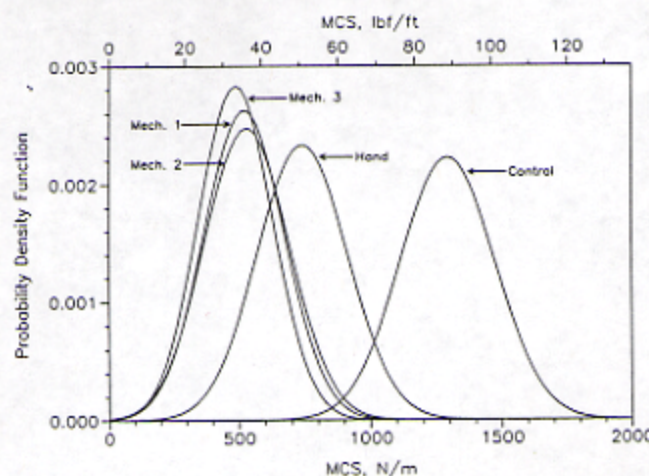


Figure 5–Probability density function curves for the four blueberry harvest treatments and control, following a 10-day storage period [0°C (32°F), 95% RH] and 1-day ambient room temperature [24°C (76°)], 1992.

bruise, maturity, and harvest experiments have shown that the device was able to quantify firmness for each of the experiments. Analysis of firmness data for each of the fruits should be limited to a specific year, however, continued collection of data for a specific fruit may develop year-to-year trends. When testing a specific sample of fruit it should be of consistent size, shape, and temperature. The position of a fruit being tested in the firmness device should be consistent for all fruit. Specifically for cherries, the measurement should be made across opposite cheeks, with the suture parallel and midway between the load cell and compression plates. When testing blueberries, the berry should be positioned so that the curvature of the fruit is approximately the same across each cheek. Strawberries should be of the same size and shape, and the measurement should be taken across either the widest or narrowest portion of the berry. This is typically just below the base of the stem.

## CONCLUSIONS

The following conclusions can be made from this study:
- A portable data-acquisition instrument to measure the firmness of cherries and berries was designed and built.
- The method of measuring firmness is quick and automatic.
- Mean chord stiffness was the best method of describing firmness of a fruit with known bruise treatments, harvest treatments, and maturity levels.
- A specific testing procedure that will provide the most consistent results for each fruit tested with the firmness device is described.
- Additional development of the software is continuing to provide a more user-friendly interface.

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