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AN INSTRUMENT FOR THE BIOYIELD DETECTION AND FIRMNESS MEASUREMENT OF APPLES

By

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ABSTRACT

AN INSTRUMENT FOR THE BIOYIELD DETECTION AND FIRMNESS MEASUREMENT OF APPLES

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The bioyield phenomenon occurs to an apple under compressive loading, which causes initial cell failure without destroying the integrity of the fruit tissue. Force at the bioyield point is useful for nondestructive evaluation of fruit firmness. A portable instrument was developed for measuring the bioyield force of apple fruit. The instrument was tested and evaluated to determine its correlation with the standard Magness-Taylor (MT) firmness tester, measure sensitivity to changes in firmness over time, and quantify firmness variation over the fruit. Bioyield force correlated well with MT force with the R^2 values of 0.835, 0.654, and 0.751 for Golden Delicious, Red Delicious, and the pooled data, respectively. Bioyield force was as sensitive to firmness change over time as MT force (R^2 = 0.990) for apples that underwent accelerated softening. The bottom (the calyx end) of an apple is significantly firmer than the middle and top of the fruit. Moreover, the south face or sunny side of an apple is significantly firmer than the north face or shady side of the fruit. Firmness measurement accuracy improves when measuring opposing sides of an apple to obtain a single firmness measurement. Because bioyield measurements do not degrade the quality of a tested apple, this instrument is useful for measuring the firmness of apples in the orchard, during postharvest handling, and monitoring storage conditions.

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INTRODUCTION

Quality directly affects the ability to store, sell, process, and consume an agricultural commodity. For hundreds of years, humans have used various methods, either subjective or objective, to assess the quality of agricultural commodities. Today, the United States Department of Agriculture (USDA) sets standards to identify and quantify the quality characteristics of each commodity. These standards directly affect the market value, cost to the consumer, and export potential. In addition, local processing facilities and packinghouses may derive their own set of standards to ensure higher quality than those set by the USDA.

Several characteristics determine the quality of apples. Color, size, and shape reflect the outward appearance of the apple. Texture or firmness, acidity, and soluble solids (Brix) reflect the edible portion of the apple. Firmness in particular, is a complex measurement because it characterizes both the texture and maturity of the fruit. Although characteristics reflecting the outward appearance tend to have a greater influence on the value of apples, firmness is of key importance in determining consumer satisfaction. Firmness also serves as an important physiological indicator in determining the best time to harvest a crop of apples. In addition, the ability to monitor firmness will enable packinghouse operators to better control and optimize postharvest handling and storage regimes, thus resulting in improved quality and a consistent supply of apples for the market.

The Magness-Taylor firmness test is the current industry standard method to measure firmness. This test begins by slicing a layer of skin off the equator of the apple and pressing a specially designed probe into the flesh. A force meter measures the amount of force required to penetrate the flesh to a specific depth. This test, invented in 1924, has served the apple industry's needs for several decades but has several drawbacks. For example, a typical packing line today sorts thousands of apples per hour by color, size, shape, weight, defects, and possibly soluble solids content (Brix). These measurements occur with minimal to no intervention of the apple flesh and surface. In addition, computers perform the tasks of measuring and sorting, effectively minimizing the risk of subjective influences and errors. Because the Magness-Taylor test penetrates the flesh, performing this test on every apple is out of the question for real-time sorting operations.

To monitor firmness in a real-time setting for fresh marketing, a device must be capable of measuring the firmness non-destructively. For this reason, researchers pursued the development of non-destructive firmness measurement techniques over the past decades. Several mechanical devices and methods were developed, but they measure different mechanical phenomena or characteristics in comparison to Magness-Taylor and hence may or may not correlate with this standard test. Ababneh (2002) investigated different designs of mechanical probes for the measurement of bioyield force for nondestructive evaluation of apple firmness. Bioyield is a mechanical phenomenon that takes place in many plant products during compression testing. Measuring bioyield involves detecting a sudden drop in compressive force while displacement continues to increase in a test. This drop in force indicates initial damage to the cellular structure. Ababneh (2002) applied the Hertz contact theory to evaluate the interaction of a rubber tip to the curvature of an apple to improve the accuracy and sensitivity of measuring the point at which bioyield occurs. His research provided guidelines for the design of a bioyield probe including the diameter, thickness, and elasticity of the rubber tip, to measure the bioyield point effectively.

The measurement of bioyield has several benefits. First, a properly designed instrument may leave a small indentation on the outside of the apple, but would be well within the confines of the USDA grading standards definition of injury. This is critical for achieving the goal of non-destructive measurement of individual apples. Second, since the bioyield measurement would not degrade the fruit, the method could be potentially useful for online sorting of individual fruit. In addition, the potential to add a bioyield tester to a robotic harvester could enhance precision agriculture techniques by measuring the firmness of on-tree apples. This would benefit the apple industry by selectively picking or sorting apples in the orchard. Finally, because the bioyield test measures the strength of the cellular tissue, it may correlate with the Magness-Taylor test better than other non-destructive mechanical tests. As a result, bioyield measurements could replace or co-exist with Magness-Taylor as a testing standard.

Therefore, the overall objective of this research was to design and build a portable bioyield instrument that can operate stand-alone or via computer for the measurement of bioyield force from the apple and evaluate the performance of the instrument for measuring apple fruit firmness in comparison with Magness-Taylor test. Specific objectives of the research were to:

1. Design and build a low-cost, portable instrument to automatically measure bioyield force from apples;

2. Determine the correlation between bioyield measurements and Magness-Taylor test for apples that came from normal postharvest storage conditions (i.e., air refrigeration and controlled atmosphere);

3. Compare bioyield measurements with Magness-Taylor firmness test to determine their sensitivity to the physiological change in apples with time; and

4. Evaluate firmness variation across the surface of the apple to determine an appropriate bioyield or firmness measurement procedure.

LITERATURE REVIEW

The quality of fruit comprises many properties and characteristics including color, size, shape, weight, flavor, texture or firmness, and aroma. The methods used to distinguish differences between samples based on these characteristics can be subjective or objective. Humans routinely perform subjective evaluation of fruit quality using their five senses. Subjective evaluation is often inefficient and prone to biased measurements between individuals, variations of judgment over time, and general human error (Harker, *et al.*, 1996). Objective instrumental methods, on the other hand, reduce human intervention, which minimizes subjectivity and human induced error when grading fruit quality. In addition, the implementation of standardized quality measurement methodologies would provide a common ground for comparison and promote universal acceptance.

Currently, destructive assessments are routinely performed on small samples to obtain a statistical indicator of the overall quality of the lot. However, the quality of individual fruit may differ greatly and the destructive sampling methods cannot reflect the quality or condition of individual fruit. To maximize quality of a lot, fruit packers need to examine and assess every individual fruit within the lot. Nondestructive measurement is thus critical to providing high quality, consistent fruit to the marketplace.

Subjective Versus Objective Testing Methodologies

Some subjective methods are relatively simple. These include visual inspection, tapping, biting, tasting, and squeezing a fruit or vegetable. These methods can serve as good indicators but because they involve a particular individual's knowledge, skill, and decision, they may not be universally accepted. Differences in an individual's background may influence the measurement of the crop's quality.

To minimize subjectivity, tools such as a ruler, color chart, and Effegi tester (a variant of the Magness-Taylor tester) can increase the measurement accuracy for dimensions, color, and firmness. Even these tools are prone to subjectivity. For instance, firmness measurement with a handheld Magness-Taylor tester is subject to operational error because the speed of penetration will affect the firmness reading. A well-developed objective measurement method will nearly eliminate human intervention all together. For example, instead of using a color chart to grade the color of apples, a color camera attached to a computer will grade color based on actual measurements and proven models. Similarly, a laser array or camera system can accurately quantify a commodity's dimensions. Finally, firmness may be measured with a texture analyzer or similar tool.

Structural and Mechanical Properties of Apple Flesh

Apples, a climacteric fruit, undergo several biochemical and physiological changes during maturity and ripening (Harker, *et al.*, 1997). The respiration rate and production of ethylene increases as starches convert into sugars (Reid, 2002b). Physically, as an apple matures, its texture begins to soften. As a result of this natural biochemical process occurring, firmness acts as an indicator for the quality, storage potential, shelf life and harvest date.

The measurement of firmness in apples has been a relatively difficult task when comparing to other quality characteristics. This is because firmness reflects the complex structural properties of the fruit. Moreover, firmness is not a well-defined textural attribute and different people may define and interpret the firmness differently. For example, food scientists may evaluate fruit firmness using a sensory evaluation method, while horticulturists often use penetration tests, such as Magness-Taylor, to measure the firmness.

An apple fruit has a complex cellular structure. The skin acts as a protective barrier between the outside environment and the flesh. The skin is comprised of dry, flattened cells (Clevenger and Hamann, 1968). The flesh of an apple is anisotropic (Abbott and Lu, 1996) and consists of elongated cells aligned in a radial fashion from the central core of the apple towards the skin. Cell sizes vary depending on the distance from the core of the apple. Cells generally increase in size as the distance from the core increases. In addition, between the cells are air pockets that make up as much as 40 percent of the entire apple's volume (Vincent, 1989). As an apple matures and ripens the number and size of these air pockets increase (Seymour *et al.*, 1993). Finally, the core of the apple contains a group of seeds, which have the potential for growing a new tree if planted.

Each cell contains cytoplasm surrounded by a rigid cellular wall. Initially, a small load placed on a group of cells causes a small level of reversible deformation. During this initial loading, the fluid pressure within each cell (turgor pressure) increases. As a load continues to increase beyond the cellular wall loading capacity, the cell may burst. This initial tissue failure, indicated by an initial peak in the stress-strain diagram, represents the bioyield point.

After the apple cells begin to burst, the cytoplasm leaks into nearby air passages and may force into nearby cells because of the increased turgor pressure. As loading increases, the ruptured cell walls flatten and begin to press on subsequent lower layers of cells. A series of successive bioyield points may occur before failure (Jeong, 1997). Failure occurs when the apple's structure can no longer withstand the increased load on its cellular structure. Segerlind and Fabbro (1978) reported that apple flesh fails when exceeding a critical normal strain value. This critical strain value ranges between 0.10 and 0.15.

Because an apple is comprised of cytoplasm-filled cells, when compressed, the apple behaves like a viscoelastic material or a material having both fluid- and solid-like properties. As a result, the rate at which the apple is loaded becomes critical (Steffe, 1996). For example, an increase in test speed may result in a higher force reading than that of a slower test speed. Maintaining consistency of load rate will ensure uniformity of measurement between samples.

Models play an important role to help understand and describe the physical nature of apple flesh. De Baerdemaeker and Segerlind (1976) used a Maxwell model (springs and dashpots) to describe the behavior of the flesh. Ababneh (2002) used finite element analysis to study the mechanical behavior of the flesh and design a probe tip for the detection of the bioyield point.

Magness-Taylor Firmness Test and Variants

Modern objective testing of apple firmness started in 1924 with the introduction of the Magness-Taylor test (Magness and Taylor, 1925). The test starts by removing a layer of skin from the apple and pressing a steel probe into the flesh. The probe has dimensions 11.11 mm (14/32 inch) in diameter with 8.73 mm (11/32 inch) radius of curvature at the point of contact. In addition, a mark 8.73 mm (11/32 inch) on the edge of the probe indicates the depth of probe penetration into the flesh to complete the test. A force meter attached to the probe indicates a numerical reading of the apple's firmness in units of Newtons (or pounds of force). It is recommended that the operator press the probe into the flesh to the depth indication mark in two seconds to improve test consistency by controlling the testing speed (Abbott and Harker, 2004).

There are several variants of the Magness-Taylor testing device depending on the degree of accuracy required for testing. The simplest and least accurate of these instruments is the Effegi handheld device (Abbott *et al.*, 1976; Harker *et al.*, 1997). It features the standard Magness-Taylor probe design with a mechanical force meter. In addition, a dial within the force meter holds position at the maximum force achieved during testing. The handheld Effegi device is commonly used because of its low cost and portability. Subjective errors run high in this configuration but the portability and ease of use make this device convenient for fieldwork and rough estimation of crop quality. An alternate use of the Effegi device involves clamping the instrument to a "drill press" or vertical rack and pinion gear set. This reduces variations in testing by providing vertical stability and a simple gear reduction, improving operator control over penetration depth and speed.

Modern versions of the Magness-Taylor device use the standard probe tip connected to a load cell to electronically measure force. Using a stepper or servo motor, the probe tip drives into the apple flesh. This mechanism achieves complete control over testing speed and penetration depth. The Instron universal testing machine is an example of this type of device (Holt, 1970). It provides a diverse platform for materials testing. This device nearly eliminates all subjective error while recording test data for future analysis. The Stable Micro Systems texture analyzer (Stable Micro Systems, Surrey, United Kingdom) operates like the Instron universal testing machine but is smaller and has a testing range specific to food textural properties.

Because of the measurement error associated with Magness-Taylor test and the inherent firmness variations across the face of an apple, it is often difficult to achieve a high degree of correlation (e.g., R-squared > 0.9) between the Magness-Taylor test and an alternative firmness test. A study conducted by Ababneh (2002) yielded an R-squared value of 0.8446 when comparing Magness-Taylor measurements from two opposing locations on the same apple

Nondestructive Compression Tests

Several nondestructive mechanical tests have been developed for fruit firmness measurement in the past. The mechanical thumb, developed in the early 1960s was an early variant to the Magness-Taylor test (Schomer, 1962). This device used a plunger and sleeve mechanism to limit the penetration depth. Upon achieving the preset penetration depth, an electrical contact closed, illuminating a flashlight. Next, the operator records the force from the attached force meter. This test imposed a slight indentation but yielded measurements comparable to the Magness-Taylor testing method.

Another device, developed and produced in Japan called the HIT (Hardness, Immaturity, and Texture) counter, measures firmness with minimal destructive effects. In contrast to the Magness-Taylor tests and variants, the HIT counter measures the time required to obtain a specified load within the elastic range of the fruit (Takao, 1994). When using the HIT counter device, firmer fruits result in a longer measured time than that of softer fruits. An online version of this instrument provides quick and accurate fruit sorting capabilities while a lightweight, handheld version of the HIT counter allows easy measurement of firmness in the field.

One method replicates an optometrist's glaucoma test. A jet of air applies a force on the apple's surface while a laser measures the deformation (Prussia *et al.*, 1994). This test measures the resulting displacement to a constant force or pressure. A similar test measured deformation using two air jets on opposite sides of a peach (Perry, 1977). When the air jet applies a force to the apple, it deforms within the apple's elastic range and no bruising or damage will occur.

The mechanical thumb, HIT counter, and glaucoma test variant try to measure firmness within the fruit's elastic range. Within this range, the fruit can undergo firmness testing without permanent damage (Abbot *et al.* 1995). However, to prevent damage to the fruit, the deformation for these tests must be small. This could cause error in measurement since the surface of the fruit is curved and the size of fruits varies. In addition, these mechanical tests essentially measure the elastic properties of fruit, which are different from the destructive Magness-Taylor measurement of the composite failure strength of the fruit tissue. Consequently, these nondestructive mechanical tests may not correlate with Magness-Taylor test well.

Bioyield Tests

Mohsenin *et al.* (1965) proposed a concept of using bioyield point as a measure of apple fruit firmness. They reasoned that bioyield could be a better indication of fruit firmness than measuring the elastic properties because bioyield goes beyond the elastic range but does not result in the rupturing of the fruit tissue. They developed a bioyield tester using a rigid steel probe. According to Ababneh (2002), the rigid probe would produce a nonuniform stress distribution within the contact area, thus causing gradual failure of the tissue. This gradual tissue failure makes the detection of bioyield point more difficult and tends to increase measurement variability.

With the advent of computerized measurement techniques using sensitive force meters and mechanized sample actuators, methods to detect and evaluate the bioyield point have improved. Ababneh (2002) applied the Hertz contact theory to develop a rubber tipped probe, which manifests the occurrence of the bioyield point and improves its detection. Lu *et al.* (2006) reported that a rubber tipped probe with the elastic modulus comparable to that of the apple would be desirable for producing uniform stress within the contact area. In addition, the rubber tipped probe correlated well with Magness-Taylor measurements but may be less sensitive in determining the effects of storage time on fruit condition for apples that were stored in elevated or room temperature environments (Lu *et al.*, 2005).

Other Non-mechanical Firmness Measurement Methods

Over the years, many other nondestructive methods have been developed for measuring fruit firmness. Impact methods involve dropping the fruit onto a transducer or vice-versa, dropping a transducer to strike the fruit. Delwiche *et al.* (1989) developed a method to sort peaches and pears by measuring the peak force and the time required to obtain the force from the resulting impact. Fruit firmness is determined using the equation F/t^2 were F is the peak force and t is the time required to obtain the force. Ultimately, this method correlated to the fruit's modulus of elasticity. A properly performed test imposes no damage to the fruit. More recently, Ruiz-Altisent and Ortiz-Canavate (2005) built and tested an online impact device for sorting and grading fruit firmness, based on the original design by Chen and Tjan (1996). A commercial impact sorting system has been recently available, but it has low correlation with Magness-Taylor firmness measurement for apples (Shmulevich *et al.*, 2003).

Acoustic vibration techniques involve applying a range of vibration frequencies into the fruit and measuring the vibration response. Typically, a speaker or similar driver induces the vibration into the fruit while a piezoelectric accelerometer measures the response. This method requires good contact between the apple and the driver and accelerometer equipment. The equation $f^2 m^{2/3}$ quantifies firmness, where f is the second resonant frequency and m is the mass of the apple (Abbott *et al.*, 1995). This test imposes minimal or no damage to the apple.

Electromagnetic energy based methods such as near-infrared spectroscopy and multispectral scattering involve exposing the apple to light source in the visible and near-infrared region. Near-infrared spectroscopy can detect soluble solids content in an online setting (Abbott *et al.*, 1997), but it still cannot measure fruit firmness accurately (Lu *et al.*, 2000; McGlone and Kawano, 1998). The multispectral scattering technique (Lu, 2004; Peng and Lu, 2006) is promising for assessing, sorting and grading apples for firmness. However, the technique is still expensive and would be more suitable for online sorting and grading of apples in the packinghouse.

Testing Standards

The United States Department of Agriculture (USDA) and the American Society of Biological and Agricultural Engineers (ASABE) set standards to unify national testing and grading methodologies. ASAE Standard S368.4 “Compression Test of Food Materials of Convex Shape” (ASAE, 2000) describes standard testing procedures for testing materials with an intact convex shape and half-convex shape. The standard recommends probe sizes, loading rates, equations for calculating the modulus of elasticity. In addition, the standard suggests a loading rate of less than 10 mm/min, at which the bioyield point could easily occur.

USDA Standards 51.300 – 51.322 “United States Standards for Grades of Apples” (USDA Agricultural Marketing Service, 2002) outlines the definitions of each quality grade level, requirements for packing and marketing, definitions of quality issues, and export standards. Standard 51.316 specifically outlines the definition of injury, which is important when defining a firmness measurement technique as non-destructive.

USDA Agricultural Handbook 66 “The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks” (USDA, 2004), outlines quality measurement techniques, postharvest pathology, commodity safety, and optimal storage conditions. In addition, commodity specific information in the commodity summaries section provides even more details about common problems and recommendations while in harvest, transport, storage, and sale.

Summary

Quality defines the value of a commodity. Subjective influences may lead to inconsistency between measurements and individuals, misinterpretation of measured results, and erroneous measurements. Objective measurement techniques minimize human influences and provide a higher degree of measurement accuracy. Developing objective measurement techniques requires a complete understanding of the quality characteristic involved and technology required to measure it.

Firmness not only provides an estimation of an apple's internal structure or hardness, but it also serves as an indicator of the apple's maturity, storage potential, postharvest quality, and shelf life. A firmness measurement device for apples must take into account the viscoelastic behavior and physical structure of the fruit to achieve accurate measurements. Several of the practical methodologies used today including the HIT counter and Effegi device provide rough estimations of firmness while remaining portable for use. Elaborate laboratory devices measure Magness-Taylor force using a load cell, actuation drive, and a computer. The size, necessity to remain level, and no or minimal vibrations make laboratory devices difficult for field application. In addition, a majority of the accepted firmness measurement methods are destructive in nature. This prevents the testing of the same fruit in several locations or over long periods.

A practical device for the future of firmness measurement should be non-destructive (as defined by USDA apple grading standard 51.316 for injury), portable, light weight, capable of computer connectivity, include an actuation drive, and act as a stand-alone unit. The device should minimize human intervention and potential sources for error. Finally, a new device should relate well with current industry standardized measurements. This will promote universal acceptance and improve general use.

MATERIALS AND METHODS

Previous research (Ababneh, 2002; Lu *et al.* 2005) showed that bioyield measurements correlated with the industry standard Magness-Taylor tests. The method is nearly non-destructive and potentially useful for assessing fruit maturity in the orchard and for measuring and monitoring the firmness of apples after harvest and/or during storage. Hence, a device specifically designed for bioyield measurement should improve measurement efficiency and reliability, and ease of field use. Specifically, the following criteria were considered in designing the bioyield measurement instrument:

- Non-destructive test: The instrument must measure the firmness of apples without imposing value-degrading damage to the fruit as specified by USDA standards for injury due to bruising (<3.18 mm or 1/8″ deep, <15.9 mm or 5/8″ diameter).
- Minimal error from subjectivity: The instrument must conduct measurements with minimal human intervention as possible.
- Low cost design: The current industry standard Magness-Taylor test using the Effegi handheld instrument is very low in cost compared to other modern methods. A low cost instrument would have greater acceptance as a replacement to other firmness measurement devices.
- Ease of operation: A wide spectrum of users must be capable of operating the device. These users may include field workers, quality inspectors, and laboratory researchers.

- Portability and ruggedness: To accommodate field operation, the instrument must be capable of performing measurements in a wide range of environments. Common locations of measurements will include the field, laboratory, and storage facilities. These locations expose the instrument to various levels of dust, humidity, temperatures, and atmospheric environments. In addition, the instrument must be capable of taking several measurements on a daily basis without a direct power connection. Finally, the device must be rugged enough for transport and accidental dropping.
- Computer connectivity: The ability to connect to a computer expands the range of operation for the consumer as well as the researcher. The device must have the capability to monitor real-time data when measuring as well as download measurements from stand-alone field operations.

Design Details

The bioyield instrument's design includes four main components (Figure 3.1). These include the force meter, actuation drive, control module, and software components.

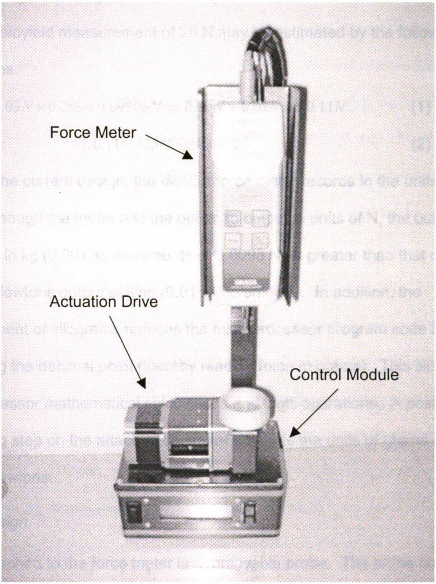


FIGURE 3.1: Bioyield Instrument Design and Component Descriptions

Force Meter

A commercial force meter (IMADA DPS-11R, Imada, Inc., Northbrook, IL) measured force up to 49.03 N with a resolution of 0.01 N. The accuracy of this device is ±0.2% of full scale ±1 least significant digit (0.01 N). Maximum error occurs when the force meter reaches its maximum load capability of 49.03 N and off by one significant digit. The accuracy of the force meter and the maximum error to a bioyield measurement of 25 N may be estimated by the following calculations:

$$49.03N \times 0.2\% = 0.09806N \Rightarrow 0.10N + 0.01N = \pm 0.11N \,. \qquad (1)$$

$$\pm 0.11N / 25N = \pm 0.44\% \qquad (2)$$

In the current design, the IMADA force meter records in the units of kg of force. Although the meter has the option to output in units of N, the output resolution in kg (0.001 kg increments or 0.0098 N) is greater than that of the device's Newtons output setting (0.01 N increments). In addition, the measurement of kilograms reduces the microprocessor program code by eliminating the decimal point (thereby reading force in grams). This simplifies microprocessor mathematical calculations and logic operations. A post-processing step on the attached computer converts the units of grams of force back to Newtons.

Probe Design

Attached to the force meter is a removable probe. The probe consists of two parts, the steel threaded shaft and a rubber tip. Using design guidelines from the research conducted by Ababneh (2002), the rubber tip thickness equals one half that of the tip diameter. A tip of 6.35 mm (1/4") in diameter and thickness of 3.18 mm (1/8") provided optimal results. In addition, the design guidelines stated that the elastic modulus of the rubber should not exceed twice that of the apple. A rubber tip of optimized elasticity minimizes the budging effect when the rubber tip is in compression. Overall, the recommended tip design minimizes stress concentrations and improves surface contact, effectively improving the accuracy and sensitivity in detection of the bioyield point.

Selecting the final design involved comparing several rubber tipped probes. Each probe consisted of a steel threaded base with a piece of polyurethane rubber with the suggested dimensions of 6.35 mm (1/4 inch) diameter and 3.18 mm (1/8 inch) thickness. The rubber pieces vary in color (Figure 3.2) and elasticity (Table 3.1) depending on the polyurethane composition.

Rubber is quantified using a shore durometer hardness test. The bioyield instrument tips were constructed from rubber pieces ranging from a shore A, number 30 (soft) to a shore D number 60 (hard). These rubber pieces are linearly elastic within a small range of compressive deformation, as shown in Figure 3.3. Given each probe tip's durometer hardness, tests were conducted to determine the equivalent elastic modulus. Table 3.1 summarizes the elastic modulus values determined from the compression tests conducted at room temperature (~22 °C).

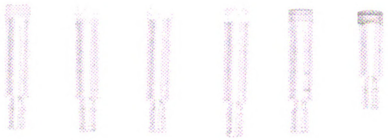


FIGURE 3.2: Probe tips of varying firmness (30A, 40A, 50A, 60A, 70A, and 75D).

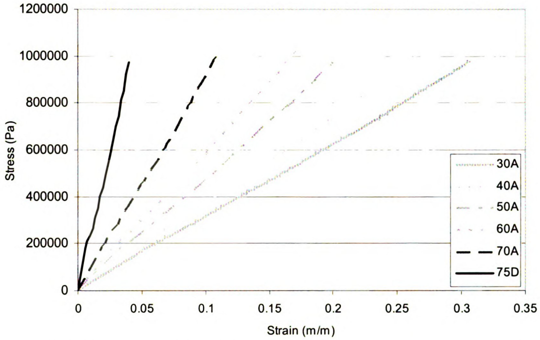


FIGURE 3.3: Plot of stress versus strain for 6.35 mm or 1/4" rubber probe tips of varying elasticity.

TABLE 3.1: Measured rubber tip elastic modulus.

Polyurethane Rubber Type	Polyurethane Rubber Sample Color	Elastic Modulus (MPa)
Black Rubber		6.048
30A	Orange	3.140
40A	Light Blue	3.700
50A	Yellow	4.790
60A	White (Clear)	5.880
70A	Blue	9.060
75D	Black	23.55

After evaluation of each rubber tipped probe, the final design selection consisted of the yellow, shore A, number 50 polyurethane rubber tipped probe. This tip had an elastic modulus of 4.790 MPa. The range of the elastic modulus values reported for 'Golden Delicious' and 'Red Delicious' apples was between 3.35 MPa and 9.10 MPa (Mohsenin, 1986). Ababneh (2002) used the elastic modulus of 4.01 MPa for the model apple in the finite element simulation of the bioyield test. In view of these and the requirements for a probe tip proposed by Ababneh (2002), this particular probe tip design was appropriate.

Actuation Drive

The actuation drive serves two main purposes. First, it provides a constant rate of displacement by actuating the apple vertically at a user-configured fixed speed. Second, the rack and pinion housing acts as a structural support arm for the force meter and connection block for the gearbox and motor assembly. The gearbox increases displacement resolution while minimizing step vibrations.

The actuation drive begins with a NEMA size 23 hybrid stepper motor (SST58D, Shinano Kenshi, Culver City, CA). This motor features 200 steps per revolution or 1.8 degrees of rotation per step. Each phase of the motor requires 6.2 volts to operate and can achieve 7.6 kg-cm of holding torque. Using a unipolar drive mechanism, the motor achieves half step increments. This allows finer movement of 400 steps per revolution or 0.9 degrees per step. Finer steps improve the fluidity of actuation while lowering overall actuation speed.

Stepper motors have the benefit of precision rotational speed control when comparing to standard DC motors (assuming no feedback control). By powering the four coils of a stepper motor in the correct order, the motor begins to turn. The cycle rate of powering each coil in sequence directly corresponds to the motor shaft speed. Stepping the motor at slower speeds causes the motor rotation to become less smooth due to longer hold times for each step. Increasing speed or switching to a half-step motor sequence improves the fluidity of motion. Extremely high actuation speeds may lead to missed steps or loss of position accuracy. The design of the actuation system balances motion fluidity and position accuracy while conducting bioyield measurements.

The output of the motor connects to an anti-backlash coupling. This prevents torsional wind-up between the motor and the input shaft of the gearbox. Two aluminum blocks surround the coupling, securely joining the motor to the gearbox.

A NEMA size 60 gearbox serves three main purposes. First, the rotational output of the stepper motor in a unipolar drive mode lacks enough torque to drive the rack and pinion directly during a test on an apple. The gear reduction ensures high torque availability throughout the testing process. Second, the gearbox effectively increases measurement resolution by increasing the number of motor steps required for a single revolution of the gearbox output. In a half-stepping, unipolar drive mode, the motor must travel through 400 steps for a single rotation. With the 12.5 to 1 gear reduction attached, the motor must perform 5000 steps for a single rotation on the output of the gearbox. Finally, the gear reduction aids in smoothing the output from the stepper motor. With gear reduction, each step has a smaller effect on the vertical movement of the final rack and pinion drive. Without a gearbox, each step would have 12.5 times greater vertical movement for each step performed.

The final output of the actuation drive is the rack and pinion gear set. This transfers rotational motion from the gearbox output into vertical motion. A "cup", mounted to the top of the rack gear, holds the apple while testing. The final output from motor to vertical movement is 0.00647 mm of travel per half step of the motor.

ASAE Standard S368.4 (ASAE, 2000) recommends a testing speed of 10 mm/min or less to observe the bioyield point of an apple. Considering the torque load necessary to operate a bioyield test and the motor speed necessary to minimize the stepping effect, the instrument performs a bioyield test at a speed of 3.65 mm/min.

Control Module

The control module consists of four main components, the housing, electronics, user interface, and battery. The housing protects the internal components from damage and various environmental conditions the device may encounter. It also aids in safety by enclosing the potentially dangerous electrical components and battery from human contact. Finally, the housing acts as a base for the actuation drive and force meter frame.

A Parallax Basic Stamp 2p24 microcontroller serves as the core of the onboard electronics. This Basic Stamp microcontroller consists of a microprocessor, EEPROM memory chip, voltage regulator, and input/output pins. This microcontroller is responsible for controlling the stepper motor, monitoring the IMADA force meter readings, communicating with a connected computer, storing test data, and displaying information on the liquid crystal display. A custom-built printed circuit board (PCB) made all necessary electrical connections between the Basic Stamp microcontroller, onboard electronics, and external hardware (Figure 3.4).

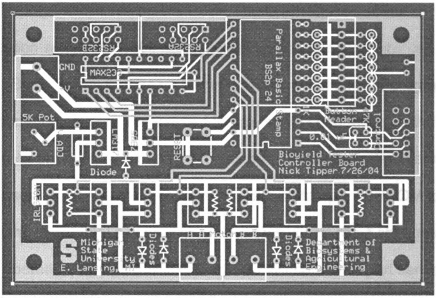


FIGURE 3.4: PCB Design for the bioyield instrument's electronics.

The Basic Stamp has direct control over each of the four motor coils to control the stepper motor. The program code determines the order to power each coil (motor rotation) and the power cycle rate of each coil (motor speed). To accommodate the motor's electrical requirements, four IRL520N MOSFET (Metal Oxide Silicon Field Effect Transistor) transistors power each motor coil with 6.2 volts. A TTL level signal from the Basic Stamp provides enough power to trigger each MOSFET.

To enable serial communications between the IMADA force meter and the basic stamp, a MAX233 RS-232 driver converts TTL level (0 Volt to 5 Volt) serial signals to RS-232 levels (-12 Volt to +12 Volt) and vice versa. The Basic Stamp communicates with the IMADA force meter using communication settings of 2400 baud, no parity, and one stop bit. In addition, the same MAX233 driver enables serial communications to the liquid crystal display (LCD). This allows the Basic

Stamp to display information on the LCD. The LCD requires serial communication settings of 4800 baud, no parity, and one stop bit.

The Basic Stamp features a single onboard serial port for programming and data communications. A recessed female serial connection on the rear of the instrument provides direct access to this port. This connection serves three main purposes. First, the port accesses the Basic Stamp's EEPROM to reprogram the instrument's control program. This allows rapid changes to variables, operation, and performance aspects. Second, the port sends real-time data during test execution. A computer attached to the instrument can monitor the data in real time with a simple terminal program with communication settings of 4800 baud, no parity, and one stop bit. Finally, in stand-alone operation mode, the port provides a method to retrieve collected field data.

The front of the control module features a rocker switch, a Crystalfontz 632 16x2-character liquid crystal display, and two red momentary switches. The display enables stand-alone operation by granting the operator access to performance variables, mode settings, and operational controls. The operator can view current settings or access control features by pressing the rocker switch. To act upon the variables or settings displayed on the LCD, the operator must press the corresponding red momentary switch. Special characters on the edge of the screen including arrows, blocks, plus and minus signs, and triangles, provide the operator suggestions of how button operations will affect the instrument operation. The Basic Stamp houses the code responsible for building the system of menus, which simplifies operation of the instrument.

Housed in a foam padded metal frame, a sealed lead-acid 12-volt battery (gel-cell) makes up the last component of the control module. The battery provides enough power for several hours of use and makes the instrument truly portable. A plug on the left side of the instrument allows the connection of a charger for the battery or external 12-volt source.

Software

Three components make up the software necessary to control and monitor the instrument and conduct data analysis. The first piece of software consists of two programs residing within the Basic Stamp microprocessor. The second piece of software is a Microsoft Excel spreadsheet with an embedded Active-X control. Finally, a virtual instrument program written with National Instruments LabVIEW software performs post processing mathematics.

The first of the two Basic Stamp programs is responsible for building menus and settings for easy operation of the instrument. Specific addresses on the onboard EEPROM (Electronically Erasable Programmable Read Only Memory) allow settings to remain after powering the instrument off. This program also ensures operational variables transfer to the second program successfully.

The second program's sole responsibility is to operate the bioyield test. This involves monitoring the user input buttons, which initiate the test and begin vertical actuation of the apple. After initiation of the test, the apple actuates quickly to the rubber tipped probe until contact occurs. Upon contact, the actuation speed drops to the designated test speed where the following events occur. First, the microprocessor reads the force from the IMADA force meter. Second, the microprocessor sends the reading to a connected computer for real-time monitoring. Next, a comparison of the current force to the prior force reading determines if bioyield has occurred. Finally, the motor actuates a single step and pauses for a set time. The pause relates to the desired test speed. These events loop until bioyield detection occurs. Upon detection of the bioyield point, the results are saved to the onboard memory and the actuation drive resets for the next test. In addition, the LCD displays the results to the operator.

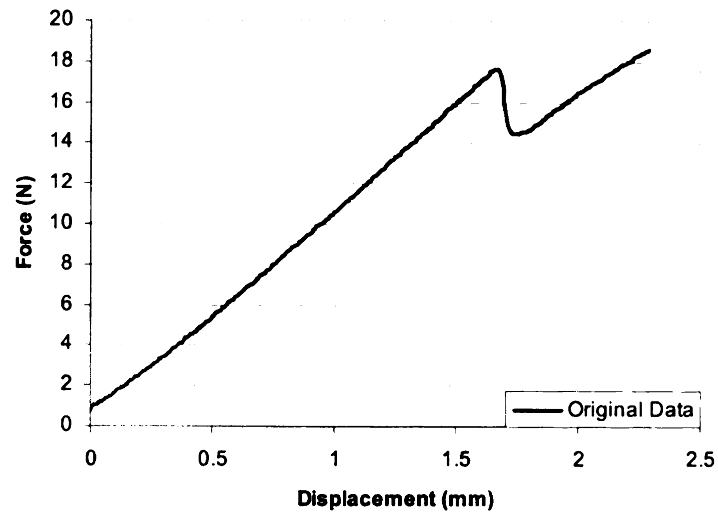
The StampDAQ software package forms the basis for real-time data acquisition between the bioyield instrument and a computer. This software, freely accessible from Parallax, uses an Active-X control within a macro, embedded in a Microsoft Excel spreadsheet. StampDAQ provides a simple solution to collect serial data between a Basic Stamp microprocessor and an attached computer. Several modifications to the original code simplify post processing, accommodate multiple bioyield tests, and provide the user with real-time information while testing.

The final piece of software called a virtual instrument, designed with National Instruments LabVIEW software, reads data collected from the StampDAQ Excel spreadsheet and performs post processing mathematics, statistics, and analysis. Analysis steps include the removal of points below a designated threshold force level. This removes effects of incomplete contact between the probe tip and apple. Using linear regression between the remaining points and the bioyield point, the line is extended from the starting 0-force, 0-

displacement point. Finally, the effects of the rubber are removed by applying the results of linear regression on the rubber force-displacement curve to the curve created by the test on the fruit. This compensates for the displacement of the rubber tip based on the force at each data point. Figure 3.5 graphically demonstrates the three-step data processing procedure used in the software.

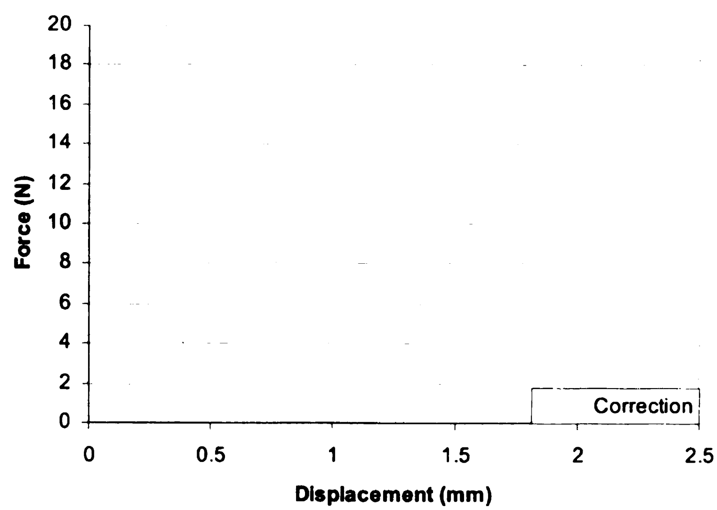
Step One:

The LabVIEW Virtual Instrument removes the initial erroneous points in the data set due to incomplete contact between the probe tip and apple. The Virtual Instrument removed points below the designated threshold of 5 N in this example.



Step Two:

The data set receives an extension to 0 mm displacement – 0 N force using linear interpolation from the 5 Newton threshold to the bioyield point. Next, the removal of points beyond the maximum drop after the bioyield point cleans up the data plot.



Step Three:

The last step involves removing the effects of the rubber. The use of linear interpolation applied to the rubber tip's force-displacement curve allows the prediction of rubber displacement at a given force level. The application of this formula corrects the displacement of each data point on the apple's force-deformation curve.

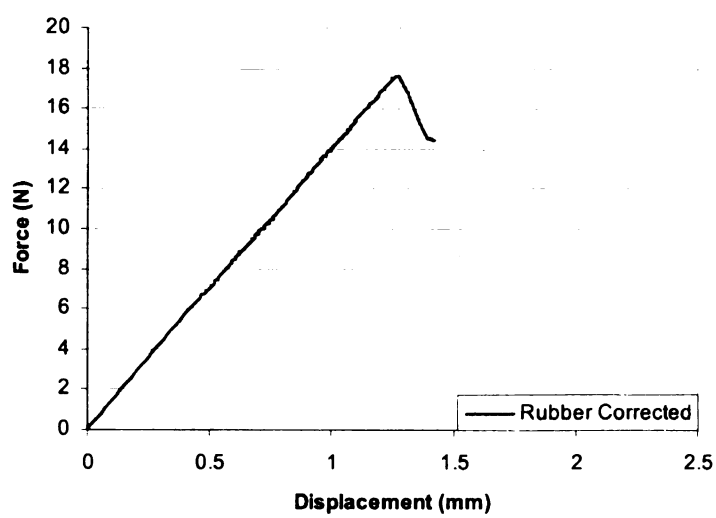


FIGURE: 3.5: Data processing steps.

The National Instruments LabVIEW virtual instrument computed all parameters for each test (Fig 3.6). These parameters included the bioyield force, displacement to bioyield force, slope of the force-deformation curve, drop in force after bioyield detection, and area under the force-deformation curve. Additionally, the virtual instrument compiled Magness-Taylor data allowing the comparison of Magness-Taylor force to each corresponding bioyield force measurement. Because the data from the Magness-Taylor and bioyield tests came from two separate testing sources, a processing step of the virtual instrument compiled every test into single spreadsheet. This simplified statistical analysis for use in spreadsheet programs such as Microsoft Excel or other analysis packages.

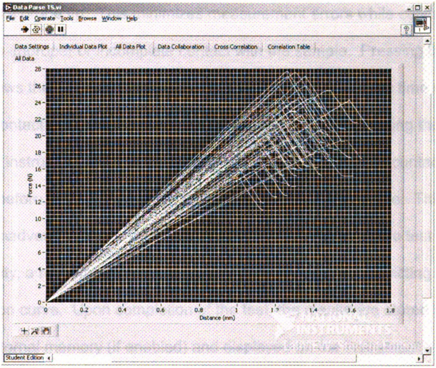


FIGURE 3.6: National Instruments - LabVIEW Student Edition parsing and analyzing collected data.

Bioyield Probe Operation and Procedures

Performing a bioyield test is relatively easy. The instruction menu for operating the bioyield tester is given in Appendix A. The initialization steps involve connecting the serial cable and loading the StampDAQ software on a computer (if desired), installing an appropriate probe tip based on the test sample, and turning the probe's power on. Next, adjustments to the settings enable serial communications, designate testing speed, and log data to the probe's internal memory.

After all initialization settings and procedures are completed, an apple is loaded into the test cup. To make adequate contact between the sample and the probe tip, rotate the apple until a flat or semi-flat surface is normal to the instrument's probe tip. This minimizes measurement errors while conducting the test due to improper or incomplete contact with the sample. Pressing the "JOG" button allows the operator to raise the apple rapidly to reduce the time required to make contact between the probe and the apple. Finally, pressing the "RUN" button the instrument initiates the testing sequence. If the apple contacts the probe tip before testing begins, the test stops and returns to home. This prevents inadvertent starts, which could result in faulty data. If the test starts successfully, a real-time plot draws on an attached computer depicting the force-deformation curve. Upon completion of the test, the results are stored in the probe's internal memory (if enabled) and displayed on the instrument's LCD. Meanwhile, the probe's actuator returns to the home position.

Magness-Taylor Testing

During the instrument validation experiments, several apples received Magness-Taylor firmness measurements using a Stable Micro Systems TA.XT2 texture analyzer. The analyzer records both peak force and force-displacement area (energy) measurements following test completion. This system is a standardized platform for the bioyield comparison. The texture analyzer uses a Magness-Taylor probe attached to 25 kg force transducer, mounted to a vertical actuator. The actuator, driven by a computer controlled motor, controls the test speed and penetration depth to minimize operator influences during testing.

Conducting a test on the Stable Micro Systems texture analyzer consists of three steps. First, removal of the skin eliminates its effect on firmness measurement when the probe penetrates the apple's flesh. The operator uses a horizontal slicer to remove the skin to a depth of approximately 3 mm. Next, the apple is loaded with the open flesh facing the Magness-Taylor probe. Placing the cut face perpendicular to the vertical probe enhances measurement accuracy. Finally, a command issued by the attached computer initiates testing. The texture analyzer drives the probe into the apple flesh at a speed of 2 mm/s, while providing real-time feedback to the attached computer. The resulting force/displacement curve from the test undergoes further processing to determine the peak force obtained, and the force-displacement area.

Bioyield Tests of Fruit Firmness

Three experiments were conducted to evaluate bioyield measurement effectiveness, instrument capabilities, and enhanced measurement techniques. Specifically, these experiments include a comparison of Magness-Taylor testing method to the bioyield testing method, monitoring changes in bioyield force versus Magness-Taylor force over time, and quantifying variations in bioyield firmness over the face of apples.

All tests were conducted at room temperature (~22 °C). In addition, all apples remained at room temperature for a period of at least 12 hours before testing started. This ensured the apple temperature reached equilibrium with the testing environment after removal from storage.

All bioyield tests started with rubber tip calibration. This step involved measuring the elasticity of the rubber tip by displacing a cylindrical steel probe against the rubber tip. Post-processing mathematics used the data collected from this step to compensate for the displacement of the rubber for each apple test. Additionally, this calibration procedure compensated for factors affecting the performance of the rubber tip at the time of the testing including temperature, wear, and humidity.

Bioyield vs. Magness-Taylor Comparison

The first experiment conducted from January 20, 2005 through February 25, 2005, compared the results of the bioyield instrument's tests to the results of Magness-Taylor tests. The samples consisted of 650 Red Delicious and 650 Golden Delicious apples (Table 3.2). The test samples came from refrigerated air and controlled atmosphere storage conditions. Testing a set of 100 apples occurred when a set of preliminary samples appeared to fill the firmness distribution at a desired firmness level. This step ensured the final test samples used for data collection would achieve a wide range of firmness levels for each apple variety.

Each sample in the experiment compared the average of two bioyield measurements to a single Magness-Taylor measurement. The offset of each bioyield measurement was approximately 45 degrees from the predetermined Magness-Taylor test location as described in figure 3.7. All tests were conducted on the equator, located on the largest diameter of the fruit.

TABLE 3.2: Sample test dates, varieties, and quantity.

Date	Variety	# of Samples
1/20/05	Red Delicious	100
1/21/05	Red Delicious	100
1/25/05	Red Delicious	100
1/27/05	Golden Delicious	100
1/28/05	Golden Delicious	100
2/1/05	Golden Delicious	100
2/2/05	Red Delicious	100
2/3/05	Golden Delicious	100
2/4/05	Red Delicious	100
2/9/05	Golden Delicious	100
2/10/05	Golden Delicious	100
2/23/05	Golden Delicious	50
2/23/05	Red Delicious	50
2/25/05	Red Delicious	100
Overall		1300

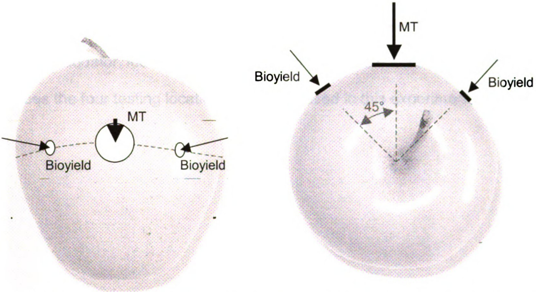


FIGURE 3.7: Bioyield and Magness-Taylor (MT) measurement locations

Bioyield vs. Time Study

The second test, conducted between February 4, 2005 and March 4, 2005, measured changes in firmness over time. The objective was to determine if bioyield measurements were as sensitive to firmness changes over time as Magness-Taylor measurements. There were eight sample groups of 33 Golden Delicious apples each. These samples were kept in five-gallon buckets covered with a lid and plastic bag to prevent individual apples from moisture loss. Each bucket remained at room temperature (~22 °C) until selected for measurement.

A sample group test occurred every 3 to 4 days. This involved measuring both bioyield and Magness-Taylor force on a randomly selected bucket of 33 apples. The comparison of firmness involved averaging two bioyield and two Magness-Taylor measurements per apple. Each of the four tests was taken on the apple's equator, located at the widest diameter of the fruit. Figure 3.8 describes the four testing locations per apple used in this experiment.

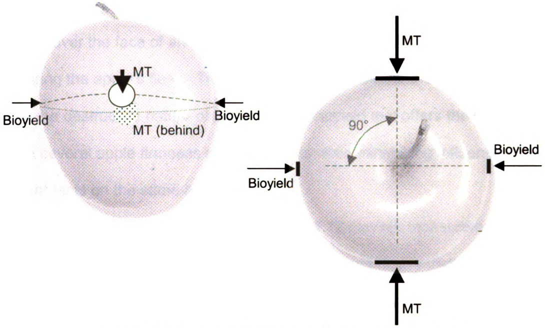


FIGURE 3.8: Measurement locations for time study

Bioyield Location Study

The objective of the third and final experiment was to quantify variations of firmness over the face of an apple. The Magness-Taylor firmness test involves puncturing the apple's flesh. This would not be suitable for the location study due to the destructive nature of the test. The bioyield test offers the opportunity to take several apple firmness measurements while minimizing influences from adjacent tests on the same apple.

The firmness location study consisted of 12 bioyield measurements on 50 Golden Delicious apples. The measurement locations (top / middle / bottom) and directions (north / east / south / west) of each test were designated in a coordinate system shown in Figures 3.9 and 3.10. The south direction designated the "sunny" or blush side of the apple (if distinguishable). This improved measurement consistency and uniformity between the fifty samples.

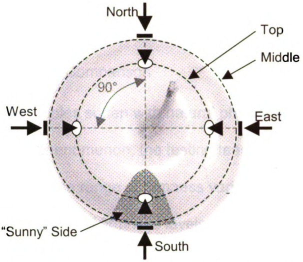


FIGURE 3.9: Top view of apple depicting bioyield measurement locations and directions relative to the orientation on the tree.

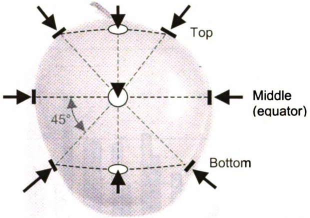


FIGURE 3.10: Side view of apple depicting offsets for top and bottom measurement locations from apple's equator (largest diameter).

RESULTS AND DISCUSSION

Bioyield vs. Magness-Taylor Comparison

While in storage, apples soften with natural physiological and biological processes. Utilizing this phenomenon, the testing team developed a conditioned set of 1300 apples with a wide range of firmness variation. A histogram was utilized to ensure a wide range of firmness levels (Figure 4.1). As expected, the Golden Delicious apples are generally softer than Red Delicious variety of apples. The experiment utilized this characteristic to enhance the range of measured firmness for experimental evaluation.

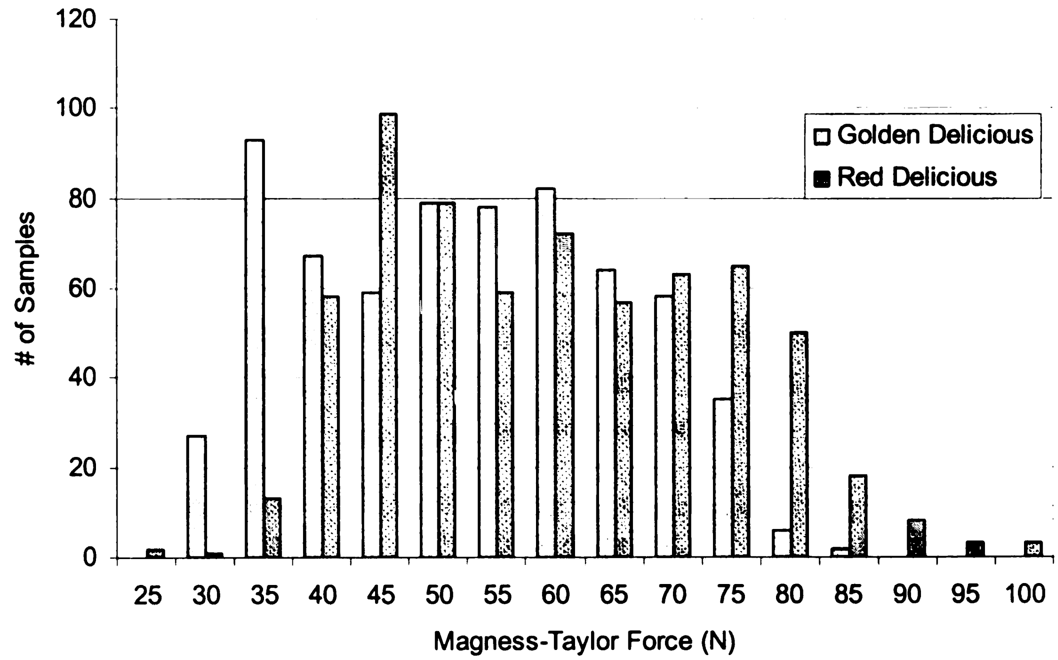


FIGURE 4.1: Histogram of Magness-Taylor firmness distribution.

Cumulative Data

Although the bioyield instrument records several pieces of information including the displacement, slope of the force-deformation curve, and area contained within the force-deformation curve, bioyield force correlated best with Magness-Taylor force. Linear regression analysis yielded an R-squared value of 0.751 (r = 0.866) on the pooled data of both Red Delicious and Golden Delicious apples (Figure 4.2). The standard error for the pooled data set was 7.10 N.

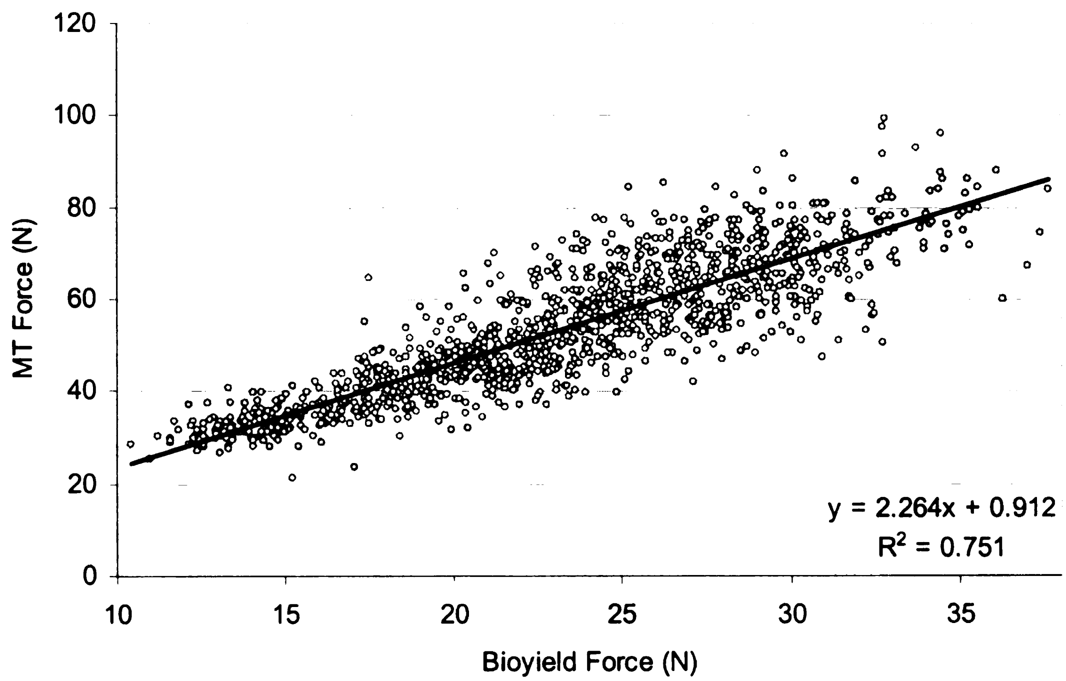


FIGURE 4.2: Magness-Taylor (MT) force versus bioyield force (N) for the entire 1300 apple data set.

Red Delicious Data

Performing data analysis on the specific apple varieties provided even more information regarding the instrument's sensitivity. Linear regression on the Red Delicious variety (Figure 4.3) yielded an R-squared value of 0.654 (r = 0.809). Standard error for the data set was 8.42 N.

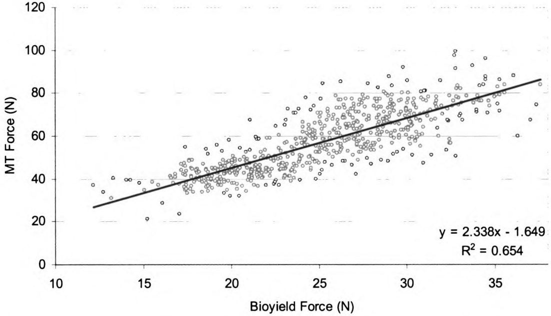


FIGURE 4.3: Magness-Taylor (MT) force versus bioyield force for Red Delicious apples.

Golden Delicious Data

The bioyield measurements on Golden Delicious apples yielded the best correlation with Magness-Taylor. The R-squared value from linear regression on the Golden Delicious data set (Figure 4.4) was 0.835 (r = 0.914). Standard error for the data set was 5.37 N.

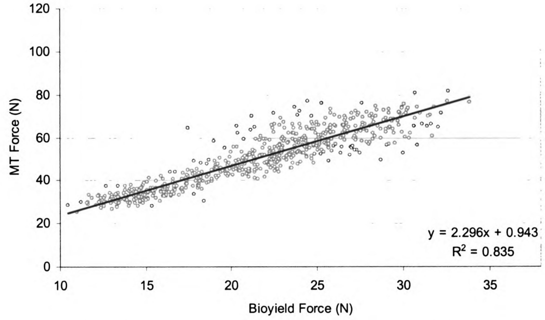


FIGURE 4.4: Magness-Taylor (MT) force versus bioyield force for Golden Delicious apples.

Discussion

The cumulative data set yielded a relatively high correlation between bioyield firmness and Magness-Taylor firmness. The results from the bioyield measurements compare favorably with the results of Magness-Taylor versus Magness-Taylor from a study conducted by Ababneh (2002). Although Red Delicious apples did not correlate as well as Golden Delicious apples, the results still demonstrated a good correlation trend. Other measured parameters including bioyield displacement, slope, area under force/displacement curve, and drop in force after bioyield detection yielded minimal to no correlation. As a result, future studies focused on bioyield force as the primary measured parameter of firmness.

The results from this experiment were better than the results of previous research conducted by Lu *et al.* (2005). Several differences may account for the increase in accuracy. One difference in previous testing methods is the actuation speed. The bioyield instrument actuates at 3.65 mm/min versus the previous instrument at 22.2 mm/min. Another difference may be the result of the optimized rubber tip design used in this research.

Variation may have also increased if the average of the two-bioyield force measurements incorrectly correlated with the single Magness-Taylor measurement on each sample. This is partly due to the experimental design. If Magness-Taylor force is measured from a relatively firm location compared to the rest of the apple (a location of peak firmness), the two bioyield force measurements will under-predict the equivalent Magness-Taylor force. The location experiment (third study) may determine if this effect plays a significant role in measurement variations.

Good correlation between bioyield force and Magness-Taylor force can be expected for several reasons. First, both firmness measurement techniques are similar because they are both quasi-static in methodology. In addition, both Magness-Taylor and bioyield techniques measure a peak force. Magness-Taylor however measures peak force, often before failure, while bioyield force is the peak force before the initial cellular rupture, a component of tissue failure.

Bioyield vs. Time Study

Two box and whisker plots, one for Magness-Taylor force (Figure 4.5) and one for bioyield force (Figure 4.6), reveal the change in firmness over a period of a month. Assuming the apples in each bucket underwent similar physiological change over time, the general trend of the apples involved a reduction in firmness. Initial observations from comparison of the box and whisker plots indicate a high correlation between the Magness-Taylor and bioyield firmness measurement methods. The top "whisker" represents the maximum of the data set while the bottom "whisker" represents the minimum of the data set. Contained in the box is 50 percent of the data from the 75^{th} to the 25^{th} percentile. The line crossing the center of the box represents the data set mean. Figures 4.5 and 4.6 utilize box and whisker plots to depict each data set per day.

Figure 4.7 compares the Magness-Taylor force with bioyield force for the average of each group consisting of 33 samples (66 test locations per measurement type) over time. Using linear regression, the R-squared value was 0.990 (r = 0.995).

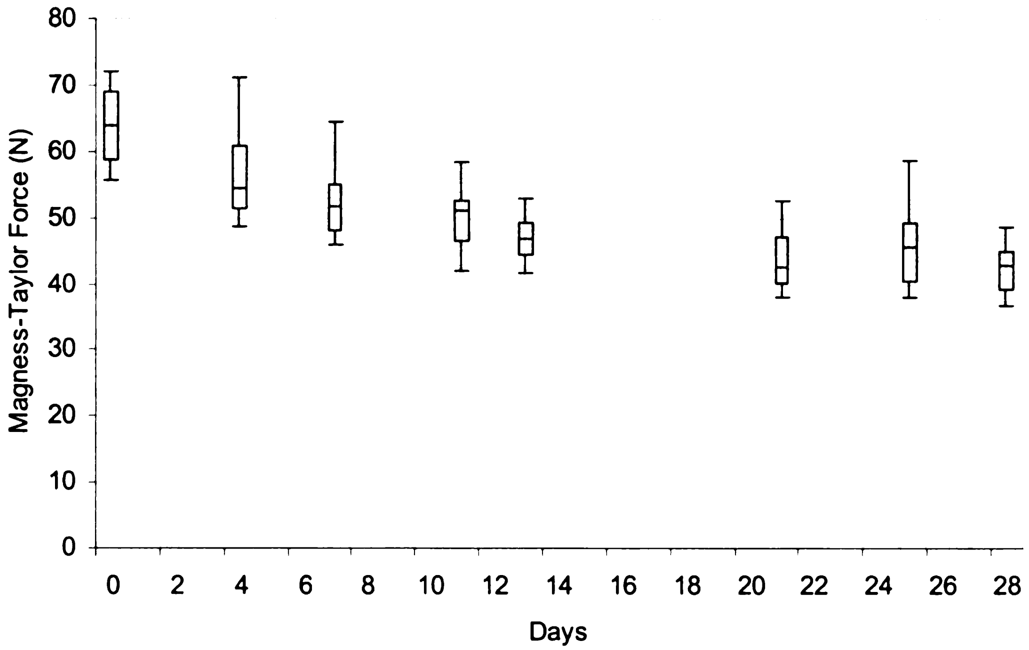


FIGURE 4.5: Magness-Taylor force versus time for Golden Delicious apples (33 fruit for each test date) stored at room temperature (~22 °C).

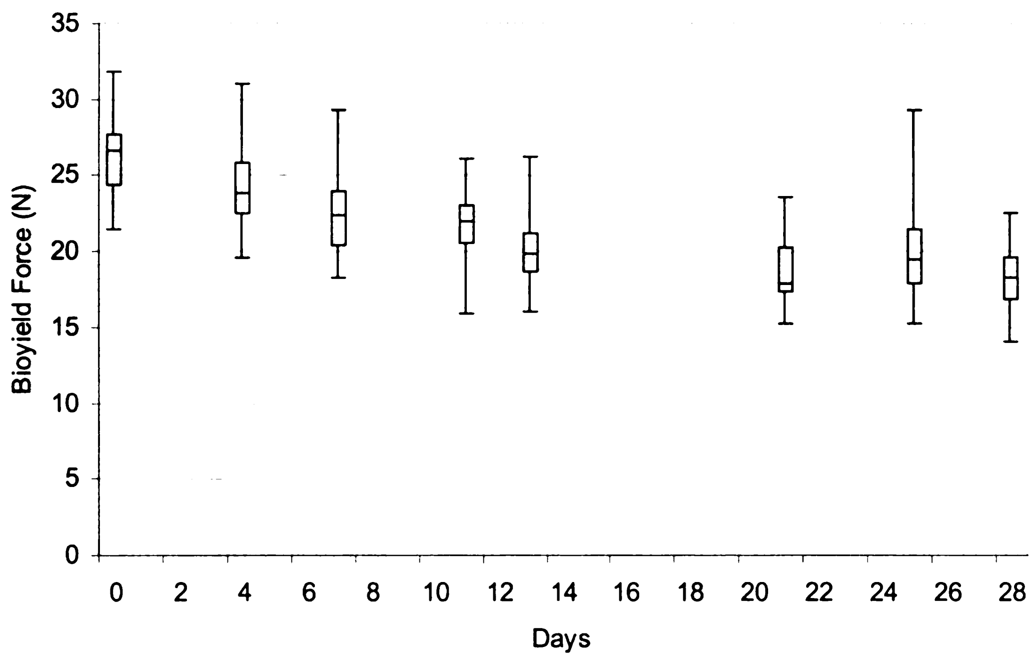


FIGURE 4.6: Bioyield force versus time for Golden Delicious apples (33 fruit for each test date) stored at room temperature (~22 °C).

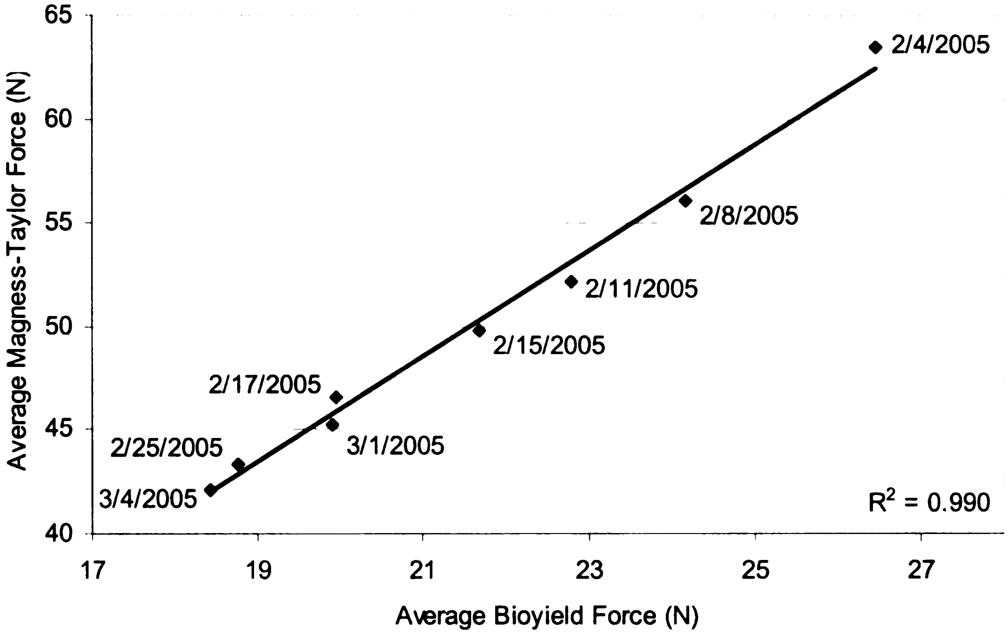


FIGURE 4.7: Magness-Taylor force versus bioyield force over the period of one month. Each data point is the average of 66 measurements from 33 apples.

Discussion

The results of this experiment confirmed that bioyield provides an effective means to measure firmness as a function of physiological change over time with Golden Delicious apples. The measurement of bioyield force appears to be as sensitive to physiological change as Magness-Taylor force for apples that underwent an accelerated softening process. The ability to monitor fruit conditions during postharvest storage is critical to maintaining and delivering high quality apples. The excellent correlation between Magness-Taylor force and bioyield force over time demonstrates that the bioyield test can provide reliable measurement and/or monitoring of fruit firmness changes during storage, which will be especially valuable for commercial application.

Bioyield Location Study

Differences in moisture content, cellular size, and other physiological factors, may result in variations in firmness over an apple's surface. The location study quantifies these variations to determine if particular locations of an apple are more adequate for bioyield tests. A majority of the study implements a statistical tool called ANOVA, short for Analysis of Variance. The first application of ANOVA used two factors with replication. This determined if there were significant variations in firmness due to face location, face direction, and/or interactions between these factors. The second application of ANOVA using single factors with replication determined what specific locations or directions are responsible for the variations in firmness.

When performing ANOVA, the F-critical statistic represents the level at which the tested factor significantly influences the measured variable. If the measured F value is higher than the F-critical level, the influencing factor plays a significant role in the measured variable. Determining F-critical involves designating a pre-determined significance level, or alpha (α). When F exceeds the F-critical with an alpha of 0.05, the tested factor significantly influences the measured variable by at least 95% of the time. The P-value is another way to interpret the results of ANOVA. The P-value is the corresponding alpha for a given F value. When the P-value is below the preset alpha level, the influencing factor is significant. Further discussions use the P-value to determine factor significance in the measured variables.

Two Factor ANOVA

Figure 4.8 describes firmness based on face layer (Top, Middle, and Bottom). Figure 4.9 uses box and whisker plots to describe the firmness based on face direction (North, East, South, and West). Table 4.1 shows the results of two-factor ANOVA with replication.

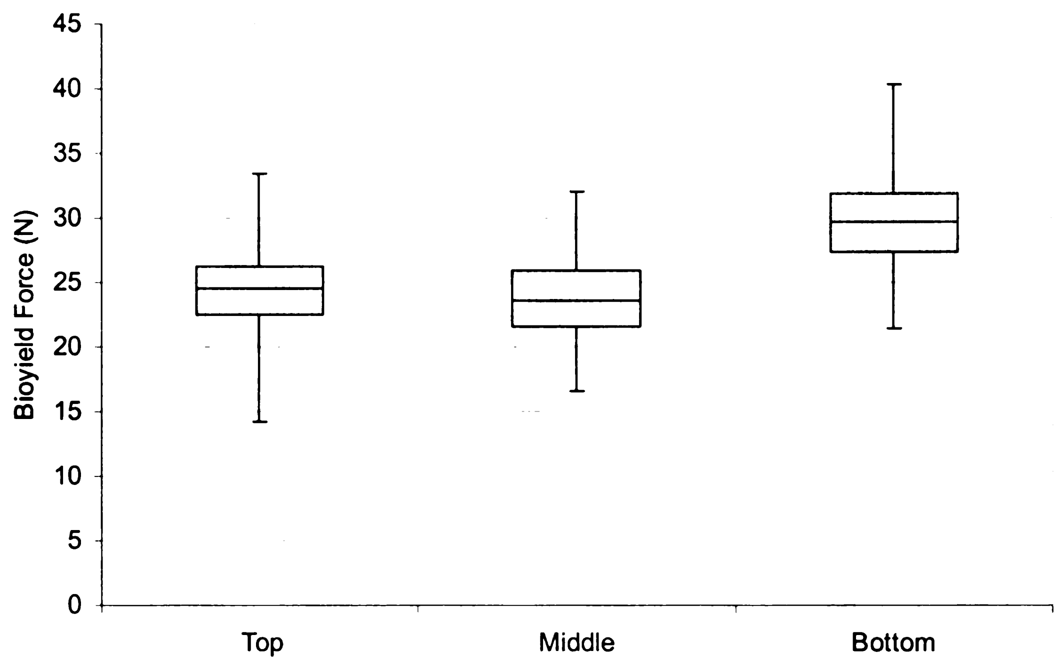


FIGURE 4.8: Bioyield force versus top / middle / bottom measurement location for 50 Golden Delicious apples. There were four bioyield measurements (North, East, South and West) for each fruit at each location.

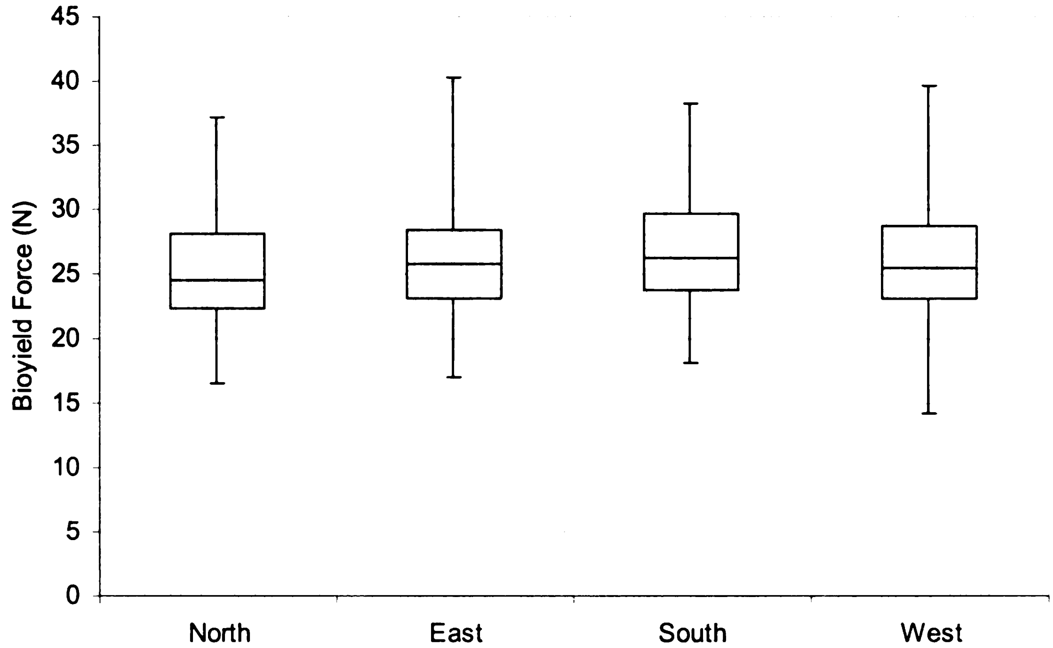


FIGURE 4.9: Bioyield force versus apple face direction from 50 Golden Delicious apples. There were three bioyield measurements (top, middle and bottom) for each fruit at each direction.

TABLE 4.1: Summary of the statistical data used in the two factor ANOVA calculations.

Bottom	North	East	West	South	Total
Count	36	36	36	36	144
Sum	1059	1075	1079	1089	4301
Average	29.41	29.87	29.96	30.24	29.87
Variance	15.71	17.11	19.94	13.46	16.30

Middle	North	East	West	South	Total
Count	36	36	36	36	144
Sum	833.3	853.1	856.4	889.7	3433
Average	23.15	23.70	23.79	24.72	23.84
Variance	6.819	11.38	7.890	8.631	8.818

Top	North	East	West	South	Total
Count	36	36	36	36	144
Sum	851.3	877.7	877.4	910.1	3517
Average	23.65	24.38	24.37	25.28	24.42
Variance	8.122	10.17	14.42	9.372	10.64

Total	North	East	West	South
Count	108	108	108	108
Sum	2812	2889	2743	2806
Average	26.04	26.75	25.40	25.98
Variance	21.63	16.50	18.18	20.35

TABLE 4.2: Two-factor ANOVA comparing the significance of layer and direction factors.

Source of Variation	SS	df	MS	F	P-value	F-critical
Layer	3188	2	1594	133.8	0.000	3.017
Direction	98.07	3	32.69	2.743	0.043	2.626
Interaction	8.765	6	1.461	0.123	0.994	2.120
Within	5006	420	11.92			
Total	8301					

The report in Table 4.2 shows that both layer (P-value 0.000 < 0.05) and direction (P-value 0.043 < 0.050) had a significant influence on the firmness of the fruit. Variations due to factor interactions were not significant (P –value 0.994 > 0.05).

Single Factor ANOVA for Apple Layer

Using ANOVA of a single factor will help determine which layer(s) and direction(s) cause the significant variations. Comparing each factor involves utilizing ANOVA of a single factor, three times for layer and six times for direction. This accounts for every possible comparison combination. The compilation of the P-values into a table assists with comparison and discussion of the results.

TABLE 4.3: Summary of data used to compare layers for single factor ANOVA calculations.

Groups	Count	Sum	Average	Variance
Top	144	3516	24.42	10.64
Middle	144	3433	23.84	8.82
Bottom	144	4301	29.87	16.30

TABLE 4.4: Single factor ANOVA comparing Top and Middle.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	24.47	1	24.47	2.515	0.114	3.874
Within Groups	2782	286	9.727			
Total	2806	287				

TABLE 4.5: Single factor ANOVA comparing Top and Bottom.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	2138	1	2138	158.8	0.000	3.874
Within Groups	3851	286	13.47			
Total	5990	287				

TABLE 4.6: Single factor ANOVA comparing Middle and Bottom.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	2620	1	2620	208.6	0.000	3.874
Within Groups	3591	286	12.56			
Total	6212	287				

TABLE 4.7: Summary of layer P-value results from tables 4.3, 4.5, and 4.6.

	Top	Middle	Bottom
Top	-	0.114	0.000
Middle	0.114	-	0.000
Bottom	0.000	0.000	-

Table 4.7 explains that the measurement layer significantly influences the firmness of the apple. Referring back to Figure 4.8, it is apparent that the bottom of the fruit is firmer when compared to the top and middle layers. This finding agrees with results from the experiment performed by Abbott and Lu (1996). The apple may be firmer in this location due to the smaller cellular size at the bottom of the fruit.

Single Factor ANOVA for Apple Face Direction

TABLE 4.8: Summary of data used to compare directions for single factor ANOVA calculations.

Groups	Count	Sum	Average	Variance
North	108	2743	25.40	18.18
East	108	2806	25.98	20.35
South	108	2888	26.75	16.50
West	108	2812	26.04	21.63

TABLE 4.9: Single factor ANOVA comparing West and South directions.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	26.89	1	26.89	1.410	0.236	3.885
Within Groups	4080	214	19.07			
Total	4107	215				

TABLE 4.10: Single factor ANOVA comparing North and South directions.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	97.46	1	97.46	5.620	0.019	3.885
Within Groups	3711	214	17.34			
Total	3809	215				

TABLE 4.11: Single factor ANOVA comparing South and East directions.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	31.46	1	31.46	1.707	0.193	3.885
Within Groups	3943	214	18.43			
Total	3975	215				

TABLE 4.12: Single factor ANOVA comparing North and West directions.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	21.96	1	21.96	1.103	0.2947	3.885
Within Groups	4260	214	19.91			
Total	4282	215				

TABLE 4.13: Single factor ANOVA comparing North and East directions.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	18.18	1	18.18	0.9436	0.3324	3.885
Within Groups	4123	214	19.26			
Total	4141	215				

TABLE 4.14: Single factor ANOVA comparing East and West directions.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	0.1789	1	0.1789	0.0085	0.9265	3.885
Within Groups	4491	214	20.99			
Total	4492	215				

TABLE 4.15: Summary of P-values for direction results found in tables 4.9, 4.10, 4.11, 4.12, 4.13, and 4.14.

	North	East	South	West
North	1.000	0.332	0.019	0.295
East	0.332	1.000	0.193	0.927
South	0.019	0.193	1.000	0.236
West	0.295	0.927	0.236	1.000

Table 4.15 compiles the results from the comparisons of direction. The comparison of North versus South was the only combination of directions that significantly varied in firmness due to measurement direction. The South face of an apple receives the most sunlight exposure, which may account for the difference in firmness when compared with the North side of the fruit. East and West sides receive lesser doses of sunlight resulting in a moderate firmness. Figure 4.9 depicted these differences in firmness, although the differences in firmness were small.

Single Factor ANOVA for Opposing Directions

Referring to Figure 4.9, it appears that North and South are opposites in firmness (South much firmer than North) while East and West appear as moderately firm. Considering this, future experimental design may want to consider the benefits of measuring opposing sides of an apple. Table 4.17 performs single factor ANOVA with replication on the combination factors of North and South versus East and West as depicted in Figure 4.10.

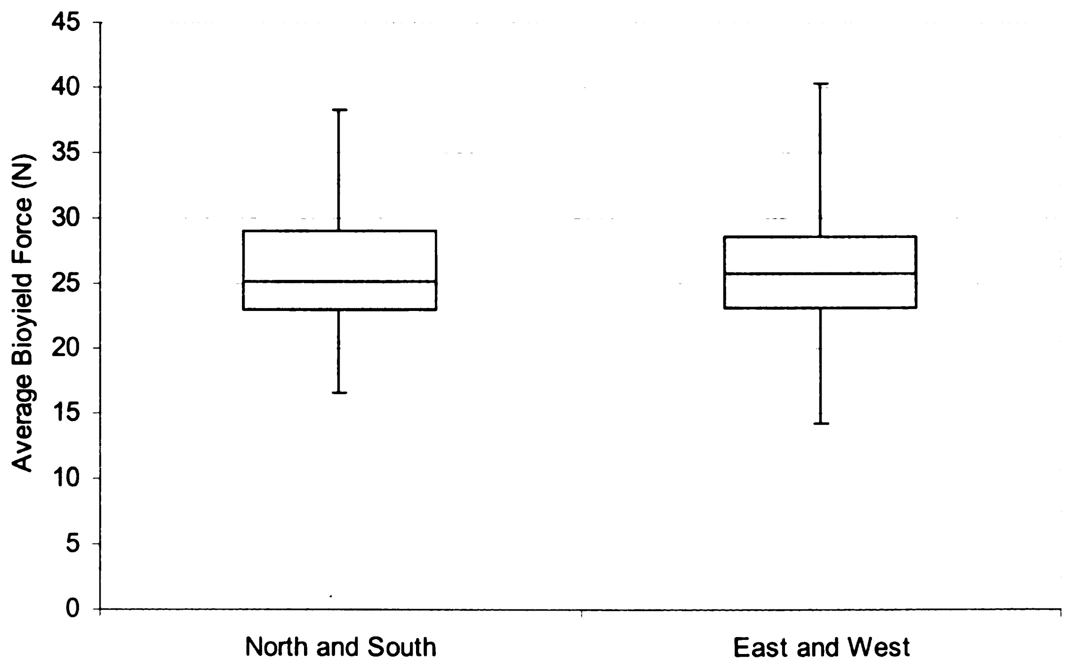


FIGURE 4.10: North and South compared to East and West for the bioyield force of 50 Golden Delicious apples.

TABLE 4.16: Summary of data used to compare direction combinations with single factor ANOVA.

Groups	Count	Sum	Average	Variance
North and South	216	5632	26.07	17.72
East and West	216	5618	26.01	20.89

TABLE 4.17: Single factor ANOVA comparing North/South and East/West combinations.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.4254	1	0.4254	0.0220	0.8821	3.863
Within Groups	8301	430	19.30			
Total	8301	431				

The direction groupings of North/South and East/West have insignificant influence on the measurement of force as seen with the ANOVA results in Table 4.17. Hence, optimal measurements in the future may involve the utilization of two firmness measurements from opposing sides of the fruit. The average of these two measurements may provide a more consistent and accurate understanding of the fruit's firmness.

Discussion

This experiment provided important information regarding the technique required to conduct optimal bioyield measurements. First, the bottom of an apple is significantly firmer than the middle and top sections. Measurements near the bottom may not accurately reflect the fruit's firmness, especially considering that firmer fruit increase variability of measurement (as seen in the Magness-Taylor experiment).

Second, the South side of an apple is significantly firmer when compared to the North side of an apple. Therefore, a single data point may not accurately reflect an apple's firmness. In the Magness-Taylor experiment, the locations of the two bioyield measurements were at 45-degree angles from the pre-designated Magness-Taylor test location. If the Magness-Taylor test location occurred on the south side of the apple, the average of the bioyield measurements would result in an under-predicted value compared to the Magness-Taylor force.

Finally, optimal testing methodology should involve two measurements when conducting bioyield measurements. The locations of the tests should be at opposing sides of the apple, preferable along the apple's equator. Conducting tests on opposing sides of the apple cancels the effects of direction and results in a measurement of the apple's firmness with a greater degree of accuracy. This method may also improve the results of other quasi-static and compression tests.

Bioyield Measurements for Firmness Evaluation

Bioyield has proven to be a good substitute for Magness-Taylor tests. Not only does the measurement technique correlate well with this industry standard test, it imposes minimal damage to the fruit. An extended test used a horizontal slicer to determine the approximate depth of bruising on several apples. Upon first inspection, a small bruise exists with a circular shape of diameter 6.35 mm (0.25 inch) to approximately 2 millimeters in depth. This dimension of bruising is smaller than the USDA definition of injury due to bruising for apples. Additional testing could help quantify the bruise dimensions in detail and determine if the bruise leads to any long-term or value-degrading effects. On several apples, the location of a bioyield test was hard to determine both visually and by touch. In general, the instrument appears to achieve the goal of non-destructive measurements.

Bioyield also proves to be a good tool for monitoring changes in firmness. This can be expected since bioyield force measurements correlate well with Magness-Taylor measurements. However, further research is needed to determine if such correlation still exists when the apple's outer layers have significant moisture loss compared to inner layers. Unlike Magness-Taylor measurements, bioyield can only measure the firmness of cellular structure near the skin.

Industry Applications and Implementation

Because bioyield is non-destructive in nature (as defined by the USDA standards for injury), this measurement technique holds great potential for scientific experiments. For example, if an experiment is limited to a relatively small sample size, the bioyield instrument allows several firmness measurements on the same apple. In addition, the bioyield instrument allows monitoring firmness of a single apple without puncturing the skin over several equatorial locations across the apple. Finally, in some scientific experiments, damage to the fruit may influence the results. Bioyield measurements provide an alternative firmness measurement technique by measuring the fruit's firmness without degrading damage.

The construction and evaluation of several rubber tip designs occurred prior to the instrument design evaluation. Unlike previous designs, these tips used polyurethane rubber. Early designs of the rubber tipped probe had shown signs of wear and dry rot especially around the contact surface edges. This may have led to inaccurate readings and lower correlation results with previous research. The rubber used in the present research not only had the recommended firmness for optimizing bioyield measurement, but the design of each tip also ensured constant contact surface area during test.

The bioyield instrument is a helpful tool for measuring the firmness of apples in a laboratory or field use setting. The development of the measurement instrument into a portable device enhances use for field and laboratory applications. The portability aspect may be beneficial to farmers and field agents who wish to monitor apple crops while the fruit grows and matures in a field environment. The computer connectivity capability for real-time analysis promotes laboratory use with detailed data logging capabilities. Finally, the device may be used on other fruits and vegetables by changing tips and the device's software. Currently the device's configuration is optimized for fruits exhibiting bioyield but may be reconfigured to perform other forms of compression and creep tests.

Futuristic applications of bioyield measurement may involve mounting a bioyield tester to a robotic arm. The robot system may detect the fruit with a vision system, grasp the fruit, measure color and soluble solids (sugar content or brix), measure firmness with bioyield, determine if the apple is ripe for picking, and label the apple with a laser engraver for data logging purposes. Utilization of this information may determine how specific trees are performing, if there are any quality issues on the tree, if quality issues occur while handling, and aid in future crop management decisions.

An online bioyield measurement system could also ensure consistent fruit in texture. Although the current system is relatively slow, the implementation of automation techniques could enhance throughput to meet the production and sorting needs of today. Additionally, an automated sampling system could allow slower test speeds while providing enough firmness information to make generalized sorting decisions and quality evaluations.

CONCLUSIONS

An instrument, based on previous research, was designed for bioyield force detection to measure firmness. The device causes minimum damage to the fruit and does not degrade it after testing. The instrument design features accurate control of loading speed, automated detection and recording of bioyield point, and ease of operation. Moreover, the device is portable and low in cost, can operate stand-alone or via computer, and thus is suitable for use in both field and laboratory environments.

A comparison study of the bioyield tester and the standard Magness-Taylor tester demonstrated that bioyield force correlated well with Magness-Taylor force and yielded an R-squared value of 0.751 for the pooled data of both Red Delicious and Golden Delicious apple varieties. Variety effect was observed from the bioyield test; bioyield force had better correlation with Magness-Taylor force for Golden Delicious apples (R-squared of 0.835) than for Red Delicious apples (R-squared of 0.654).

When Golden Delicious apples were subjected to accelerated softening by keeping at room temperature, the trend of average bioyield force change was the same as that of average Magness-Taylor force change. Correlation of the sample average of bioyield firmness to the sample average of Magness-Taylor firmness over the period of 28 days yielded an R-squared value of 0.990.

A further study quantified the variations in firmness over an apple's surface. Statistical analyses showed significant variations in firmness due to both layer and direction (circumferential) factors. The bottom section (or the calyx end) of an apple is significantly firmer than the middle and top sections. Furthermore, the South side (sunny or blush side) of the fruit is significantly firmer than the North side (shady side) of the fruit. When conducting bioyield testing of apples, the average firmness from opposing sides of the apple eliminates significant variations in fruit firmness and provides a higher degree of accurately measuring the fruit's overall firmness.

Areas of Further Research

Apples are viscoelastic and hence testing speed will affect bioyield testing. Previous bioyield studies used a relatively fast speed compared to this bioyield instrument; however, the results from this experiment were better than the previous experiments. Therefore, it would be beneficial to determine the speed range at which accurate measurements occur while minimizing testing time. This would be beneficial for automation purposes.

Although Red Delicious and Golden Delicious apples are some of the most common apples sold as fresh fruit, the correlation of bioyield and Magness-Taylor measurements of other varieties are unknown. Testing bioyield on other varieties could help define the capabilities and limitations of bioyield measurement and the bioyield instrument constructed for this experiment.

Experiments to define an optimum rubber tip should continue. Previous studies may have used a tip that was too soft leading to inaccurate measurements. All experiments performed in this research used a single probe tip design based on the research conducted by Ababneh (2002). It may be necessary to use a firmer probe to improve the accuracy of measuring bioyield firmness on firm apples.

Bioyield tests may provide a solution for long-term storage monitoring of apples. However, additional research is necessary to quantify the long-term effects of bioyield measurement on the quality of fruit. Although this study indicated minimal damage to the fruit following a test, quantification of the long-term damage may validate the non-destructive nature of bioyield tests.

Lu *et al.* (2005) indicated that the correlation accuracy of bioyield firmness to Magness-Taylor firmness is related to firmness level. Although this phenomenon was observed in Figure 4.2, the level of variability based on firmness level was not quantified. Future studies may need to determine the physical phenomena leading to this reduction of accuracy at high firmness levels. This may include verifying measurement technique and test speed as well as determining the effects of apple variety on measurement accuracy.

The bioyield instrument provides a large amount of information for further analysis. Although the studies conducted in this research focused on bioyield force, other data components such as bioyield displacement may aid in the development of a stress-strain “scatter plot” called a texture map. This texture map may assist in finding textural patterns of apples such as those found in sensory evaluations.

APPENDIX A: Bioyield Instrument Operation Instructions

Bioyield Acquisition Program Procedures:

Installation:

1. Install StampDAQ software.
2. Available at: http://www.parallax.com/dl/sw/StampDAQ.zip
3. Install Bioyield Data Collection spreadsheet.

Operation:

1. Open Bioyield Data Collection spreadsheet.
2. On the "Bioyield Acquisition Program" window, select:
   - The COM port being used for link between instrument and computer.
   - 4800 Baud rate.
   - Starting sample number. This relates to the column (test) number. The maximum number of bioyield tests per spreadsheet is 250.
3. Select the "Data" worksheet.
4. When ready to begin tests, press the "Connect" button on the "Bioyield Acquisition Program" window.
5. Conduct bioyield tests. The cells will automatically increment and fill with data.

Bioyield Instrument Operation:

Initialization:

1. The device operates off battery when the charger is not connected. It is recommended that the charger remain connected at all times if a power connection is available.
2. Turn the instrument's power ON with power switch located on the left side of the electrical enclosure.
3. Turn the IMADA force meter ON.
4. Wait for the device to complete the homing sequence.
5. Use the black toggle switch to scroll through menus of settings. Use red buttons to change values or settings.

Bioyield Instrument Menu Screens:

Test [start-up screen]	This is the screen used to run the bioyield test. The "Jog" button increments the test platform vertically before testing. The "Run" button starts the bioyield test.
Sample #	This indicates the sample number to be tested. The sample number can be changed with the "+" and "-" buttons. The default starting value is 0.
Test Speed	This sets the time in milliseconds between each half-step of vertical movement of the actuator. Smaller values increase testing speed but may cause stepping errors. Larger values decrease testing speed but decrease fluidity of actuation. Default test speed value is 25.
Detect	This allows the instrument to automatically detect the fruit's surface. When set to "automatic", and the test begins, the actuator rises rapidly to detect the fruit's surface. "Manual" detection however, is quicker because it allows you to "Jog" the actuator and manually start the bioyield detection sequence. Default setting is "Manual".
Store	This gives the operator the option to store the bioyield results to the internal EEPROM memory manually or automatically. If "Automatic" is enabled, the results are displayed and immediately stored to the EEPROM memory. If "Manual" is enabled, following a test, the results are displayed and the operator will have the choice store or discard the test results. Default setting is "Manual".
Settings	This stores the current settings into the EEPROM memory. This prevents the settings from erasing after the instrument is powered off. To save the current settings, press the "Save" button.
EEPROM	This screen allows the operator to send the EEPROM stored results to an attached computer or erase (over-write) the current values. To send the values to an attached computer, press the "Dump" button. To erase the EEPROM values, press the "Erase" button. Erasing is the same as resetting the Sample # to 0.

Conducting Bioyield Tests:

1. Place an apple in the holder above the actuation drive.
2. On the Bioyield Test Screen, press the "Jog" button to lift the apple near the probe tip. Do not make contact with the tip or the test will automatically restart. When the apple is within a few millimeters of the probe tip, press the "Run" button. The actuation drive will operate the test and automatically release upon completion.
3. The results of the test will display including the peak Bioyield Force and number of steps to achieve the force from initial contact. Depending on the EEPROM menu setting, the device may request that the data be saved or discarded.
4. If connected to a computer, the spreadsheet will display the force – deformation plot and automatically increase sample number for each test conducted. The sample number on the spreadsheet may not relate to the sample number on the device.

Operation Recommendations, and Cautions:

- Keep a "clean" copy of the original Bioyield Acquisition Program spreadsheet. Perform tests on a renamed copy of this spreadsheet.
- When conducting Bioyield tests using the Bioyield Acquisition Program spreadsheet, ensure the spreadsheet or "Bioyield Acquisition Program" window is selected (foreground window). Operating other software while conducting bioyield tests may interrupt the data stream and cause missing data or blank cells.
- Internal data storage (EEPROM data) may automatically reset when powering the instrument on. It is not recommended that the EEPROM storage functions be used at this time.
- To ensure accurate measurements, occasionally inspect the probe tip for signs of cracks, wear, and dry rot. Probe tips can be replaced by un-screwing the tip and connection collar from the IMADA force meter. Use caution when replacing tips. Using tools or over-tightening the tip may cause permanent damage to the force meter.
- Do not hold the device by the probe tip or expose the probe tip to large forces. Exposing the tip and force meter to these forces can cause permanent damage to the force meter and measurement accuracy.
- Do not open the electrical housing of the instrument unless repair is necessary. A large 12-volt gel-cell battery contained in the housing may cause bodily harm if not handled with caution. In addition, mechanical pinch-points may damage to internal wires if the housing is not properly closed.

APPENDIX B: Bioyield Instrument Program Code

```
'{$STAMP BS2p,BY5.1-1.bsp}
'{$PBASIC 2.5}

'Nicholas C Tipper
'Bioyield Probe Program
'Version 5.1, Program (0)

'This program establishes the variables and settings required to run
'the bioyield tester.  After settings are established, they are loaded
'into scratch pad memory for program 1 to use.  Within this menu are
'settings dump and erase the stored values within the EEPROM.  All
'comments including this use the "'" character to denote the start of
'a comment.  Most code lines include a comment to the right or
'directly following the line of code.

MENUSEL VAR Nib                         'Menu number
SAMPLE VAR Word                         'Sample #
SPEED VAR Word                          'Speed of motor during test
SETTINGS VAR Byte                       'Settings byte (BIT0 = RTS, BIT1
                                        '= Point/Plot, BIT2 = Auto
                                        'Detection, BIT3 = Auto Store)
TEMPA VAR Byte                          'Temporary Byte for reading
TEMPB VAR Byte                          'Temporary Byte for reading
TEMPBIT VAR Bit                         'Temporary Bit
TEMPWORD VAR Word                       'Temporary Word variable
DUMP VAR Word                           'Dump counter

LCD CON 11                              'LCD Connection Pin
LCDBAUD CON 500                         '4800 Baud, No Parity, 1 Stop Bit
COMP CON 16                             'Computer connection pin
COMPBAUD CON 500                        '4800 Baud, 8 bit, no parity, 1
stop bit

DIRD = %1111                            'Set motor pins as outputs
OUTD = %0000                            'Turn motor off (battery save)
STORE 0                                 'Set EEPROM Read/Write location
READ 0,SETTINGS                         'Read Variables from EEPROM
READ 1,SAMPLE.HIGHBYTE                  '
READ 2,SAMPLE.LOWBYTE                   '
READ 3,SPEED.HIGHBYTE                   '
READ 4,SPEED.LOWBYTE                    '
GET 5,MENUSEL

MENU:                                   'Main menu
DO WHILE INA <> 15                      'Wait until no button is pressed
LOOP                                    '
BRANCH MENUSEL,[MENU0,MENU1,MENU2,MENU3,MENU3,MENU5,MENU6]
                                        'Go to appropriate menu
                                        'MENUSEL Table
                                        '0  MENU0    Test menu
                                        '1  MENU1    Sample #
                                        '2  MENU2    Test Speed
                                        '3  MENU3    Autodetection Mode
                                        '4  MENU4    Store  (Auto,
                                        'Manual) Store BYP automatically
                                        '5  MENU5    Memory (Dump, Erase)
                                        'Dump stored points or mark for
                                        'erase, tells # of stored points
                                        '6  MENU6    Settings (Save)
                                        'Save settings as default
```

```
IF MENUSEL = 7 THEN MENUHIGHFIX          'Menu Looping: if end, goto
                                         'beginning, vice versa
MENUSEL = 6                              '
GOTO MENU                                '
MENUHIGHFIX:                             '
MENUSEL = 0                              '
GOTO MENU                                '


MENU0:                                   'Test Menu
PUT 0,SETTINGS                           'Place variables scratchpad RAM
PUT 1,SAMPLE.HIGHBYTE                    '
PUT 2,SAMPLE.LOWBYTE                     '
PUT 3,SPEED.HIGHBYTE                     '
PUT 4,SPEED.LOWBYTE                      '
RUN 1                                    'Start Test Program


MENU1:                                   'Sample # menu
SEROUT LCD,LCDBAUD,[012,017,000,000,030,001,026,"Sample
#",017,014,000,"+",030,001,016,017,000,001,030,001,027,DEC SAMPLE,"
",017,014,001,"-",030,001,016]
                                         'Write LCD screen


DO                                       'MENU1 Loop
  DO WHILE INA = 15                      'Wait until button pressed
  LOOP                                   '
  SELECT INA                             'Build cases for pressed button
    CASE 011                             'Top right button
    SAMPLE = SAMPLE + 1                  'Add 1 to sample #
    IF SAMPLE = 3072 THEN GOSUB SAMPLEFIX1
                                         'Fix sample #
    SEROUT LCD,LCDBAUD,[017,001,001,DEC SAMPLE,"   "]
                                         'Write LCD screen
    PAUSE 50
    CASE 007                             'Bottom right button
    SAMPLE = SAMPLE - 1                  'Subtract 1 from sample #
    IF SAMPLE = 65535 THEN GOSUB SAMPLEFIX0
                                         'Fix sample #
    SEROUT LCD,LCDBAUD,[017,001,001,DEC SAMPLE,"   "]
                                         'Write LCD screen
    PAUSE 50
  ENDSELECT                              'End cases
  GOSUB MENUCHANGE                       'Menu button sub
LOOP                                     'End MENU1 Loop
SAMPLEFIX0:                              'Repair Sample #
SAMPLE = 0                               '
RETURN                                   '
SAMPLEFIX1:                              '
SAMPLE = 3071                            '
RETURN                                   '


MENU2:                                   'Sample # menu
SEROUT LCD,LCDBAUD,[012,017,000,000,030,001,026,"Test
Speed",017,014,000,"+",030,001,016,017,000,001,030,001,027,DEC SPEED,
"   ",017,014,001,"-",030,001,016]
                                         'Write LCD screen
DO                                       'MENU2 Loop
  DO WHILE INA = 15                      'Wait until button pressed
  LOOP                                   '
```

```
  SELECT INA                               'Build cases for pressed button
    CASE 011                               'Top right button
    SPEED = SPEED + 1                      'Add 1 to sample #
    IF SPEED = 1501 THEN GOSUB SPEEDFIX1
                                           'Fix sample #
    SEROUT LCD,LCDBAUD,[017,001,001,DEC SPEED,"   "]
                                           'Write LCD screen
    PAUSE 50                               'Prevent too fast looping
    CASE 007                               'Bottom right button
    SPEED = SPEED - 1                      'Subtract 1 from sample #
    IF SPEED = 65535 THEN GOSUB SPEEDFIX0
                                           'Fix sample #
    SEROUT LCD,LCDBAUD,[017,001,001,DEC SPEED,"   "]
                                           'Write LCD screen
    PAUSE 50                               'Prevent too fast looping
  ENDSELECT                                'End cases
  GOSUB MENUCHANGE                         'Menu button sub
LOOP                                       'End MENU2 Loop
SPEEDFIX0:                                 'Repair Speed
SPEED = 0                                  '
RETURN                                     '
SPEEDFIX1:                                 '
SPEED = 1500                               '
RETURN                                     '


MENU3:                                     'Selection menus (4)
SELECT MENUSEL                             'Build cases on menu
  CASE 003                                 'Menu 5
  SEROUT
LCD,LCDBAUD,[012,017,000,000,030,001,026,"Detect",017,011,000,"Auto",01
7,000,001,030,001,027,017,009,001,"Manual"]
                                           'Write LCD Screen
  TEMPBIT = SETTINGS.BIT0                  'Read setting
  CASE 004                                 'Menu 6
  SEROUT
LCD,LCDBAUD,[012,017,000,000,030,001,026,"Store",017,011,000,"Auto",017
,000,001,030,001,027,017,009,001,"Manual"]
                                           'Write LCD Screen
  TEMPBIT = SETTINGS.BIT1                  'Read setting
ENDSELECT                                  'End Cases
SELECT TEMPBIT                             'Build cases setting on or off
  CASE 000                                 'Setting off
  SEROUT LCD,LCDBAUD,[017,015,000,030,001,016,017,015,001,209]
                                           'Write LCD Screen setting A off
  CASE 001                                 'Setting on
  SEROUT LCD,LCDBAUD,[017,015,000,209,017,015,001,030,001,016]
                                           'Write LCD Screen setting A on
ENDSELECT                                  'End Cases
DO                                         'MENU3 Loop
  DO WHILE INA = 15                        'Wait until button pressed
  LOOP                                     '
  SELECT INA                               'Build cases for pressed button
    CASE 011                               'Top right button
       SELECT MENUSEL                      'Build cases on menu, set setting
                                           'A on
          CASE 003                         '
          SETTINGS.BIT0 = 1                '
          CASE 004                         '
          SETTINGS.BIT1 = 1                '
          'CASE 005                        '
          'SETTINGS.BIT2 = 1               '
          'CASE 006                        '
          'SETTINGS.BIT3 = 1               '
```

```
      ENDSELECT                             'End Cases
      SEROUT LCD,LCDBAUD,[017,015,000,209,017,015,001,030,001,016]
                                            'Write LCD Screen RTS on
    CASE 007                                'Bottom right button
      SELECT MENUSEL                        'Build cases on menu, set setting
                                            'A off
        CASE 003                            '
        SETTINGS.BIT0 = 0                   '
        CASE 004                            '
        SETTINGS.BIT1 = 0                   '
        'CASE 005                           '
        'SETTINGS.BIT2 = 0                  '
        'CASE 006                           '
        'SETTINGS.BIT3 = 0                  '
      ENDSELECT                             '
    SEROUT LCD,LCDBAUD,[017,015,000,030,001,016,017,015,001,209]
                                            'Write LCD Screen RTS off
  ENDSELECT                                 'End Cases
  GOSUB MENUCHANGE                          'Menu button sub
LOOP                                        'End MENU3 Loop


MENU5:                                      'Settings Menu
SEROUT LCD,LCDBAUD,[012,017,000,000,030,001,026,"Settings",017,011,000,
"Save",030,001,016,017,000,001,030,001,027]
                                            'Write LCD screen
DO                                          'MENU9 Loop
  DO WHILE INA = 15                         'Wait until button pressed
  LOOP                                      '
  SELECT INA                                'Build cases for pressed button
    CASE 011                                'Top right button
     SEROUT LCD,LCDBAUD,[012,017,000,000,209,"Saving.."]
                                            'Write LCD screen
     STORE 0                                'Set store location
     READ 0,TEMPA                           'Read Settings
     IF SETTINGS = TEMPA THEN OKSETTINGS
                                            'If settings same, continue
     WRITE 0,SETTINGS                       'Write Settings
     OKSETTINGS:                            '
     READ 1,TEMPA                           'Read Sample
     READ 2,TEMPB                           'Read Sample
     IF SAMPLE.HIGHBYTE = TEMPA AND SAMPLE.LOWBYTE = TEMPB THEN
     OKSAMPLE
                                            'If Sample # same, continue
     WRITE 1,SAMPLE.HIGHBYTE                'Write Sample
     WRITE 2,SAMPLE.LOWBYTE                 'Write Sample
     OKSAMPLE:                              '
     READ 3,TEMPA                           'Read Speed
     READ 4,TEMPB                           'Read Speed
     IF SPEED.HIGHBYTE = TEMPA AND SPEED.LOWBYTE = TEMPB THEN OKSPEED
                                            'If Speed same, continue
     WRITE 3,SPEED.HIGHBYTE                 'Write Speed
     WRITE 4,SPEED.LOWBYTE                  'Write Speed
     OKSPEED:                               '
     PAUSE 1000                             '
     MENUSEL = 0                            'Set to Test menu
     GOTO MENU                              'Return to menu
    ENDSELECT                               'End Cases
  GOSUB MENUCHANGE                          'Check menu buttons
LOOP                                        'End MENU0 Loop


MENU6:                                      'Memory Menu
```

```
SEROUT
LCD,LCDBAUD,[012,017,000,000,030,001,026,"Memory",017,011,000,"Dump",03
0,001,016,017,000,001,030,001,027,017,010,001,"Erase",030,001,016]
                                      'Write LCD Screen
DO                                    'MENU7 Loop
  DO WHILE INA = 15                   'Wait until button pressed
  LOOP                                '
  SELECT INA                          'Build cases for pressed button
    CASE 011                          'Top right button
      SEROUT LCD,LCDBAUD,[012,017,000,000,209,"Dumping.."]
                                      'Write LCD Screen
      SEROUT COMP,COMPBAUD,[CR,"CLEARDATA",CR,"LABEL,Disp,Force",CR]
                                      'Clear Excel, setup labels
      IF SAMPLE = 0 THEN DUMPCOMPLETE
      FOR DUMP = 0 TO SAMPLE - 1      'Begin looping through data
        STORE DUMP/512 + 2            'Determine read location
        READ (DUMP // 512) * 4 + 0,TEMPWORD.HIGHBYTE
                                      'Read Displacement
        READ (DUMP // 512) * 4 + 1,TEMPWORD.LOWBYTE
                                      '
        SEROUT COMP,COMPBAUD,["DATA,",DEC TEMPWORD,","]
                                      'Send sample number and
                                      'displacement
        READ (DUMP // 512) * 4 + 2,TEMPWORD.HIGHBYTE
                                      'Read force
        READ (DUMP // 512) * 4 + 3,TEMPWORD.LOWBYTE
                                      '
        SEROUT COMP,COMPBAUD,[DEC TEMPWORD,CR]
                                      'Send force, finalize send
        PAUSE 10                      'Pause between line sent
      NEXT                            'Loop
      DUMPCOMPLETE:
      STORE 0                         'Reestablish store location
      SEROUT LCD,LCDBAUD,[012,017,000,000,209,"Complete"]
                                      'Write LCD Screen
      PAUSE 1000                      'Pause
      GOTO MENU6                      'Return to MENU9
    CASE 007                          'Bottom right button
      SEROUT LCD,LCDBAUD,[012,017,000,000,209,"Erasing.."]
                                      'Write LCD Screen
      STORE 0                         'Set store Location
      SAMPLE = 0                      'Set Sample to 0
      WRITE 1,0                       'Write sample word to EEPROM
      WRITE 2,0                       '
      PAUSE 1000                      'Pause
      SEROUT LCD,LCDBAUD,[012,017,000,000,209,"Complete"]
                                      'Write LCD Screen
      PAUSE 1000                      'Pause
      GOTO MENU6                      'Return to MENU9
  ENDSELECT                           'End cases
  GOSUB MENUCHANGE                    'Menu button sub
LOOP                                  'Loop

MENUCHANGE:                           'Menu button selection changes
SELECT INA                            'Build sacse for pressed button
  CASE 013                            'Top left button
  MENUSEL = MENUSEL - 1               'Menu up
  GOTO MENU                           'Return to main menu
  CASE 014                            'Bottom left button
  MENUSEL = MENUSEL + 1               'Meun down
  GOTO MENU                           'Return to main menu
ENDSELECT                             'End cases
RETURN                                'Return from previous location
```

```
'{$STAMP BS2p}
'{$PBASIC 2.5}

'Nicholas C Tipper
'Bioyield Probe Program
'Version 5.1, Program (1)

'After reading variables established by program in memory bank #0, this
'program starts the motor, establishes connection with the IMADA force
'meter, and begins test sequence.  The test can be started by computer
'or by buttons on the tester.

MOTORPOS VAR Nib                      'Motor position
POSITION VAR Word                     'Rack and pinion position
MOTORSTEP VAR Bit                     'Stepping (1 = Full, 0 = Half)
PLOOP VAR Byte                        'Counter for limit switch
SETTINGS VAR Byte                     'Settings byte (BIT0 = RTS,
                                      'BIT1 = Point/Plot, BIT2 = Auto
                                      'Detection, BIT3 = Auto Store)
SAMPLE VAR Word                       'Sample #
SPEED VAR Word                        'Speed of testing
IMADA VAR Byte(8)                     'IMADA Serial Data String
IMADAVAL VAR Word                     'IMADA Data / used as temp timer
IMADAOLD VAR Word                     'Previous IMADA reading
IMADABYP VAR Word
SIZE VAR Word                         'Position and displacement size
CMD VAR Byte                          'Command from computer
LABEL VAR Bit                         'Labeling for RTS
BYP VAR Bit

IMADAOUT CON 10                       'Output pin for IMADA
IMADAIN CON 9                         'Input pin for IMADA
IMADABAUD CON 1021                    '2400 baud, 8 bit, no parity,
                                      '1 stop bit
COMP CON 16                           'Computer connection pin
COMPBAUD CON 500                      '4800 Baud, 8 bit, no parity,
                                      '1 stop bit
LCD CON 11                            'LCD Connection Pin
LCDBAUD CON 500                       '4800 Baud, 8 bit, no parity,
                                      '1 stop bit

DIRD = %1111                          'Set motor pins as outputs
LABEL = 0                             'Labeling for RTS
START:                                'Start marker
GOSUB INITIALIZE                      'Initialize probe

MAIN:                                 'Main Loop
SEROUT LCD,LCDBAUD,[012,017,000,000,030,001,026,"Test #",DEC
SAMPLE,017,012,000,"Jog",030,001,016,017,000,001,030,001,027,017,012,00
1,"Run",030,001,016,004]
                                      'Write LCD Screen
DO WHILE INA <> 15                    'Wait until key released
LOOP

DO WHILE INA = 15                     'Wait until button pressed
LOOP

SELECT INA
  CASE 011                            'Top right button
    MOTORSTEP = 1                     'Full stepping
    SEROUT LCD,LCDBAUD,[017,000,000," ",017,000,001,209,"Running"]
                                      'Write LCD Screen
    DO WHILE (INA = 11 AND POSITION <= 6000)
                                      'Loop while holding button
```

```
      GOSUB POSUP                         'Reposition motor
      PAUSE 4                             'Pause between steps
                                          '(lower = faster)
    LOOP
    IF POSITION >= 6000 THEN JOGHIGH     'Position beyond limit
    GOTO MAIN:                            'Return to MAIN
    JOGHIGH:                              'Position limit handler
    SEROUT LCD,LCDBAUD,[012,017,000,001,209,"Returning"]
                                          'Write LCD Screen
    PAUSE 2000                            'Wait before moving
    GOSUB RESET                           'Reset position
    GOTO MAIN                             'Return to MAIN

  CASE 007                                'Bottom Right Button,
                                          'begin testing
    BYP = 0
    RUNTEST:
    DO WHILE INA <> 15                    'Wait until button released
    LOOP
    IMADAOLD = 0                          'Previous Imada reading reset
    IMADAVAL = 0
    SEROUT IMADAOUT,IMADABAUD,["D",CR]
                                          'Send Imada read command
    SERIN  IMADAIN,IMADABAUD,1000,IMADAERROR,[STR IMADA\8]
                                          'Recieve Imada string
    IMADAVAL = ((IMADA(1)-48)*1000)+((IMADA(3)-48)*100)+((IMADA(4)-
    48)*10)+((IMADA(5)-48))
                                          'Evaluate Imada string
    IF IMADAVAL > 5 THEN NODATA          'Stop test prematurely if
                                          'touching (establish good test)
    SEROUT IMADAOUT,IMADABAUD,["Z",CR]
                                          'Tare Imada
    IF SETTINGS.BIT0 = 0 THEN TEST       'Autodetection
    SEROUT LCD,LCDBAUD,[017,000,001,209,"Detect",017,011,001,
    "Test",030,001,016]
                                          'Write LCD Screen

    DETECTOR:
    SIZE = 0                              'Apple size position reset
    MOTORSTEP = 1                         'Half stepping
    DO WHILE POSITION <= 6000 AND INA <> 007 AND IMADAVAL < 5000
                                          'Prevent damage, stop with
                                          'bottom right button
      SEROUT IMADAOUT,IMADABAUD,["D",CR]
                                          'Send Imada read command
      SERIN  IMADAIN,IMADABAUD,1000,IMADAERROR,[STR IMADA\8]
                                          'Recieve Imada string
      IMADAVAL = ((IMADA(1)-48)*1000)+((IMADA(3)-48)*100)+((IMADA(4)-
      48)*10)+((IMADA(5)-48))
                                          'Evaluate Imada string
      IF IMADAVAL > 50 THEN TEST         'Slow test upon detection
GOSUB POSUP
    LOOP
    IF POSITION >= 6000 OR IMADAVAL >= 5000 THEN NODATA
                                          'Error handler
    TEST:                                 'Begin testing at regular speed
    DO WHILE INA <> 15                    'Wait until button released
    LOOP
    MOTORSTEP = 0                         'Half Stepping
    SEROUT LCD,LCDBAUD,[017,010,000,"Pause",017,000,001,209,
    "Running",017,011,001,"Stop",030,001,016]
                                          'Write LCD Screen
    DO WHILE POSITION <= 6000 AND IMADAVAL < 5000
                                          'Prevent damage, stop with
```

```
                                        'bottom right button
    IF INA = 7 THEN TESTEND
    IF INA <> 11 THEN TESTGO
    SEROUT LCD,LCDBAUD,[017,001,001,"Paused ",017,010,000,"  Run"]
    DO WHILE INA <> 15
    LOOP
    DO
    IF INA = 007 THEN TESTEND
    IF INA = 011 THEN TESTUNP
    LOOP
    TESTUNP:
    DO WHILE INA <> 15
    LOOP
    SEROUT LCD,LCDBAUD,[017,001,001,"Running",017,010,000,"Pause"]
    TESTGO:
    SEROUT IMADAOUT,IMADABAUD,["D",CR]
                                        'Send Imada read command
    SERIN  IMADAIN,IMADABAUD,1000,IMADAERROR,[STR IMADA\8]
                                        'Read Imada data string
    IMADAVAL = ((IMADA(1)-48)*1000)+((IMADA(3)-48)*100)+((IMADA(4)-
    48)*10)+((IMADA(5)-48))
                                        'Interpret Imada data string
    IF SIZE <> 0 THEN GOTO SIZER        'If size established, continue
    SIZE = POSITION                     'Set size position
    SIZER:
    GOSUB SENDPLOTDATA
    IF IMADAVAL < IMADAOLD THEN TESTEND
                                        'BIOYIELD DETECTED! (END TEST)
    IMADAOLD = IMADAVAL                 'Store IMADAVAL for bioyield
                                        'detection upon next loop
    GOSUB POSUP                         'Actuate motor
    PAUSE SPEED                         'Wait timer (speed,
                                        'lower = faster)
  LOOP

  TESTEND:                              'Begin test finalization
  SEROUT COMP,COMPBAUD,["DONE",CR]      'Alert Macro testing complete
  LABEL = 0                             'Re-establish labels in Macro
  SIZE = POSITION - SIZE - 1            'Finalize size
  PAUSE 1000                            'Stop motor for 1 second
  MOTORSTEP = 1                         'Full Stepping
  IF IMADAVAL < 20 OR SIZE > 50000  THEN NODATA
                                        'Detect if error in test
                                        '(no data collected)
  SEROUT LCD,LCDBAUD,[012,017,000,001,209,DEC IMADAOLD,017,005,001,
  "g",017,007,001,DEC SIZE,017,011,001,"Step",017,000,000,209,
  "Test #",DEC SAMPLE]
                                        'Write LCD Screen (final data)
SENDPOINTDATA                           'Send data to computer if RTS on
  DO WHILE INA <> 15                    'Wait until no key pressed
  LOOP                                  '
  SELECT SETTINGS.BIT1                  'Autostore, autonext setting
    CASE 000                            'Manual store
      SEROUT LCD,LCDBAUD,[017,010,000,"Store",030,001,016]
                                        'Write LCD Screen
      GOSUB RESET                       'Reset rack position
      DO WHILE INA = 15                 'Wait until button pressed
      LOOP

      IF INA = 011 THEN GOSUB MEMSTORE
                                        'If store key pressed,
                                        'write to EEPROM
    CASE 001                            'Autostore on, wait for
                                        'next or autonext
```

```
        GOSUB RESET                         'Reset rack position
        GOSUB MEMSTORE                      'Store data to EEPROM
    ENDSELECT
    GOTO MAIN                               'Return to MAIN
    NODATA:                                 'No data found
    SEROUT LCD,LCDBAUD,[012,017,001,000,"No Data",017,000,
    001,209,"Resetting"]
                                            'Write LCD Screen
    GOSUB RESET                             'Reset position
    SEROUT IMADAOUT,IMADABAUD,["Z",CR]
    GOTO MAIN                               'Return to MAIN

  CASE 013
    PUT 5,6
    RUN 0

  CASE 014
    PUT 5,1
    RUN 0
ENDSELECT
GOTO MAIN                                   'Return to MAIN

SENDPLOTDATA:                               'Send data to computer
                                            'for plotting
IF LABEL = 1 THEN SKIPLABEL0                'Determine if labeling required
SEROUT COMP,COMPBAUD,[CR,"CLEARDATA",CR,"LABEL,Disp (mm),
Force (N),,",CR]
                                            'First data, clear excel,
                                            'setup labels
LABEL = 1
SKIPLABEL0:                                 'No need to label
SEROUT COMP,COMPBAUD,["DATA,",DEC POSITION - SIZE,",",DEC IMADAVAL,CR]
                                            'Send Data to computer
RETURN                                      'Return


MEMSTORE:                                   'EEPROM memory storage sub
SEROUT LCD,LCDBAUD,[012,017,000,001,209,"Storing"]
                                            'Write LCD Screen
'BYPPLOT:
STORE SAMPLE/512 + 2                        'Set storage slot based on
                                            'sample number
WRITE (SAMPLE // 512) * 4 ,SIZE.HIGHBYTE
                                            'Store SIZE.HIGHBYTE
WRITE (SAMPLE // 512) * 4 + 1,SIZE.LOWBYTE
                                            'Store SIZE.LOWBYTE
WRITE (SAMPLE // 512) * 4 + 2,IMADAOLD.HIGHBYTE
                                            'Store IMADAOLD.HIGHBYTE
WRITE (SAMPLE // 512) * 4 + 3,IMADAOLD.LOWBYTE
                                            'Store IMADAOLD.LOWBYTE
SAMPLE = SAMPLE + 1                         'Increase sample number
STORE 0                                     'Select first program slot
WRITE 5,SAMPLE.HIGHBYTE                     'Write SAMPLE.HIGHBYTE
WRITE 5,SAMPLE.LOWBYTE                      'Write SAMPLE.LOWBYTE
STORE 1                                     'Return to this program slot
PAUSE 250                                   'Pause (act like writing)
RETURN                                      'Return to previous location

INITIALIZE:                                 'Initialization sequence
GET 0,SETTINGS                              'Read SETTINGS
GET 1,SAMPLE.HIGHBYTE                       'Read SAMPLE.HIGHBYTE
GET 2,SAMPLE.LOWBYTE                        'Read SAMPLE.LOWBYTE
GET 3,SPEED.HIGHBYTE                        'Read SPEED.HIGHBYTE
GET 4,SPEED.LOWBYTE                         'Read SPEED.LOWBYTE
```

```
SEROUT LCD,LCDBAUD,[004,020,024,012,017,000,000,209,"Initializing"]
                                        'Write LCD Screen
SEROUT IMADAOUT,IMADABAUD,["D",CR]      'Send IMADA read command
SERIN  IMADAIN,IMADABAUD,1000,IMADAERROR,[STR IMADA\8]
                                        'Read IMADA string to
                                        'test on / off
SEROUT IMADAOUT,IMADABAUD,["Z",CR]      'Send IMADA tare
GOSUB RESET                             'Reset motor position
SEROUT LCD,LCDBAUD,[012,017,000,000,209,"Ready"]
                                        'Write LCD Screen
PAUSE 250                               'Pause for "Ready"
RETURN                                  'Return from location

RESETPAUSE:                             'Try to unstuck the motor
                                        '(test complete)
PAUSE 1000
MOTORSTEP = 0
FOR CMD = 0 TO 50
GOSUB POSUP
NEXT

RESET:                                  'Reset sequence
MOTORPOS = (MOTORPOS / 2) * 2           'Get motor onto single
                                        'coil firing
MOTORSTEP = 1                           'Full stepping
DO WHILE IN6 = 1                        'Continue motor until zero
                                        'button pressed
GOSUB POSDOWN                           'Actuate motor down
PAUSE 3                                 'Motor speed timer
IF POSITION > 30000 AND POSITION // 3000 = 0 THEN RESETPAUSE
                                        'Prevent motor burnup
LOOP
FOR PLOOP = 0 TO 255                    'Upon button pressed, begin count
IF IN6 = 1 THEN RESET                   'If button released, restart
                                        'motor down
NEXT
RESETUP:                                'Start running motor up
                                        'off switch
MOTORSTEP = 0                           'Half stepping
DO WHILE IN6 = 0                        'Continue motor until zero
                                        'button released
GOSUB POSUP                             'Actuate motor up
PAUSE 10                                'Motor speed timer
LOOP
FOR PLOOP = 0 TO 255                    'Upon button released,
                                        'begin count
IF IN6 = 0 THEN RESETUP                 'If button pressed, restart
                                        'motor up
NEXT
POSITION = 0                            'Zero position
RETURN

POSDOWN:
MOTORPOS = MOTORPOS - (MOTORSTEP + 1)
POSITION = POSITION - (MOTORSTEP + 1)
GOTO MOTOR
POSUP:
MOTORPOS = MOTORPOS + (MOTORSTEP + 1)
POSITION = POSITION + (MOTORSTEP + 1)
GOTO MOTOR
MOTOR:
BRANCH MOTORPOS,[MOTOR0,MOTOR1,MOTOR2,MOTOR3,MOTOR4,MOTOR5,MOTOR6,
MOTOR7, MOTORPOS0,MOTORPOS1,MOTORPOS0,MOTORPOS0,MOTORPOS0,MOTORPOS0,
MOTORPOS6,MOTORPOS7]
```

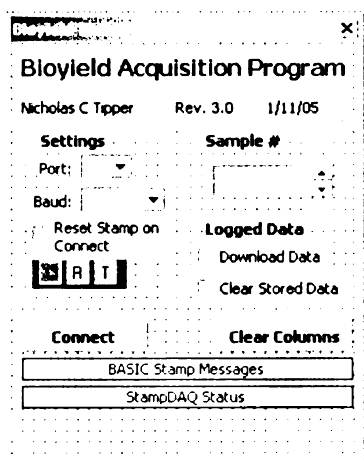
```
MOTORPOS0:
MOTORPOS = 0
GOTO MOTOR
MOTORPOS1:
MOTORPOS = 1
GOTO MOTOR
MOTORPOS6:
MOTORPOS = 6
GOTO MOTOR
MOTORPOS7:
MOTORPOS = 7
GOTO MOTOR
MOTOR0:
OUTD = %0001
RETURN
MOTOR1:
OUTD = %0011
RETURN
MOTOR2:
OUTD = %0010
RETURN
MOTOR3:
OUTD = %0110
RETURN
MOTOR4:
OUTD = %0100
RETURN
MOTOR5:
OUTD = %1100
RETURN
MOTOR6:
OUTD = %1000
RETURN
MOTOR7:
OUTD = %1001
RETURN

IMADAERROR:                                 'Imada error encountered
                                            '(probably turned off)
SEROUT LCD,LCDBAUD,[012,017,000,000,209,"Imada Error"]
                                            'Write LCD Screen
IELOOP:                                     'Loop until error resolved
SEROUT IMADAOUT,IMADABAUD,["D",CR]          'Send read command
SERIN  IMADAIN,IMADABAUD,2000,IELOOP,[STR IMADA\8]
                                            'Determine if read successful
SEROUT LCD,LCDBAUD,[012,017,000,000,209,"Restarting"]
                                            'Write LCD Screen
PAUSE 1000                                  'Pause
GOTO START                                  'Restart program
```

APPENDIX C: Biovield Data Collector Code

The bioyield data collector consists of a macro written with VBA (Visual Basic for Applications) embedded inside of a Microsoft Excel spreadsheet. This macro uses the SelmaWare StampDAQ Active-X control, which is available from the website of Parallax, Inc. (http://www.parallax.com). Parallax, Inc. and Martin Hebel of SelmaWare Solutions wrote the original VBA code. Modifications to the VBA code enhanced operation for this application by performing preliminary mathematics, data analysis, and improved data collection.

frmSTAMPDAQ(userform)



frmSTAMPDAQ(code)

```
Dim Row              'Holds Excel row number for populating
Dim timestamp
Dim speedstamp
Dim speedA
Dim sender As Boolean
Dim FlagConnect As Boolean
```

```
Private Sub cboBAUD_Change()
    stamp.Disconnect
    cmdConnect.Caption = "Connect"
    FlagConnect = False
    stamp.Baud = cboBAUD
End Sub
```

```
Private Sub cboPort_DropButtonClick()
   stamp.Disconnect
   cmdConnect.Caption = "Connect"
   FlagConnect = False
   stamp.Port = cboPort
End Sub
```

```
Private Sub chkReset_Click()
If chkReset.Value = True Then
     Beep
     txtStatus2 = "Waiting for data reset..."
End If
End Sub
```

```
Private Sub cmdClear_Click()
    Beep
    Call clearSheet
End Sub
```

```
Private Sub cmdConnect_Click()
If FlagConnect = False Then
  On Error GoTo ConnectErr
  stamp.DTREnabled = CBool(chkDTR)
  stamp.Connect
  cmdConnect.Caption = "Disconnect"
  FlagConnect = True
  txtStatus2 = "Connected"
Else
  stamp.Disconnect
  cmdConnect.Caption = "Connect"
  FlagConnect = False
  txtStatus2 = "Disconnected"
End If
Exit Sub

ConnectErr:
Call MsgBox("StampDAQ could not connect." & vbCrLf & "Please check port
settings", vbExclamation)
End Sub
```

```
Private Sub chkDump_Click()
If chkDump.Value = True Then
    Beep
    txtStatus2 = "Waiting for Download..."
End If
End Sub
```

```
Private Sub SpinButton1_Change()
TextBox1.Value = SpinButton1.Value
End Sub
```

```
Private Sub stamp_CommError()
' On comm error beep and display

Beep
MsgBox ("Data or Communications error")
  txtStatus2 = "Data or Comm Error"
End Sub
```

```
Private Sub stamp_DataError()
  txtStatus2 = "Error: Data < ASCII 13 or > ASCII 200"
End Sub
```

```
Private Sub stamp_DataReady()
'Fires upon incoming data ending in a chr(13) or CR

On Error GoTo Data_Error
Dim DataVal() As String
Dim data As String
Dim cc

While stamp.gotData = True
  data = stamp.GetData          'Accept new data
  cc = countChar(data, ",")
  If data <> "" Then
    DataVal = Split(data, ",")  'Split up comma-delimited
                                'data to DataVal(0) through ?

    Select Case DataVal(0)
    Case "CMD?"                 'If data is INST?, send response
        txtStatus2 = "Stamp requesting instruction..."
        If chkDump.Value = True Then
            stamp.SendData ("11")
                                'Tell Stamp to dump
            Exit Sub
        End If

        If chkReset = True Then
            stamp.SendData ("22")
                                'Tell Stamp to reset
            Exit Sub
        End If


    Case "CLEARDATA"
        Beep
        txtStatus2 = "Clearing sheet..."
        Call clearSheet

    Case "LABEL"                'Data Beginning with "LABEL"
                                'indicates to label cells
                                'Sample Stamp Code: DEBUG "LABEL,
                                'Value X, Value Y",CR
                                'Each column gets a comma separated
value
        txtStatus2 = "Setting labels"
        timestamp = Hour(Time) * 24 * 60 + Minute(Time) * 60 +
        Second(Time)
        speedstamp = 0
        speedA = 0
        Sheets("Collect").Cells(1, 1) = DataVal(1)
        If cc >= 2 Then Sheets("Collect").Cells(1, 2) = DataVal(2)
        Sheets("Data").Cells(1, SpinButton1.Value + 1).Select
        Sheets("Data").Cells(1, SpinButton1.Value + 1) =
        SpinButton1.Value
        If Sheets("Data").Cells(4, SpinButton1.Value + 1) <> 0 Then
         Sheets("Data").Cells(4, SpinButton1.Value + 1) = Null
        Row = 11                'Skip a few rows

    Case "DATA"                 'Incoming data starts with 1
                                'Sample Stamp Code: DEBUG "DATA,1,2,3"
                                'Parse each data value into cells
        If Row = 11 Then Call clearSheet
        Row = Row + 1           'Increment row number
        txtStatus2 = "Accepting data for Row " & (Row - 1)
        Sheets("Collect").Cells(Row - 10, 1) = DataVal(1) *
```

```
         0.0064748409
        Sheets("Data").Cells(Row, 1) = DataVal(1) * 0.0064748409
        If cc >= 2 Then Sheets("Collect").Cells(Row - 10, 2) =
        DataVal(2) / 1000 * 9.81
        If cc >= 2 Then Sheets("Data").Cells(Row, SpinButton1.Value +
         1) = DataVal(2) / 1000 * 9.81
        If cc >= 3 Then Sheets("Collect").Cells(Row, 3) = DataVal(3)
        If timestamp = Hour(Time) * 24 * 60 + Minute(Time) * 60 +
         Second(Time) Then GoTo speedskip
        speedstamp = speedstamp + 1
        If speedstamp = 1 Then speedA = Sheets("Data").Cells(Row, 1):
         timestamp = Hour(Time) * 24 * 60 + Minute(Time) * 60 +
         Second(Time): GoTo speedskip
        If Sheets("Data").Cells(4, SpinButton1.Value + 1) = 0 Then
         Sheets("Data").Cells(4, SpinButton1.Value + 1) =
         (Sheets("Data").Cells(Row, 1) - speedA) * 60 Else
         Sheets("Data").Cells(4, SpinButton1.Value + 1) =
         ((Sheets("Data").Cells(4, SpinButton1.Value + 1) *
         (speedstamp - 1) + (Sheets("Data").Cells(Row, 1) - speedA) *
         60)) / speedstamp
        speedA = Sheets("Data").Cells(Row, 1)
        timestamp = Hour(Time) * 24 * 60 + Minute(Time) * 60 +
         Second(Time)
speedskip:

    Case "DUMPING"              'Stamp says DUMPING
        txtStatus2 = "Download starting..."
        Call clearSheet
        Row = 11

    Case "RESET"            'Stamp Says it is reseting
            Beep
            txtStatus2 = "Data cleared!"
            chkReset.Value = False

    Case "DONE"
         If Sheets("Data").Cells(12, SpinButton1.Value + 1) = "" Then
          txtStatus2 = "No Data!": GoTo doneskip
         Sheets("Data").Cells(2, SpinButton1.Value + 1) =
          Sheets("Data").Cells(Row - 1, SpinButton1.Value + 1)
         Sheets("Data").Cells(3, SpinButton1.Value + 1) =
          Sheets("Data").Cells(Row - 1, 1)
         SpinButton1.Value = SpinButton1.Value + 1
         txtStatus2 = "Operation Complete!"
doneskip:
         stamp.ClearBuffer
         chkDump.Value = False
         Row = 11
         Beep


    Case "MSG"
           txtStatus1 = DataVal(1)

    Case "OK"
         'stamp.ClearBuffer
         txtStatus2 = "OK!"
         End

    End Select
End If
Wend
Exit Sub
```

```
Data_Error:
End Sub
```

```
Private Sub clearSheet()
        Sheets("Collect").Range("A2:J65000").Value = Null
                                 'Clear columns
        Row = 11
End Sub
```

```
Private Function countChar(stringIn As String, stringChar As String)
For X = 1 To Len(stringIn)
    If Mid(stringIn, X, 1) = stringChar Then
        countChar = countChar + 1
    End If
Next
End Function
```

```
Private Function ReplaceData(strData)
        strData = Replace(strData, "TIME", Time)
        strData = Replace(strData, "DATE", Date)
        ReplaceData = strData
End Function
```

```
Private Sub TextBox1_Change()
SpinButton1.Value = TextBox1.Value
End Sub
```

```
Private Sub userform_Initialize()
cboPort.AddItem "1"
cboPort.AddItem "2"
cboPort.AddItem "3"
cboPort.AddItem "4"
cboPort.AddItem "5"
cboPort.AddItem "6"
cboPort.AddItem "7"
cboPort.AddItem "8"
cboPort.AddItem "9"
cboPort.Text = "1"

cboBAUD.AddItem ("300")
cboBAUD.AddItem ("600")
cboBAUD.AddItem ("1200")
cboBAUD.AddItem ("2400")
cboBAUD.AddItem ("4800")
cboBAUD.AddItem ("9600")
cboBAUD.AddItem ("14400")
cboBAUD.AddItem ("19200")
cboBAUD.AddItem ("28800")
cboBAUD.AddItem ("38400")
cboBAUD.AddItem ("56000")
cboBAUD.Text = "4800"

stamp.Register = "Parallax:StampDAQ:A1F31"
Row = 11
TextBox1.Value = SpinButton1.Value
Sheets("Data").Cells(1, 1) = "Sample #"
Sheets("Data").Cells(2, 1) = "Max Force (N)"
Sheets("Data").Cells(3, 1) = "Max Disp (mm)"
Sheets("Data").Cells(4, 1) = "Approx Speed (mm/min)"
Sheets("Data").Cells(10, 1) = "Displacement (mm)"
End Sub
```

APPENDIX D: Bioyield (BY) versus Magness-Taylor (MT) Data for Red Delicious (R) and Golden Delicious (G) Apples.

Test Date: 1/20/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	29.23	1.106	16.34	74.99	R	34	23.06	0.972	11.19	65.33	R	67	28.75	0.792	11.31	66.77	R
2	31.60	1.056	16.60	74.85	R	35	27.81	0.857	11.78	84.25	R	68	30.81	0.923	14.29	77.86	R
3	28.46	1.081	15.35	69.84	R	36	34.00	1.053	18.02	78.65	R	69	27.02	0.747	10.10	73.37	R
4	26.17	0.863	11.30	76.69	R	37	29.29	1.055	15.57	71.94	R	70	33.71	0.906	15.01	93.03	R
5	34.36	0.968	16.53	83.70	R	38	34.99	0.997	17.45	78.05	R	71	31.67	1.015	15.93	73.65	R
6	33.09	1.011	16.50	75.32	R	39	33.98	0.978	16.60	71.02	R	72	35.17	0.965	17.01	82.86	R
7	35.29	0.976	17.09	79.42	R	40	28.23	1.160	16.48	77.30	R	73	29.73	1.015	15.04	80.09	R
8	37.40	1.063	19.68	74.32	R	41	31.95	0.951	15.22	74.07	R	74	30.05	0.904	14.03	75.59	R
9	31.23	0.986	15.25	78.13	R	42	27.64	1.094	15.21	73.72	R	75	32.80	0.973	16.00	78.12	R
10	34.62	1.241	21.33	76.39	R	43	31.63	0.975	15.29	67.90	R	76	35.25	1.082	18.68	86.18	R
11	35.13	1.038	18.06	79.01	R	44	35.55	0.958	16.83	84.14	R	77	29.20	0.925	13.45	83.36	R
12	33.42	1.000	16.59	78.55	R	45	27.03	1.081	14.53	74.80	R	78	31.12	0.974	15.15	76.57	R
13	33.04	1.142	18.74	81.94	R	46	28.70	0.827	12.01	80.43	R	79	32.74	0.859	14.00	91.58	R
14	34.71	1.162	20.21	74.04	R	47	32.71	0.999	16.32	97.31	R	80	30.06	0.985	14.66	85.95	R
15	31.67	0.948	14.94	78.28	R	48	27.77	0.824	11.74	67.71	R	81	32.88	0.871	14.07	83.57	R
16	29.93	1.046	15.65	69.17	R	49	31.91	0.835	13.24	85.72	R	82	26.05	0.895	11.65	73.03	R
17	32.82	0.799	13.17	82.11	R	50	26.28	0.848	11.04	76.70	R	83	32.34	1.112	18.00	66.84	R
18	34.49	0.928	15.83	86.25	R	51	31.75	1.146	17.99	72.54	R	84	28.32	0.951	13.47	72.83	R
19	36.09	0.930	16.37	88.11	R	52	34.16	0.910	15.42	76.42	R	85	31.69	1.028	16.57	76.24	R
20	37.02	0.787	14.34	67.30	R	53	30.00	0.960	14.14	73.13	R	86	27.30	0.818	11.11	74.54	R
21	23.59	0.814	9.55	70.91	R	54	26.10	1.042	13.68	67.43	R	87	30.94	1.271	19.78	64.22	R
22	32.33	0.868	13.80	72.63	R	55	29.31	1.048	15.18	74.45	R	88	28.83	0.711	10.19	79.59	R
23	26.43	0.926	12.23	74.63	R	56	32.02	0.996	15.92	70.08	R	89	30.44	0.967	14.59	74.43	R
24	26.69	0.767	10.13	71.14	R	57	33.07	1.090	17.86	70.42	R	90	35.57	0.945	16.48	79.96	R
25	31.37	1.221	19.30	72.28	R	58	33.80	0.936	15.68	75.28	R	91	31.20	1.009	15.69	71.11	R
26	29.80	0.902	13.56	62.95	R	59	28.94	0.934	13.24	78.83	R	92	24.75	0.812	10.23	73.99	R
27	23.71	1.048	12.47	70.61	R	60	26.83	0.877	11.65	72.50	R	93	28.49	1.130	16.41	77.36	R
28	26.26	0.847	11.03	85.45	R	61	32.78	1.103	18.15	99.24	R	94	30.54	1.070	16.21	73.08	R
29	32.57	1.029	16.67	74.17	R	62	29.18	0.828	12.12	78.99	R	95	29.80	0.941	13.98	91.79	R
30	32.91	1.070	17.36	74.42	R	63	26.48	1.081	14.72	73.21	R	96	31.07	1.037	15.90	80.87	R
31	34.58	1.052	18.06	70.87	R	64	32.43	1.059	17.24	78.91	R	97	29.02	0.913	13.16	87.81	R
32	33.97	1.166	19.64	77.00	R	65	37.61	0.940	17.40	83.89	R	98	34.10	0.891	15.00	83.51	R
33	34.46	0.858	14.57	87.72	R	66	32.94	0.986	16.14	78.04	R	99	26.00	0.794	10.31	78.70	R
												100	35.28	1.060	18.44	71.51	R

Test Date: 1/21/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	26.98	0.822	11.11	68.59	R	34	29.69	0.929	13.74	71.09	R	67	26.52	0.852	11.20	68.40	R
2	28.93	1.004	14.64	73.18	R	35	24.27	0.758	9.31	77.61	R	68	26.76	1.036	13.72	64.66	R
3	28.42	0.879	12.82	66.39	R	36	28.68	0.960	13.68	67.82	R	69	29.99	0.996	14.73	63.94	R
4	30.15	0.842	12.71	67.68	R	37	30.14	0.871	13.12	69.89	R	70	29.57	0.938	13.71	69.76	R
5	26.46	0.662	8.76	70.04	R	38	28.33	0.929	13.20	77.23	R	71	29.13	0.850	12.11	76.92	R
6	26.21	0.741	9.65	73.27	R	39	23.88	0.887	10.18	72.83	R	72	26.41	0.841	11.06	68.37	R
7	25.10	0.854	10.70	68.83	R	40	27.87	0.749	10.55	67.85	R	73	25.26	0.828	10.22	84.29	R
8	30.75	0.949	14.68	67.65	R	41	24.78	1.182	14.93	65.99	R	74	32.97	1.119	18.30	69.19	R
9	25.90	0.824	10.73	69.73	R	42	27.39	0.851	11.63	63.64	R	75	29.19	0.820	12.02	72.97	R
10	28.85	1.141	16.64	68.69	R	43	30.08	0.621	9.19	80.21	R	76	28.75	1.011	14.29	71.03	R
11	30.35	0.694	10.57	75.47	R	44	30.99	0.872	13.45	80.92	R	77	27.37	0.855	11.53	76.70	R
12	30.28	0.935	14.13	66.53	R	45	28.37	0.971	13.79	82.62	R	78	29.06	0.876	12.63	75.18	R
13	28.54	0.886	12.62	73.36	R	46	26.37	0.981	12.97	69.12	R	79	29.78	1.431	20.97	53.97	R
14	30.80	0.966	14.93	70.54	R	47	25.56	0.737	9.35	72.63	R	80	25.36	0.800	10.13	64.62	R
15	26.89	1.248	16.83	77.34	R	48	28.35	0.794	11.25	68.45	R	81	27.46	0.863	11.84	75.45	R
16	28.97	1.036	15.05	66.64	R	49	27.89	0.756	10.57	69.44	R	82	19.66	0.741	7.33	42.48	R
17	28.30	0.922	12.99	75.96	R	50	33.98	1.014	17.18	72.38	R	83	23.25	0.836	9.83	72.77	R
18	28.65	0.784	11.23	64.44	R	51	30.43	1.056	16.63	77.22	R	84	30.42	0.726	11.06	70.27	R
19	24.14	0.843	10.14	66.69	R	52	28.17	0.743	10.48	73.95	R	85	27.52	0.993	13.73	79.24	R
20	30.55	0.802	12.27	67.76	R	53	27.57	1.071	14.80	69.68	R	86	34.47	0.930	15.89	96.16	R
21	24.56	0.870	10.59	72.08	R	54	34.22	1.072	18.05	76.59	R	87	25.53	0.651	8.30	71.07	R
22	25.11	0.658	8.19	77.42	R	55	29.33	0.897	13.11	66.06	R	88	30.98	1.140	17.91	70.70	R
23	28.63	0.800	11.44	61.86	R	56	30.11	0.743	11.19	77.14	R	89	29.60	0.871	12.98	76.29	R
24	27.13	0.858	11.57	71.28	R	57	36.29	1.014	18.39	59.78	R	90	28.45	0.872	12.25	73.71	R
25	24.96	0.812	9.98	70.77	R	58	29.57	0.853	12.58	65.47	R	91	30.22	0.808	12.22	66.76	R
26	25.08	0.795	9.96	66.65	R	59	27.20	0.982	13.41	67.05	R	92	30.08	0.840	12.71	64.38	R
27	28.42	0.850	12.05	58.11	R	60	31.15	0.938	14.58	69.43	R	93	21.08	0.821	8.50	67.64	R
28	25.50	0.762	9.67	67.44	R	61	27.31	0.700	9.56	71.06	R	94	29.02	0.862	12.52	68.81	R
29	25.58	0.931	11.89	69.30	R	62	29.68	0.752	11.21	76.81	R	95	27.81	0.936	12.98	77.76	R
30	32.65	0.888	14.48	76.54	R	63	30.81	0.792	12.12	80.66	R	96	30.96	0.997	15.58	76.98	R
31	30.00	0.998	14.88	71.68	R	64	23.14	0.746	8.54	67.47	R	97	29.04	1.056	15.26	70.89	R
32	32.42	0.994	16.14	58.74	R	65	24.95	0.942	11.75	70.60	R	98	27.60	0.894	12.45	77.29	R
33	24.46	0.809	9.88	65.11	R	66	26.98	0.735	9.79	72.54	R	99	29.98	1.196	19.85	72.66	R
												100	29.11	0.775	11.37	66.07	R

Test Date: 1/25/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	24.55	0.931	11.35	43.90	R	34	24.68	0.902	11.13	58.58	R	67	29.11	1.046	15.25	59.86	R
2	27.08	1.072	14.57	59.11	R	35	27.29	1.035	14.01	57.76	R	68	28.55	1.041	15.17	54.63	R
3	26.57	1.117	14.73	65.10	R	36	24.78	1.007	12.52	60.95	R	69	24.81	1.015	12.62	62.41	R
4	29.48	0.966	14.25	52.69	R	37	25.65	1.091	13.93	58.63	R	70	26.25	1.168	15.27	53.65	R
5	29.69	1.127	16.64	62.63	R	38	24.66	0.927	11.44	49.31	R	71	23.70	1.087	13.08	58.75	R
6	23.92	0.956	11.42	48.95	R	39	23.89	0.802	9.46	47.70	R	72	26.76	0.958	13.03	70.06	R
7	28.00	1.088	15.17	55.10	R	40	29.99	1.053	15.76	60.27	R	73	30.73	1.077	16.50	60.43	R
8	19.91	0.842	8.29	58.18	R	41	28.20	1.196	16.75	56.91	R	74	31.78	1.007	16.12	59.82	R
9	22.52	1.022	11.52	50.73	R	42	23.10	1.061	12.89	56.85	R	75	27.57	1.222	16.58	54.61	R
10	25.21	1.081	13.57	61.01	R	43	24.51	0.925	11.45	60.63	R	76	30.51	1.227	18.77	57.43	R
11	31.41	1.214	19.10	50.88	R	44	25.57	0.853	10.79	51.78	R	77	24.24	0.832	10.02	57.46	R
12	24.96	0.975	12.24	52.35	R	45	25.87	1.066	13.81	62.99	R	78	25.74	0.950	12.14	55.87	R
13	25.58	0.849	10.91	55.82	R	46	30.08	0.953	14.13	63.75	R	79	25.47	1.058	13.48	53.39	R
14	30.30	1.162	17.47	65.26	R	47	25.21	0.945	11.79	63.11	R	80	26.05	0.971	12.56	61.61	R
15	26.54	0.927	12.35	65.71	R	48	29.35	1.014	14.89	62.38	R	81	29.29	1.109	16.42	58.90	R
16	30.28	0.916	13.90	64.66	R	49	27.91	0.948	13.16	54.46	R	82	25.28	1.033	12.99	58.39	R
17	27.65	0.979	13.47	56.27	R	50	24.86	0.952	11.65	55.08	R	83	25.85	1.157	15.02	50.33	R
18	28.92	1.025	14.79	67.09	R	51	28.51	1.010	14.22	60.25	R	84	33.15	0.956	15.66	67.52	R
19	25.31	1.149	14.42	58.78	R	52	27.64	0.994	13.82	56.42	R	85	26.10	1.101	14.43	56.90	R
20	23.50	0.881	10.26	54.95	R	53	24.53	0.947	11.56	50.74	R	86	20.89	0.933	9.82	52.44	R
21	26.64	0.948	12.54	63.59	R	54	26.97	1.128	15.30	64.91	R	87	25.07	1.076	13.49	52.41	R
22	30.23	1.198	18.12	56.12	R	55	25.63	0.878	11.16	61.20	R	88	28.41	1.282	18.04	62.67	R
23	30.11	1.111	16.53	62.65	R	56	29.17	0.883	12.89	56.61	R	89	26.65	0.936	12.46	53.13	R
24	20.53	0.855	8.67	54.19	R	57	26.21	1.141	14.89	63.54	R	90	25.11	1.154	14.50	55.53	R
25	23.79	0.998	11.88	56.39	R	58	25.06	0.870	10.72	54.36	R	91	26.73	0.905	12.09	58.73	R
26	27.52	1.005	13.65	54.26	R	59	24.40	0.864	10.56	61.08	R	92	31.38	1.149	17.91	67.34	R
27	27.82	0.972	13.64	57.24	R	60	35.14	0.998	17.38	75.11	R	93	30.13	1.144	17.26	58.77	R
28	27.16	1.276	17.27	55.86	R	61	30.79	1.080	16.49	66.88	R	94	30.56	1.207	18.28	62.03	R
29	29.11	1.022	14.82	61.53	R	62	27.41	0.906	12.47	54.94	R	95	28.17	1.012	13.99	53.48	R
30	26.25	1.159	15.42	55.03	R	63	27.20	1.096	14.87	57.16	R	96	26.27	1.190	16.10	59.83	R
31	30.51	1.117	16.94	58.19	R	64	27.69	1.194	16.56	53.95	R	97	28.89	1.017	14.72	68.26	R
32	23.56	0.950	11.12	51.40	R	65	24.85	0.856	10.68	52.71	R	98	30.91	1.242	19.11	61.17	R
33	28.41	1.018	14.43	65.09	R	66	30.63	1.035	15.96	59.70	R	99	28.35	1.023	14.36	61.09	R
												100	28.88	1.080	15.70	62.03	R

Test Date: 1/27/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	24.39	1.302	15.94	55.60	G	34	29.02	1.309	18.70	62.79	G	67	27.31	1.260	17.11	62.46	G
2	26.55	1.287	16.98	65.21	G	35	22.18	1.000	11.08	47.35	G	68	28.25	1.072	15.02	59.49	G
3	25.84	1.131	14.45	64.25	G	36	25.70	1.179	15.08	55.67	G	69	28.41	1.106	15.66	70.18	G
4	18.69	1.022	10.01	49.39	G	37	25.45	1.329	17.01	57.59	G	70	27.39	1.284	17.53	70.69	G
5	28.31	1.399	19.75	67.12	G	38	31.59	1.320	20.89	70.32	G	71	25.09	1.154	14.54	56.22	G
6	29.72	1.180	17.51	67.90	G	39	27.52	1.226	16.84	63.63	G	72	29.94	1.204	18.00	62.57	G
7	28.25	1.338	18.83	62.31	G	40	31.72	1.392	22.15	60.58	G	73	24.89	1.108	13.79	57.61	G
8	28.53	1.265	18.02	65.60	G	41	29.46	1.217	17.87	68.61	G	74	29.75	1.151	17.11	65.63	G
9	25.28	1.352	16.85	76.30	G	42	26.64	1.150	15.18	58.75	G	75	24.46	1.130	13.72	64.12	G
10	30.08	1.342	20.02	70.62	G	43	30.81	1.280	19.67	74.21	G	76	26.09	1.215	15.74	65.31	G
11	29.19	1.395	20.17	64.45	G	44	29.22	1.381	19.86	73.16	G	77	29.02	1.355	19.54	69.07	G
12	28.75	1.199	16.94	64.09	G	45	29.56	1.278	18.84	57.32	G	78	30.67	1.190	18.34	65.26	G
13	20.28	1.040	10.62	45.17	G	46	28.42	1.427	20.36	74.85	G	79	22.24	1.408	15.75	54.99	G
14	25.75	1.246	16.14	63.21	G	47	25.81	0.966	12.43	71.31	G	80	31.66	1.390	21.83	66.35	G
15	26.42	1.283	16.94	59.54	G	48	24.01	1.046	12.74	53.12	G	81	24.98	1.187	14.81	56.25	G
16	23.03	1.368	15.79	60.09	G	49	24.32	1.147	14.05	59.11	G	82	30.82	1.219	18.65	56.40	G
17	32.24	1.136	18.03	71.42	G	50	25.82	1.042	13.43	62.13	G	83	28.90	1.268	18.14	67.59	G
18	27.81	1.293	18.06	66.16	G	51	21.71	1.115	12.13	60.84	G	84	22.97	1.382	15.87	59.08	G
19	24.76	1.225	15.07	66.14	G	52	23.35	1.105	12.93	61.96	G	85	20.36	1.190	12.02	62.21	G
20	29.01	1.263	18.22	68.11	G	53	27.91	1.257	17.38	63.11	G	86	27.26	1.246	17.02	59.93	G
21	26.44	1.076	14.24	55.40	G	54	19.61	1.093	10.77	55.22	G	87	25.12	1.205	15.12	66.02	G
22	25.77	1.195	15.34	64.44	G	55	18.59	1.026	9.59	47.44	G	88	26.48	1.442	19.42	61.92	G
23	29.36	1.216	17.65	67.57	G	56	21.72	1.004	10.83	51.69	G	89	25.65	1.115	14.25	63.64	G
24	25.09	1.101	13.93	60.39	G	57	27.90	1.266	17.63	57.97	G	90	32.06	1.322	21.13	64.82	G
25	23.99	1.337	16.21	72.19	G	58	22.03	0.922	10.24	59.45	G	91	29.31	1.241	18.31	68.68	G
26	25.60	1.191	15.30	62.38	G	59	20.16	1.117	11.31	55.65	G	92	27.28	1.132	15.30	72.32	G
27	30.45	1.289	19.36	62.32	G	60	23.94	1.229	14.73	57.48	G	93	28.39	1.367	19.25	60.86	G
28	27.63	1.220	16.73	65.08	G	61	24.27	1.117	13.50	60.69	G	94	28.10	1.068	14.79	58.12	G
29	28.74	1.195	17.15	59.84	G	62	28.11	1.385	19.35	70.22	G	95	21.33	1.036	10.99	50.80	G
30	27.13	1.063	14.88	69.27	G	63	28.03	1.103	15.44	56.84	G	96	29.18	1.077	15.57	57.03	G
31	30.16	1.213	18.22	71.25	G	64	27.35	1.277	17.41	54.33	G	97	30.07	1.283	19.28	75.49	G
32	23.86	1.225	14.65	70.28	G	65	26.81	1.290	17.49	62.86	G	98	32.66	1.156	18.61	81.51	G
33	27.62	1.457	20.04	76.11	G	66	29.22	1.204	17.64	71.24	G	99	27.65	1.312	18.07	66.60	G
												100	22.51	1.202	13.71	66.39	G

Test Date: 1/28/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	29.51	1.568	23.41	62.17	G	34	29.95	1.058	16.07	74.03	G	67	23.57	1.310	15.42	61.89	G
2	26.51	1.157	15.22	65.90	G	35	29.87	1.089	16.23	69.67	G	68	20.73	0.945	9.81	59.44	G
3	26.63	1.026	13.84	69.92	G	36	31.81	1.252	19.80	74.29	G	69	21.45	0.894	9.57	59.45	G
4	29.82	1.168	17.54	71.58	G	37	26.63	1.083	14.34	70.10	G	70	29.96	1.209	17.96	73.93	G
5	31.47	1.107	17.27	70.11	G	38	30.27	1.128	16.98	72.71	G	71	22.25	0.912	10.12	58.84	G
6	24.71	0.907	11.16	64.12	G	39	22.86	1.078	12.29	65.82	G	72	21.65	0.911	9.86	58.94	G
7	22.87	0.997	11.27	69.04	G	40	27.29	1.102	15.05	59.02	G	73	27.66	1.192	16.40	65.86	G
8	29.41	1.250	18.52	63.83	G	41	31.41	1.407	22.35	65.58	G	74	31.03	1.223	19.06	71.53	G
9	28.99	1.132	16.53	63.78	G	42	23.72	1.004	11.92	74.09	G	75	23.08	0.966	11.13	67.32	G
10	25.38	1.051	13.54	61.96	G	43	25.20	1.079	13.64	60.94	G	76	23.76	1.044	12.34	61.57	G
11	22.47	0.988	11.08	71.48	G	44	27.43	1.213	16.55	71.66	G	77	30.70	1.137	17.45	80.85	G
12	27.00	1.289	17.52	68.48	G	45	28.88	1.161	16.59	68.11	G	78	17.48	0.938	8.28	64.57	G
13	26.73	1.210	16.25	62.28	G	46	25.83	1.049	13.41	62.40	G	79	26.68	1.049	13.98	69.27	G
14	30.15	1.105	16.61	60.29	G	47	27.02	1.124	15.07	71.40	G	80	23.62	1.072	12.65	64.43	G
15	23.14	1.057	12.21	64.65	G	48	32.60	1.146	18.72	77.11	G	81	27.24	1.076	14.64	65.45	G
16	25.30	0.957	12.17	59.85	G	49	28.50	1.048	14.79	72.64	G	82	25.67	1.201	15.41	58.20	G
17	28.19	1.018	14.30	70.90	G	50	28.18	1.037	14.59	66.03	G	83	24.03	0.995	11.97	64.56	G
18	26.87	1.065	14.34	64.74	G	51	26.06	1.033	13.41	70.54	G	84	22.84	1.024	11.67	56.99	G
19	24.68	1.220	15.14	69.88	G	52	26.65	1.080	14.31	68.35	G	85	23.97	1.010	12.22	66.33	G
20	25.48	1.060	13.46	66.11	G	53	26.62	1.128	15.01	65.86	G	86	24.43	1.084	13.40	64.88	G
21	24.74	1.115	13.68	63.89	G	54	26.57	1.125	14.96	60.65	G	87	22.48	1.039	11.57	62.51	G
22	29.10	1.125	16.37	67.61	G	55	29.76	1.155	17.32	71.89	G	88	21.22	0.894	9.53	69.99	G
23	33.87	0.941	15.85	76.70	G	56	26.71	1.206	16.34	66.83	G	89	20.34	0.987	10.11	65.39	G
24	27.93	1.004	13.90	71.73	G	57	21.14	0.952	10.08	63.34	G	90	22.43	1.060	11.82	64.28	G
25	22.37	0.943	10.52	66.06	G	58	29.28	1.236	18.19	64.98	G	91	24.93	1.124	14.08	62.01	G
26	28.28	1.179	16.78	68.93	G	59	26.33	1.130	14.87	69.44	G	92	26.07	1.032	13.38	65.74	G
27	28.10	0.964	13.89	65.34	G	60	27.76	1.126	15.50	64.19	G	93	24.20	1.007	12.16	56.37	G
28	30.70	1.059	16.38	68.98	G	61	24.97	0.867	10.79	67.20	G	94	24.89	1.036	12.83	63.78	G
29	24.46	1.095	13.37	77.15	G	62	26.55	1.028	13.54	65.95	G	95	23.84	0.941	11.17	61.65	G
30	21.40	1.040	11.14	64.81	G	63	25.54	1.013	12.90	69.14	G	96	25.78	1.043	13.37	65.92	G
31	28.88	1.665	25.21	72.74	G	64	19.01	0.943	9.04	58.22	G	97	25.76	1.111	14.35	64.33	G
32	25.79	0.889	11.49	73.31	G	65	27.68	1.150	15.95	69.48	G	98	25.02	1.021	12.94	65.78	G
33	31.11	1.138	17.72	66.51	G	66	24.70	1.127	13.84	67.31	G	99	30.30	1.030	15.52	73.68	G
												100	24.37	0.943	11.69	58.68	G

Test Date: 2/1/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	15.26	0.758	5.83	34.88	G	34	13.45	0.735	4.93	29.32	G	67	12.59	0.798	4.97	30.11	G
2	14.26	0.659	4.67	35.23	G	35	12.98	0.804	5.19	31.12	G	68	13.28	0.756	4.96	29.73	G
3	13.79	0.767	5.26	37.26	G	36	14.81	0.861	6.42	29.27	G	69	11.23	0.597	3.32	30.07	G
4	12.39	0.725	4.54	31.64	G	37	14.97	0.952	7.17	31.41	G	70	13.41	0.722	4.84	34.29	G
5	14.60	0.767	5.57	32.90	G	38	14.56	0.779	5.64	35.73	G	71	14.05	0.819	5.72	27.90	G
6	13.99	0.701	4.86	29.92	G	39	14.66	0.777	5.73	30.10	G	72	12.58	0.713	4.49	31.70	G
7	15.88	0.810	6.44	34.96	G	40	14.10	0.871	6.09	29.79	G	73	14.11	0.775	5.43	35.95	G
8	13.30	0.736	4.84	32.21	G	41	12.66	0.775	4.95	29.70	G	74	11.61	0.690	3.98	29.99	G
9	14.84	0.787	5.80	30.92	G	42	13.32	0.743	4.95	28.08	G	75	13.85	0.887	6.10	32.90	G
10	15.14	0.825	6.23	31.91	G	43	13.78	0.790	5.44	30.94	G	76	11.00	0.786	4.36	25.06	G
11	14.74	0.830	6.11	31.60	G	44	13.84	0.754	5.22	32.37	G	77	12.35	0.809	5.03	30.20	G
12	14.59	0.803	5.85	32.12	G	45	13.46	0.786	5.27	32.32	G	78	15.46	0.758	5.91	34.26	G
13	13.71	0.660	4.53	33.54	G	46	13.21	0.764	5.04	32.28	G	79	17.82	1.038	9.25	33.81	G
14	12.95	0.691	4.45	29.56	G	47	14.33	0.821	5.89	32.71	G	80	14.80	1.219	9.13	36.73	G
15	14.12	0.686	4.86	33.50	G	48	13.26	0.782	5.16	31.81	G	81	14.29	0.997	7.17	30.60	G
16	12.55	0.729	4.56	27.80	G	49	12.60	0.765	4.88	32.91	G	82	14.79	0.787	5.83	32.09	G
17	11.85	0.686	4.04	31.59	G	50	14.21	0.768	5.45	33.70	G	83	14.73	0.749	5.49	36.31	G
18	13.05	0.743	4.83	30.33	G	51	14.36	1.250	9.17	29.54	G	84	12.12	0.695	4.22	28.28	G
19	13.34	0.889	5.96	31.99	G	52	11.72	0.818	4.84	33.24	G	85	14.29	0.908	6.45	30.96	G
20	15.00	0.793	5.97	31.07	G	53	18.40	0.919	8.46	30.19	G	86	11.62	0.821	4.75	28.93	G
21	14.65	0.756	5.54	30.90	G	54	14.65	0.908	6.82	30.35	G	87	15.56	0.764	5.92	35.57	G
22	13.46	0.783	5.27	29.83	G	55	12.59	0.845	5.30	28.24	G	88	12.29	0.651	3.97	29.84	G
23	13.05	0.813	5.36	33.37	G	56	13.08	0.726	4.74	30.23	G	89	12.38	0.803	4.94	28.31	G
24	15.16	0.762	5.81	34.06	G	57	13.54	0.822	5.55	31.23	G	90	10.44	0.746	3.93	28.43	G
25	15.38	0.869	6.66	28.14	G	58	14.07	0.823	5.77	29.34	G	91	11.60	0.762	4.40	29.30	G
26	14.81	0.737	5.43	32.54	G	59	14.83	0.888	6.54	37.94	G	92	13.71	1.038	7.12	31.25	G
27	12.27	0.826	5.07	33.23	G	60	13.74	0.903	6.19	33.44	G	93	16.49	0.888	7.34	33.56	G
28	13.37	0.790	5.19	31.76	G	61	13.31	0.736	4.91	27.50	G	94	13.28	0.851	5.69	33.59	G
29	12.96	0.847	5.48	31.73	G	62	13.94	0.857	6.00	31.00	G	95	13.39	0.810	5.59	37.45	G
30	15.11	0.775	5.81	31.45	G	63	13.72	0.788	5.38	31.64	G	96	15.85	0.882	6.96	30.16	G
31	14.75	0.790	5.79	36.01	G	64	14.42	0.863	6.24	32.99	G	97	12.93	0.817	5.33	30.80	G
32	13.03	0.785	5.11	32.34	G	65	13.05	0.876	5.72	26.44	G	98	13.33	0.776	5.18	31.00	G
33	12.41	0.789	4.88	27.26	G	66	14.46	0.784	5.63	31.25	G	99	15.00	0.909	6.82	30.98	G
												100	14.56	0.859	6.51	28.18	G

Test Date: 2/2/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	17.47	0.710	6.10	38.54	R	34	20.47	0.760	7.75	44.88	R	67	17.06	0.792	7.05	37.40	R
2	14.27	0.608	4.41	39.51	R	35	21.85	0.926	10.10	40.73	R	68	18.10	0.654	6.09	44.50	R
3	21.53	0.816	8.76	36.50	R	36	22.67	0.914	10.43	49.16	R	69	18.38	0.863	7.92	38.43	R
4	19.28	0.921	8.94	37.17	R	37	18.96	0.815	7.63	41.16	R	70	22.46	0.975	10.97	37.68	R
5	25.21	0.878	11.10	44.03	R	38	22.49	0.914	10.34	48.11	R	71	14.04	0.709	5.32	39.59	R
6	15.21	0.882	6.79	21.17	R	39	20.50	0.850	9.03	48.62	R	72	16.09	0.865	6.93	28.80	R
7	18.62	0.723	6.72	44.47	R	40	18.40	0.786	7.26	46.86	R	73	17.37	0.981	8.50	35.55	R
8	17.60	0.649	5.69	48.22	R	41	19.61	0.827	8.14	39.39	R	74	13.33	0.692	4.65	40.39	R
9	26.98	1.019	13.62	50.87	R	42	20.74	0.881	9.17	42.86	R	75	18.26	0.684	6.26	40.84	R
10	17.51	0.862	7.63	33.05	R	43	22.90	1.022	11.80	44.37	R	76	19.44	0.993	9.63	39.74	R
11	17.29	0.724	6.36	46.56	R	44	17.73	0.917	8.13	40.72	R	77	16.54	0.791	6.67	41.42	R
12	22.76	0.859	9.75	37.16	R	45	19.23	0.779	7.52	39.68	R	78	18.67	0.694	6.50	36.25	R
13	17.47	0.674	5.91	37.15	R	46	20.76	0.750	7.75	49.96	R	79	18.78	0.810	7.63	37.00	R
14	21.24	0.632	6.69	43.03	R	47	21.22	0.905	9.66	41.36	R	80	23.05	0.750	8.77	40.28	R
15	17.19	0.693	6.08	46.72	R	48	17.99	0.706	6.36	39.15	R	81	18.99	0.859	8.26	44.53	R
16	19.43	0.718	6.86	37.00	R	49	21.54	1.063	11.35	43.93	R	82	21.65	1.032	11.29	44.51	R
17	20.25	0.791	7.97	42.45	R	50	22.23	0.809	8.98	58.88	R	83	23.28	0.948	11.42	50.05	R
18	16.74	0.727	6.08	38.03	R	51	17.42	0.889	7.72	35.39	R	84	20.45	1.015	10.53	31.99	R
19	19.94	0.773	7.70	31.80	R	52	22.16	0.963	10.70	44.25	R	85	15.04	0.718	5.45	34.78	R
20	17.06	1.318	11.43	23.63	R	53	21.76	0.802	8.71	42.69	R	86	18.36	0.809	7.44	33.61	R
21	16.85	0.738	6.21	42.01	R	54	19.64	0.802	7.94	42.67	R	87	23.34	1.013	11.80	41.09	R
22	19.16	0.603	5.74	39.14	R	55	22.07	0.673	7.39	45.23	R	88	20.38	1.000	10.30	37.53	R
23	20.04	0.696	6.94	45.18	R	56	21.10	0.771	8.07	47.56	R	89	17.35	0.841	7.32	35.98	R
24	21.16	0.910	9.55	44.32	R	57	24.31	0.926	11.27	47.31	R	90	17.36	0.822	7.25	47.35	R
25	20.28	1.125	11.35	46.10	R	58	18.71	0.813	7.67	51.40	R	91	21.67	0.748	8.16	43.46	R
26	17.75	0.687	6.27	41.19	R	59	18.59	0.730	6.78	39.97	R	92	22.03	0.948	10.41	43.94	R
27	12.75	0.734	4.69	33.98	R	60	20.06	0.827	8.49	38.15	R	93	17.86	0.706	6.35	33.91	R
28	19.22	0.791	7.64	44.39	R	61	18.05	0.646	5.96	40.08	R	94	20.85	0.726	7.58	34.31	R
29	12.18	0.641	4.05	36.91	R	62	20.36	0.862	8.86	35.17	R	95	23.42	0.873	10.32	38.88	R
30	19.74	1.144	11.77	47.53	R	63	18.59	0.788	7.32	37.92	R	96	21.54	0.884	9.49	40.77	R
31	21.06	1.051	11.15	47.45	R	64	22.56	0.851	9.69	39.52	R	97	19.33	0.772	7.47	37.91	R
32	18.68	0.859	7.99	34.25	R	65	19.78	0.669	6.69	34.57	R	98	21.16	0.676	7.15	44.28	R
33	19.56	0.935	9.17	45.87	R	66	18.68	0.870	8.10	42.93	R	99	23.15	0.750	8.70	45.16	R
												100	19.35	0.861	8.40	38.36	R

Test Date: 2/3/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	15.35	0.874	6.76	35.05	G	34	15.90	0.941	7.50	34.59	G	67	15.99	0.989	7.89	40.42	G
2	12.91	0.709	4.55	34.29	G	35	16.58	1.090	8.99	40.41	G	68	16.25	0.998	8.10	36.04	G
3	15.45	0.859	6.66	32.53	G	36	15.32	0.829	6.37	36.42	G	69	13.38	0.762	5.15	32.18	G
4	17.78	0.863	7.66	37.39	G	37	13.90	0.744	5.18	32.44	G	70	17.42	1.028	9.22	42.44	G
5	17.43	0.959	8.38	39.50	G	38	14.60	1.012	7.43	35.34	G	71	14.15	0.751	5.67	37.75	G
6	14.90	0.769	5.78	32.77	G	39	15.45	0.985	7.64	35.77	G	72	16.13	0.939	7.60	35.72	G
7	16.32	0.928	7.57	36.66	G	40	20.42	1.104	11.27	44.14	G	73	15.06	0.878	6.62	39.13	G
8	16.17	0.796	6.50	32.81	G	41	17.43	0.980	8.55	38.06	G	74	16.15	0.855	6.98	36.99	G
9	14.74	0.761	5.69	33.68	G	42	14.32	0.790	5.74	35.87	G	75	16.46	0.884	7.28	33.11	G
10	17.99	1.015	9.20	41.11	G	43	18.09	0.989	8.95	38.29	G	76	17.16	1.051	9.14	34.47	G
11	17.05	1.048	9.06	35.73	G	44	17.49	0.876	7.71	44.91	G	77	17.90	0.904	8.02	42.53	G
12	16.48	0.817	6.74	32.78	G	45	14.22	0.881	6.26	35.39	G	78	18.24	1.020	9.27	41.68	G
13	16.02	0.763	6.12	32.51	G	46	15.61	0.934	7.33	31.74	G	79	13.94	0.811	5.76	32.89	G
14	15.62	0.916	7.21	36.63	G	47	16.07	0.838	6.68	32.78	G	80	16.03	0.930	7.47	37.38	G
15	16.52	0.973	8.03	34.72	G	48	15.07	0.829	6.29	35.68	G	81	13.84	0.875	6.11	33.25	G
16	16.19	0.904	7.38	35.34	G	49	15.57	0.754	5.94	35.68	G	82	17.99	0.968	8.77	45.40	G
17	14.86	0.900	6.67	33.27	G	50	17.37	0.797	6.89	36.35	G	83	18.04	0.938	8.45	36.40	G
18	16.77	1.057	8.92	37.05	G	51	15.45	0.918	7.06	36.31	G	84	17.72	0.935	8.30	44.18	G
19	16.08	0.906	7.32	34.75	G	52	16.69	0.732	6.18	35.97	G	85	17.14	0.845	7.30	40.60	G
20	15.46	0.942	7.26	34.96	G	53	18.35	1.065	9.84	39.83	G	86	17.20	1.024	8.80	43.41	G
21	14.53	0.880	6.39	35.19	G	54	17.13	0.906	7.71	35.60	G	87	19.03	0.966	9.26	45.59	G
22	17.38	0.987	8.58	38.32	G	55	15.44	0.776	6.01	35.02	G	88	16.67	1.096	9.12	33.76	G
23	14.05	0.803	5.71	35.20	G	56	13.73	0.804	5.50	34.28	G	89	16.70	0.879	7.37	43.69	G
24	17.47	1.278	11.19	42.13	G	57	12.21	0.872	5.39	32.63	G	90	18.09	0.924	8.31	43.37	G
25	13.81	1.130	7.77	35.48	G	58	16.13	0.934	7.51	38.17	G	91	14.89	0.855	6.43	38.57	G
26	14.15	0.928	6.64	35.06	G	59	16.59	0.824	6.88	39.29	G	92	12.70	0.888	5.67	37.28	G
27	16.17	1.011	8.09	33.16	G	60	14.49	0.851	6.23	35.86	G	93	17.09	0.941	8.04	36.45	G
28	23.63	1.317	15.50	51.14	G	61	18.03	0.855	7.72	37.81	G	94	15.14	0.781	6.00	34.71	G
29	14.42	0.927	6.70	34.37	G	62	15.63	1.089	8.50	39.88	G	95	16.70	0.939	7.80	38.41	G
30	15.19	0.959	7.26	41.14	G	63	16.81	0.939	7.88	37.22	G	96	14.93	0.912	6.79	33.23	G
31	17.32	1.035	9.13	41.07	G	64	16.65	1.058	8.81	35.99	G	97	15.93	0.788	6.26	37.00	G
32	15.03	0.880	6.65	34.62	G	65	19.03	1.133	10.85	48.98	G	98	15.87	0.818	6.56	42.05	G
33	16.36	1.256	10.39	34.57	G	66	16.71	0.868	7.34	35.66	G	99	16.94	0.801	6.81	33.04	G
												100	18.28	0.890	8.15	35.89	G

Test Date: 2/4/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	17.65	0.704	6.22	48.82	R	34	19.12	0.773	7.33	44.92	R	67	22.34	0.816	9.17	44.72	R
2	20.28	0.993	10.49	41.78	R	35	19.88	0.705	7.06	48.10	R	68	18.04	0.890	8.06	43.69	R
3	22.09	0.910	10.10	49.78	R	36	23.08	0.776	8.97	44.55	R	69	20.27	1.008	10.21	48.47	R
4	21.68	0.650	7.04	44.33	R	37	21.99	0.770	8.49	44.88	R	70	20.13	1.013	10.12	45.35	R
5	23.61	0.884	10.44	47.06	R	38	22.88	0.721	8.23	53.14	R	71	21.70	0.906	9.76	46.21	R
6	19.91	0.866	8.50	43.02	R	39	22.30	0.824	9.22	49.34	R	72	20.06	0.920	9.38	48.53	R
7	19.21	0.855	8.28	55.77	R	40	20.14	0.740	7.42	50.41	R	73	19.49	0.822	7.82	52.85	R
8	16.82	0.665	5.56	40.63	R	41	24.71	0.899	11.07	62.68	R	74	21.40	0.785	8.42	45.93	R
9	18.59	0.821	7.57	43.94	R	42	24.86	0.969	12.12	48.49	R	75	21.99	0.898	9.84	43.13	R
10	17.80	0.928	8.35	48.81	R	43	22.17	0.926	10.24	50.70	R	76	21.62	0.816	8.91	42.35	R
11	21.18	0.720	7.61	38.68	R	44	22.77	0.814	9.19	54.40	R	77	20.06	0.746	7.55	45.67	R
12	19.85	0.808	7.98	47.69	R	45	22.26	0.757	8.39	41.33	R	78	22.86	0.886	10.14	44.40	R
13	23.52	0.766	8.96	45.21	R	46	21.86	0.809	8.82	50.72	R	79	23.97	0.925	11.01	49.03	R
14	23.12	0.831	9.59	46.61	R	47	22.96	1.009	11.61	44.45	R	80	21.71	0.784	8.59	49.56	R
15	18.89	0.910	8.67	39.56	R	48	18.94	0.780	7.30	44.93	R	81	22.58	0.965	10.88	49.49	R
16	23.92	0.863	10.28	50.97	R	49	22.90	0.954	11.00	47.25	R	82	24.06	0.865	10.47	50.75	R
17	22.80	1.054	12.09	44.01	R	50	23.44	0.948	11.17	43.49	R	83	22.75	0.799	9.17	46.30	R
18	19.83	0.842	8.28	39.03	R	51	20.05	0.711	7.16	47.57	R	84	26.51	0.839	10.97	48.09	R
19	20.95	0.998	10.45	45.00	R	52	24.53	1.019	12.70	47.17	R	85	27.30	1.081	14.89	52.51	R
20	21.52	0.858	9.55	58.48	R	53	24.23	0.892	10.77	55.97	R	86	25.34	0.968	12.24	47.89	R
21	21.62	0.899	9.70	44.15	R	54	21.19	0.707	7.56	43.83	R	87	25.02	0.958	12.02	47.54	R
22	18.58	0.751	6.93	53.69	R	55	20.96	0.806	8.45	39.35	R	88	28.01	1.021	14.46	53.29	R
23	25.75	0.864	11.03	46.33	R	56	21.73	0.995	10.63	52.70	R	89	26.02	1.102	14.24	51.87	R
24	17.61	0.792	6.98	48.47	R	57	21.79	0.944	10.23	40.30	R	90	24.80	0.964	11.90	47.80	R
25	21.52	0.857	9.40	42.45	R	58	24.91	0.974	12.09	48.28	R	91	20.89	0.723	7.57	46.20	R
26	20.35	0.829	8.73	42.72	R	59	17.41	0.747	6.46	46.07	R	92	21.36	0.765	8.31	44.73	R
27	24.84	0.891	11.15	52.47	R	60	21.39	0.734	7.78	50.17	R	93	20.34	0.776	7.92	43.40	R
28	26.88	1.032	13.91	46.27	R	61	17.73	0.930	8.27	45.07	R	94	24.57	0.788	9.67	45.21	R
29	22.89	0.820	9.58	49.89	R	62	21.10	0.921	9.63	53.66	R	95	20.88	0.915	9.52	48.44	R
30	20.14	0.767	7.73	44.56	R	63	23.40	1.005	11.91	41.15	R	96	20.25	0.799	8.03	49.41	R
31	23.62	0.988	11.82	40.35	R	64	22.53	0.819	9.24	38.67	R	97	19.58	0.806	7.91	48.75	R
32	20.74	0.866	9.00	42.70	R	65	19.64	0.771	7.69	43.71	R	98	21.96	0.691	7.58	53.32	R
33	19.27	0.766	7.33	44.03	R	66	20.94	0.851	8.83	49.03	R	99	21.45	0.755	8.39	46.58	R
												100	19.93	0.902	8.93	42.88	R

Test Date: 2/9/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	17.83	1.323	11.91	49.11	G	34	23.84	1.943	23.46	58.09	G	67	20.79	1.286	13.36	47.41	G
2	22.83	1.240	14.14	51.20	G	35	22.74	1.603	18.27	55.82	G	68	22.10	1.395	15.39	47.93	G
3	23.77	1.448	17.15	58.28	G	36	22.71	1.189	13.50	51.93	G	69	22.98	1.229	14.06	54.75	G
4	21.87	1.329	14.52	51.71	G	37	23.75	1.680	19.87	58.60	G	70	22.43	1.382	15.45	46.76	G
5	19.11	1.378	13.21	47.29	G	38	22.27	1.416	15.80	49.54	G	71	20.84	1.270	13.25	49.29	G
6	21.06	1.439	15.17	45.43	G	39	24.83	1.635	20.34	56.10	G	72	21.39	1.363	14.63	47.37	G
7	21.04	1.116	11.68	41.62	G	40	20.64	1.550	16.08	46.22	G	73	23.24	1.289	14.91	51.58	G
8	20.90	1.398	14.57	49.12	G	41	25.87	1.534	19.74	53.60	G	74	16.44	1.235	10.20	43.91	G
9	19.11	1.400	13.34	42.22	G	42	22.60	1.387	15.57	49.58	G	75	23.82	1.605	19.06	52.72	G
10	19.52	1.294	12.65	44.26	G	43	25.26	1.521	19.34	54.22	G	76	21.94	1.254	13.68	47.94	G
11	18.67	1.393	13.39	42.47	G	44	20.85	1.315	13.66	50.29	G	77	22.67	1.214	13.74	48.03	G
12	20.10	1.334	13.64	46.51	G	45	21.97	1.343	14.69	57.12	G	78	23.46	1.385	16.19	52.91	G
13	22.92	1.517	17.32	52.57	G	46	24.42	1.450	17.78	51.37	G	79	22.25	1.284	14.23	50.13	G
14	21.11	1.647	17.19	52.75	G	47	20.82	1.183	12.27	51.42	G	80	20.94	1.327	13.84	44.67	G
15	22.78	1.461	16.36	54.98	G	48	21.25	1.508	16.01	54.20	G	81	22.29	1.284	14.16	45.95	G
16	19.22	1.304	12.62	47.71	G	49	24.33	1.515	18.35	59.81	G	82	21.00	1.201	12.66	44.40	G
17	18.89	1.346	13.07	39.61	G	50	21.20	1.416	14.97	48.46	G	83	17.90	1.336	11.93	43.41	G
18	23.03	1.251	14.35	54.18	G	51	19.98	1.312	13.09	53.34	G	84	18.29	1.063	9.71	43.98	G
19	28.74	1.294	18.41	49.47	G	52	21.54	1.478	15.91	47.34	G	85	25.57	1.414	17.99	59.08	G
20	19.81	1.359	13.40	43.27	G	53	22.38	1.412	15.83	49.76	G	86	20.66	1.228	12.84	50.46	G
21	29.07	1.849	26.71	56.39	G	54	19.22	1.516	14.46	45.70	G	87	20.93	1.254	13.20	50.61	G
22	21.44	1.278	13.61	49.83	G	55	23.94	1.405	16.89	53.78	G	88	19.79	1.340	13.30	47.07	G
23	24.29	1.547	18.52	55.64	G	56	23.49	1.702	19.80	45.54	G	89	25.98	1.447	18.75	56.20	G
24	26.40	1.503	19.83	52.81	G	57	22.12	1.317	14.48	48.17	G	90	20.42	1.223	12.44	49.37	G
25	22.71	1.610	18.22	49.40	G	58	22.81	1.347	15.30	49.39	G	91	19.85	1.314	13.11	48.10	G
26	19.35	1.348	13.14	50.23	G	59	17.75	1.044	9.26	42.83	G	92	23.02	1.259	14.47	56.18	G
27	20.65	1.479	15.29	45.05	G	60	24.68	1.265	15.69	51.24	G	93	23.01	1.260	14.39	53.84	G
28	24.08	1.599	19.14	48.38	G	61	19.83	1.218	11.94	47.27	G	94	23.05	1.345	15.50	50.51	G
29	22.43	1.419	15.85	53.21	G	62	23.68	1.531	18.28	61.87	G	95	20.86	1.163	12.25	48.88	G
30	23.99	1.631	19.85	59.33	G	63	19.13	1.277	12.20	46.03	G	96	24.20	1.316	16.03	52.90	G
31	27.21	1.593	21.46	54.11	G	64	21.08	1.320	13.91	43.87	G	97	20.27	1.488	15.01	48.85	G
32	19.91	1.340	13.27	50.83	G	65	21.90	1.518	16.55	59.49	G	98	22.34	1.326	14.90	53.56	G
33	24.36	1.512	18.56	58.44	G	66	23.72	1.557	18.71	56.26	G	99	18.21	1.226	11.13	40.32	G
												100	19.16	1.296	12.41	45.60	G

Test Date: 2/10/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	22.65	1.618	18.23	48.98	G	34	23.56	1.619	19.05	59.53	G	67	21.05	1.473	15.47	52.02	G
2	26.98	1.485	19.93	55.39	G	35	25.13	1.400	17.85	61.09	G	68	21.29	1.512	16.09	49.07	G
3	23.55	1.687	19.94	45.68	G	36	22.84	1.500	16.99	53.08	G	69	22.74	1.423	16.19	48.47	G
4	25.50	1.575	19.86	61.74	G	37	25.32	1.773	22.38	59.87	G	70	22.39	1.588	17.77	49.60	G
5	22.82	1.365	15.54	51.26	G	38	27.06	1.409	19.15	55.07	G	71	25.19	1.736	21.61	58.10	G
6	24.84	1.618	20.09	56.68	G	39	19.62	1.327	12.99	44.58	G	72	21.97	1.623	17.72	51.63	G
7	20.24	1.281	12.86	47.35	G	40	24.39	1.457	17.66	50.68	G	73	25.83	1.710	22.01	64.25	G
8	22.86	1.649	18.80	56.48	G	41	23.87	1.536	18.32	53.43	G	74	25.21	1.689	21.06	52.31	G
9	25.70	1.643	20.96	49.24	G	42	20.79	1.593	16.54	51.32	G	75	26.00	1.956	25.44	62.59	G
10	24.73	1.587	19.52	49.83	G	43	21.83	1.493	16.74	55.06	G	76	26.91	1.446	19.52	51.97	G
11	21.57	1.557	16.84	40.67	G	44	23.71	1.615	18.94	55.01	G	77	22.27	1.677	18.81	53.23	G
12	22.98	1.537	17.57	54.20	G	45	20.75	1.610	16.60	48.47	G	78	22.55	1.778	20.08	55.53	G
13	22.43	1.558	17.89	51.74	G	46	30.02	1.636	24.30	52.57	G	79	23.31	1.554	18.34	57.51	G
14	25.71	1.692	21.92	54.94	G	47	23.38	1.409	16.35	52.51	G	80	23.61	1.614	18.94	53.46	G
15	23.12	1.479	16.87	59.46	G	48	19.26	1.263	12.25	42.19	G	81	27.16	1.477	20.05	59.96	G
16	18.24	1.360	12.44	48.17	G	49	23.88	1.593	18.93	47.80	G	82	23.53	1.499	17.65	50.56	G
17	23.35	1.689	19.81	57.69	G	50	25.18	1.478	18.43	56.92	G	83	23.57	1.671	19.58	66.14	G
18	24.83	1.428	17.66	48.20	G	51	27.49	1.382	18.71	52.85	G	84	25.40	1.547	19.68	53.12	G
19	27.63	1.526	21.10	58.52	G	52	23.39	1.582	18.53	51.74	G	85	27.57	1.930	26.29	63.02	G
20	19.78	1.458	14.69	42.02	G	53	19.42	1.389	13.43	44.06	G	86	21.25	1.378	14.59	54.24	G
21	21.24	1.763	18.77	52.29	G	54	23.97	1.391	16.65	59.28	G	87	22.48	1.266	14.24	53.59	G
22	22.79	1.416	16.17	52.88	G	55	24.87	1.348	16.64	52.30	G	88	20.63	1.459	15.17	53.09	G
23	24.45	1.478	18.02	56.77	G	56	21.69	1.369	14.77	51.20	G	89	25.43	1.533	19.47	53.41	G
24	21.39	1.418	15.28	53.86	G	57	24.41	1.576	19.14	54.34	G	90	25.71	1.442	18.72	57.04	G
25	26.65	1.886	25.00	63.72	G	58	22.56	1.549	17.51	46.30	G	91	24.22	1.519	18.13	58.99	G
26	23.09	1.427	16.56	58.25	G	59	19.67	1.286	12.66	49.03	G	92	27.23	1.825	24.70	60.47	G
27	23.33	1.800	20.89	52.31	G	60	24.25	1.432	17.44	52.65	G	93	24.09	1.626	19.62	58.72	G
28	25.84	1.760	22.77	59.48	G	61	22.23	1.580	17.40	52.03	G	94	21.10	1.255	13.28	51.96	G
29	23.90	1.420	16.95	53.41	G	62	30.35	1.713	25.88	59.70	G	95	22.25	1.536	17.01	52.25	G
30	19.85	1.410	13.98	43.19	G	63	26.10	1.646	21.47	57.05	G	96	22.54	1.438	16.20	48.59	G
31	21.94	1.498	16.41	41.46	G	64	23.60	1.605	18.75	48.11	G	97	27.10	1.668	22.50	55.91	G
32	25.00	1.650	20.42	58.69	G	65	22.56	1.356	15.35	51.89	G	98	24.58	1.683	20.49	54.97	G
33	24.16	1.518	18.25	59.97	G	66	25.57	1.575	20.18	56.96	G	99	22.60	1.291	14.67	49.40	G
												100	25.04	1.334	16.60	54.08	G

Test Date: 2/23/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	27.42	1.300	18.30	52.59	R	34	26.27	1.123	14.79	53.25	R	67	18.72	1.208	11.38	39.45	G
2	21.03	1.091	11.60	41.51	R	35	30.34	1.378	21.84	51.12	R	68	22.92	1.225	14.25	46.56	G
3	20.93	1.199	12.51	47.86	R	36	24.12	1.157	14.66	45.94	R	69	22.06	1.403	15.43	43.81	G
4	25.11	1.046	13.05	42.31	R	37	22.00	1.219	13.96	37.01	R	70	18.59	1.131	10.56	41.72	G
5	21.20	1.225	13.15	40.35	R	38	23.95	1.329	16.42	39.57	R	71	21.39	1.174	12.61	43.69	G
6	26.39	1.088	14.12	48.39	R	39	23.11	0.984	11.79	41.38	R	72	20.16	1.128	11.36	44.99	G
7	26.24	1.148	15.06	52.53	R	40	32.74	1.392	22.78	50.55	R	73	18.88	1.281	12.09	40.54	G
8	27.23	1.158	15.81	48.55	R	41	27.67	0.899	12.35	55.89	R	74	20.24	1.292	13.01	46.48	G
9	23.78	1.121	13.42	46.10	R	42	26.59	0.930	12.34	77.55	R	75	20.44	1.269	12.93	44.99	G
10	22.26	1.052	11.71	43.27	R	43	28.53	1.051	14.87	48.54	R	76	19.13	1.369	13.03	41.09	G
11	24.88	1.228	15.31	39.62	R	44	24.48	0.915	11.26	50.25	R	77	19.41	1.190	11.56	45.79	G
12	23.06	1.209	13.89	41.57	R	45	27.03	1.023	13.82	66.17	R	78	20.48	1.254	12.84	44.43	G
13	21.34	1.044	11.11	37.25	R	46	27.04	1.023	13.75	58.54	R	79	20.38	1.352	13.81	46.76	G
14	30.93	1.296	20.17	47.43	R	47	32.46	1.119	17.98	56.76	R	80	21.70	1.489	16.15	45.15	G
15	27.11	1.085	14.81	42.17	R	48	32.23	1.057	17.28	53.40	R	81	22.98	1.524	17.69	55.15	G
16	25.20	1.287	16.34	54.58	R	49	26.28	1.121	14.70	55.09	R	82	23.23	1.351	15.68	49.63	G
17	28.33	1.271	18.27	68.28	R	50	28.15	1.065	14.86	55.88	R	83	22.79	1.352	15.50	49.76	G
18	23.13	1.205	13.89	51.86	R	51	18.58	1.257	11.73	38.74	G	84	22.53	1.156	13.00	50.83	G
19	27.99	1.206	16.74	46.80	R	52	20.85	1.280	13.26	44.91	G	85	20.66	1.172	12.08	42.53	G
20	26.31	1.293	16.98	54.25	R	53	22.46	1.225	13.69	49.84	G	86	20.50	1.318	13.45	48.45	G
21	30.31	1.164	17.71	59.52	R	54	21.51	1.282	13.96	45.41	G	87	22.06	1.161	12.80	48.76	G
22	25.34	0.969	12.35	54.10	R	55	20.46	1.157	11.79	49.57	G	88	22.73	1.326	15.11	45.30	G
23	26.64	1.126	14.82	58.22	R	56	20.93	1.404	14.67	42.83	G	89	20.35	1.259	12.80	55.73	G
24	32.41	1.138	18.50	56.58	R	57	20.59	1.235	12.72	49.05	G	90	18.18	1.242	11.33	39.85	G
25	29.24	0.922	13.46	51.50	R	58	22.79	1.339	15.23	43.89	G	91	19.51	1.148	11.17	44.51	G
26	23.63	0.815	9.54	54.10	R	59	20.07	1.211	12.17	45.59	G	92	21.02	1.061	11.25	45.42	G
27	25.43	0.916	11.65	55.80	R	60	16.67	1.157	9.71	37.55	G	93	18.96	1.004	9.51	44.73	G
28	30.77	1.080	16.52	55.09	R	61	17.95	1.086	9.72	39.66	G	94	19.12	1.135	10.84	44.81	G
29	27.77	1.051	14.65	49.87	R	62	18.11	1.266	11.61	37.42	G	95	17.33	1.176	10.17	39.99	G
30	26.31	1.023	13.70	58.85	R	63	20.12	1.131	11.45	42.28	G	96	18.89	1.196	11.29	44.63	G
31	25.88	0.961	12.37	53.00	R	64	19.56	1.282	12.62	44.77	G	97	19.93	1.064	10.72	45.25	G
32	28.95	1.239	17.76	48.46	R	65	20.14	1.184	11.97	46.38	G	98	22.54	1.212	13.64	44.39	G
33	23.47	0.969	11.81	44.08	R	66	19.66	1.321	13.08	42.88	G	99	21.39	1.196	12.74	44.71	G
												100	21.38	1.209	12.86	41.20	G

Test Date 2/25/2005

Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety	Sample #	BY Force	BY Disp	BY Area	MT Force	Variety
1	22.59	0.744	8.56	64.49	R	34	26.18	0.746	9.90	61.52	R	67	19.43	1.185	11.60	45.47	R
2	24.63	0.873	11.02	61.01	R	35	24.88	0.835	10.44	59.00	R	68	17.70	1.409	12.58	35.24	R
3	24.65	0.664	8.26	61.16	R	36	24.09	0.720	8.65	64.42	R	69	19.25	1.095	10.55	42.76	R
4	29.06	0.772	11.22	73.49	R	37	27.35	0.898	12.27	61.05	R	70	19.22	1.104	10.58	42.54	R
5	24.44	0.807	9.85	63.37	R	38	21.44	0.881	9.34	59.48	R	71	19.70	1.089	10.83	46.07	R
6	22.08	0.735	8.06	58.93	R	39	27.97	0.838	11.77	61.35	R	72	19.65	1.110	10.93	38.62	R
7	26.90	0.796	10.66	60.33	R	40	24.52	0.777	9.52	59.95	R	73	17.72	0.886	7.77	36.39	R
8	32.29	0.909	14.73	67.50	R	41	22.74	0.816	9.31	60.50	R	74	20.16	1.304	13.25	38.16	R
9	24.66	0.738	9.03	60.56	R	42	25.93	0.964	12.47	63.33	R	75	14.75	1.033	7.88	37.92	R
10	29.59	0.904	13.53	60.27	R	43	24.02	0.799	9.53	58.96	R	76	17.39	1.083	9.34	34.87	R
11	28.68	0.755	10.78	65.35	R	44	25.64	1.097	14.15	59.02	R	77	13.17	1.001	7.05	30.94	R
12	26.50	0.827	10.93	57.49	R	45	30.23	1.000	15.05	71.77	R	78	18.70	1.357	12.39	41.78	R
13	21.59	0.787	8.43	58.62	R	46	25.83	0.777	9.87	67.88	R	79	17.43	1.062	9.26	43.64	R
14	27.25	0.752	10.30	66.34	R	47	27.19	0.919	12.45	63.50	R	80	19.40	1.146	11.30	40.56	R
15	28.09	0.795	11.13	56.86	R	48	24.21	0.999	12.26	58.28	R	81	18.22	0.948	8.67	39.60	R
16	29.56	0.800	11.88	58.88	R	49	17.39	0.763	6.59	55.07	R	82	18.01	0.812	7.29	44.27	R
17	24.36	0.800	9.59	61.39	R	50	27.00	0.925	12.48	63.24	R	83	18.68	0.851	8.14	39.90	R
18	26.27	0.799	10.42	56.39	R	51	19.62	1.120	10.97	42.42	R	84	18.60	1.111	10.34	36.17	R
19	26.76	0.815	10.98	65.53	R	52	15.84	1.065	8.44	36.94	R	85	19.13	1.031	9.96	38.85	R
20	27.54	0.851	11.79	58.43	R	53	21.52	1.139	12.11	41.67	R	86	17.40	0.937	8.33	41.66	R
21	25.15	0.813	10.24	70.57	R	54	18.10	1.046	9.40	42.53	R	87	16.58	0.752	6.29	40.17	R
22	24.69	0.849	10.43	60.46	R	55	20.66	1.304	13.57	36.40	R	88	18.22	1.072	9.81	43.05	R
23	27.48	0.826	11.27	64.49	R	56	18.89	1.053	10.07	39.78	R	89	18.68	1.170	11.17	36.64	R
24	26.12	0.781	10.24	65.58	R	57	22.99	1.112	12.82	47.17	R	90	17.83	0.969	8.59	44.47	R
25	31.75	0.908	14.38	63.85	R	58	20.05	1.112	11.19	43.40	R	91	20.40	1.001	10.20	43.84	R
26	27.25	0.885	12.12	60.54	R	59	17.15	1.063	9.24	44.01	R	92	19.40	1.290	12.49	47.08	R
27	24.06	0.783	9.29	56.66	R	60	18.46	1.197	11.12	40.46	R	93	20.52	1.177	12.03	45.10	R
28	24.11	0.709	8.49	61.70	R	61	18.94	1.094	10.39	41.02	R	94	21.15	1.000	10.54	43.32	R
29	24.42	0.748	9.13	55.80	R	62	18.92	1.175	11.26	35.70	R	95	21.03	1.243	13.15	40.91	R
30	23.22	0.963	11.13	57.08	R	63	23.67	1.359	16.15	43.25	R	96	23.20	1.171	13.60	46.99	R
31	25.14	0.806	10.15	65.44	R	64	17.28	1.042	9.01	42.24	R	97	21.57	1.218	13.10	45.70	R
32	27.18	0.918	12.34	56.21	R	65	17.90	0.989	8.85	38.56	R	98	17.43	1.187	10.50	35.23	R
33	24.27	0.825	9.96	58.66	R	66	19.61	0.961	9.50	33.30	R	99	19.72	1.069	10.41	44.58	R
												100	15.53	1.008	7.85	38.37	R

APPENDIX E: Bioyield (BY) and Magness-Taylor (MT) versus Time Study Data for Golden Delicious Apples

2/4/2005					2/8/2005					2/11/2005				
Sample #	BY Force	BY Disp	BY Area	MT Force	Sample #	BY Force	BY Disp	BY Area	MT Force	Sample #	BY Force	BY Disp	BY Area	MT Force
1	26.62	1.275	16.93	56.57	1	20.43	1.193	12.25	51.47	1	24.01	1.331	15.93	49.33
2	27.38	1.355	18.37	65.53	2	26.24	1.316	17.09	62.75	2	28.37	1.565	22.44	60.07
3	26.95	1.308	17.78	63.31	3	25.14	1.160	14.50	62.92	3	23.13	1.055	12.14	54.11
4	26.42	1.328	17.58	63.49	4	24.83	1.064	13.21	47.81	4	19.45	1.108	10.82	45.11
5	28.07	1.380	19.25	69.82	5	25.34	1.351	17.08	55.15	5	18.36	1.082	10.02	42.36
6	26.37	1.146	15.04	47.91	6	19.65	1.080	10.65	46.14	6	29.34	1.490	21.66	64.58
7	27.00	1.192	15.81	69.19	7	22.55	1.080	12.26	49.54	7	19.77	1.124	11.14	48.98
8	31.78	1.423	22.48	67.48	8	20.84	1.196	12.46	49.36	8	22.39	1.259	14.06	49.94
9	27.76	1.375	18.95	70.35	9	20.26	1.103	11.23	51.29	9	19.85	1.076	10.67	43.63
10	27.42	1.400	19.15	68.72	10	23.13	1.123	12.93	54.37	10	20.06	1.148	11.61	44.68
11	26.36	1.253	17.07	68.80	11	22.46	1.223	13.83	48.09	11	20.42	1.198	12.40	56.52
12	29.88	1.257	18.61	69.55	12	26.17	1.312	17.40	70.20	12	27.44	1.203	16.46	51.75
13	24.17	1.162	14.42	59.56	13	23.77	1.184	13.99	54.55	13	21.71	1.147	12.42	51.12
14	21.50	1.035	11.24	61.84	14	27.13	1.390	18.61	60.87	14	28.42	1.440	20.57	59.35
15	26.71	1.259	17.19	68.80	15	23.91	1.151	13.86	47.58	15	22.28	1.106	12.32	44.97
16	22.84	1.054	12.06	58.69	16	22.71	1.018	11.56	46.89	16	23.30	1.099	12.73	55.93
17	28.08	1.286	18.05	71.97	17	21.68	1.106	12.00	53.36	17	19.55	1.115	10.91	46.27
18	23.66	1.084	12.92	55.55	18	19.69	1.041	10.22	51.59	18	18.31	0.986	8.97	47.50
19	30.97	1.334	20.92	72.15	19	23.27	1.280	14.89	56.65	19	25.31	1.389	17.48	61.03
20	27.67	1.235	17.10	71.20	20	23.91	1.401	16.70	55.15	20	21.28	1.222	12.94	47.96
21	24.44	1.054	12.93	60.46	21	25.78	1.280	16.43	69.45	21	21.22	1.288	13.65	46.14
22	26.65	1.399	18.88	63.89	22	24.14	1.085	13.07	65.13	22	22.05	1.464	16.12	52.91
23	24.26	1.352	16.47	61.10	23	23.33	1.231	14.29	55.14	23	20.42	1.198	12.27	51.33
24	27.87	1.349	18.65	66.10	24	22.93	1.201	13.86	56.94	24	25.84	1.210	15.58	53.26
25	28.88	1.010	15.25	55.31	25	24.45	1.128	13.78	52.97	25	22.79	1.367	15.51	51.59
26	26.18	1.273	16.75	56.28	26	28.05	1.279	18.22	71.11	26	23.42	1.222	14.27	61.69
27	22.40	1.174	13.22	50.54	27	27.25	1.240	16.82	56.78	27	19.99	1.135	11.33	50.84
28	25.36	1.309	16.60	62.35	28	31.01	1.503	23.28	64.16	28	22.92	1.273	14.84	54.33
29	28.61	1.383	19.95	70.05	29	25.82	1.159	14.92	52.08	29	26.52	1.270	16.87	54.99
30	27.16	1.289	17.57	70.33	30	26.51	1.336	17.65	53.37	30	23.07	1.436	16.65	53.08
31	25.76	1.177	15.21	65.77	31	29.55	1.315	19.41	62.91	31	21.13	1.243	13.07	54.43
32	24.11	1.317	16.06	54.32	32	24.91	1.450	17.97	54.53	32	23.94	1.311	15.60	53.62
33	23.91	1.262	15.01	57.80	33	21.20	1.161	12.32	59.69	33	26.42	1.497	19.62	58.37

2/15/2005					2/17/2005					2/25/2005				
Sample #	BY Force	BY Disp	BY Area	MT Force	Sample #	BY Force	BY Disp	BY Area	MT Force	Sample #	BY Force	BY Disp	BY Area	MT Force
1	21.99	1.207	13.38	52.35	1	21.63	1.084	11.70	52.77	1	20.31	1.412	14.64	45.27
2	23.51	1.277	15.00	56.90	2	18.97	1.143	10.83	41.44	2	20.24	1.378	13.94	44.75
3	20.59	1.257	13.01	50.39	3	17.87	1.086	9.72	43.82	3	19.56	1.363	13.34	43.59
4	17.53	1.152	10.28	44.89	4	16.12	1.008	8.15	42.12	4	18.63	1.120	10.52	43.58
5	23.52	1.264	14.90	58.37	5	15.99	1.078	8.65	39.44	5	17.64	1.261	11.19	35.62
6	17.58	1.134	10.00	38.45	6	18.07	1.244	11.31	47.09	6	20.13	1.392	14.00	47.89
7	18.50	1.167	11.02	40.40	7	22.71	1.091	12.39	47.00	7	20.33	1.310	13.35	50.70
8	22.73	1.168	13.25	44.02	8	20.56	0.878	9.07	49.16	8	17.79	1.083	9.62	41.63
9	20.67	1.110	11.56	51.14	9	19.93	1.056	10.52	46.36	9	16.59	1.232	10.27	36.80
10	21.34	1.320	14.16	52.50	10	21.25	1.075	11.42	46.67	10	16.20	1.232	10.07	36.97
11	19.95	1.095	10.95	44.62	11	18.81	1.186	11.15	44.36	11	17.90	1.472	13.41	41.52
12	24.65	1.290	15.95	52.82	12	19.66	1.244	12.17	46.52	12	21.75	1.335	14.50	48.97
13	18.40	1.381	12.82	50.66	13	19.66	1.156	11.41	47.38	13	18.34	1.240	11.29	42.65
14	23.04	1.372	16.00	51.88	14	18.52	1.023	9.40	43.86	14	19.63	1.137	11.17	41.08
15	22.05	1.161	12.84	50.29	15	17.18	1.143	9.96	38.98	15	17.32	1.115	9.73	38.81
16	20.93	1.146	12.07	44.24	16	22.09	1.121	12.37	50.49	16	22.47	1.281	14.40	48.97
17	15.91	0.992	7.91	37.91	17	20.97	1.335	13.99	46.05	17	17.38	1.253	11.09	43.58
18	22.97	1.179	13.71	52.48	18	17.78	1.061	9.48	37.98	18	15.23	1.131	8.74	40.06
19	22.82	1.059	12.05	52.64	19	20.16	1.182	12.00	52.91	19	21.65	1.445	15.55	47.63
20	20.13	1.500	15.07	46.87	20	19.93	1.200	12.08	48.76	20	15.91	1.262	10.12	34.81
21	21.65	1.209	13.01	54.52	21	21.32	1.203	12.82	52.30	21	21.42	1.359	14.57	52.09
22	26.06	1.313	17.06	55.99	22	20.86	1.195	12.44	47.51	22	16.04	1.144	9.14	39.57
23	23.47	1.468	17.23	56.49	23	19.75	1.183	11.68	44.94	23	21.29	1.223	12.97	50.92
24	25.07	1.321	16.42	51.15	24	18.15	1.209	11.00	44.97	24	17.95	1.515	13.67	42.95
25	22.01	1.197	13.09	49.47	25	22.57	1.291	14.61	51.76	25	17.91	1.261	11.30	41.13
26	22.22	1.243	13.87	47.29	26	19.97	1.436	14.58	47.17	26	16.91	1.055	8.89	40.04
27	21.64	1.270	13.74	51.81	27	18.63	1.173	10.89	48.19	27	19.08	1.286	12.32	41.71
28	22.26	1.260	14.04	52.12	28	20.52	1.454	14.95	51.92	28	16.93	1.208	10.20	39.83
29	23.59	1.200	14.13	54.28	29	21.37	1.140	12.20	45.58	29	17.39	1.328	11.55	43.25
30	23.29	1.265	14.86	52.17	30	19.81	1.231	12.25	48.04	30	16.09	1.281	10.34	41.56
31	22.98	1.151	13.24	48.01	31	19.45	1.194	11.59	42.55	31	23.55	1.292	15.07	52.67
32	20.39	1.239	12.57	45.55	32	26.24	1.204	15.72	49.97	32	21.96	1.430	15.86	47.17
					33	22.05	1.222	13.40	49.70	33	17.60	1.329	11.77	41.54

3/1/2005					3/4/2005				
Sample #	BY Force	BY Disp	BY Area	MT Force	Sample #	BY Force	BY Disp	BY Area	MT Force
1	17.85	1.190	10.61	43.44	1	17.96	1.030	9.27	37.41
2	18.72	1.082	10.17	40.29	2	17.80	1.203	10.75	43.36
3	16.62	0.950	7.89	37.27	3	19.16	1.151	11.00	43.17
4	19.53	1.096	10.72	41.46	4	15.07	1.228	9.35	37.17
5	17.21	1.237	10.78	35.48	5	18.19	1.212	11.13	44.45
6	21.03	1.141	12.01	40.96	6	19.62	1.235	12.06	42.81
7	18.55	1.067	9.88	37.06	7	18.32	1.273	11.80	45.64
8	17.90	1.216	10.87	47.59	8	16.77	1.102	9.53	40.08
9	18.89	1.014	9.55	39.58	9	15.58	1.088	8.57	36.60
10	17.56	1.151	10.13	34.57	10	16.08	1.056	8.58	36.47
11	18.82	1.088	10.22	41.41	11	17.18	1.068	9.29	35.46
12	15.93	1.143	9.16	49.82	12	15.28	1.160	9.03	45.05
13	17.78	1.066	9.50	40.45	13	21.61	1.326	14.30	45.88
14	21.64	1.330	14.50	52.01	14	15.91	1.035	8.22	39.39
15	21.90	1.231	13.41	45.39	15	17.65	1.345	11.87	41.92
16	16.72	1.165	9.80	41.78	16	21.70	1.151	12.41	45.61
17	24.78	1.367	16.90	53.20	17	19.73	1.214	12.05	47.94
18	15.30	0.990	7.59	37.26	18	21.21	1.108	11.68	39.43
19	18.74	1.106	10.47	51.82	19	17.63	1.173	10.46	45.03
20	19.57	1.104	10.82	49.16	20	18.47	1.059	9.77	39.81
21	20.15	1.280	12.88	48.20	21	16.68	1.111	9.34	37.23
22	21.52	1.290	13.92	43.84	22	18.75	1.255	11.88	45.66
23	19.45	1.330	12.96	48.83	23	16.78	1.138	9.57	42.63
24	20.87	1.473	15.36	45.51	24	19.37	1.259	12.25	42.93
25	21.57	1.273	13.87	51.39	25	14.12	1.196	8.58	35.17
26	20.04	1.270	12.78	48.53	26	19.31	1.254	11.99	41.48
27	18.80	1.211	11.36	49.23	27	21.88	1.300	14.32	44.74
28	19.57	1.100	10.74	46.03	28	18.30	1.239	11.48	43.09
29	22.11	1.246	13.84	48.91	29	19.29	1.184	11.56	37.65
30	17.47	1.087	9.59	38.44	30	21.51	1.492	15.93	48.66
31	25.91	1.506	19.40	53.36	31	17.94	1.216	10.96	44.58
32	29.34	1.444	20.84	58.82	32	20.76	1.239	12.84	44.35
33	24.81	1.383	17.16	52.81	33	22.48	1.180	13.08	48.38

APPENDIX F: Bioyield (BY) Firmness Location Study for Golden Delicious Apples (N-North, E-East, S-South, W-West; T-Top, M-Middle, B-Bottom)

Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area
1	N	T	21.01	1.148	12.06	4	N	T	32.76	1.216	19.86	7	N	T	23.51	1.188	13.87
1	N	M	19.39	1.240	12.27	4	N	M	28.19	1.153	15.95	7	N	M	25.21	1.161	14.50
1	N	B	24.61	1.439	17.81	4	N	B	29.91	1.256	18.63	7	N	B	28.68	1.274	18.04
1	E	T	24.92	1.270	15.73	4	E	T	19.07	0.886	8.47	7	E	T	20.97	1.226	12.78
1	E	M	20.98	1.125	11.84	4	E	M	27.49	1.165	15.87	7	E	M	22.56	1.387	15.60
1	E	B	28.57	1.436	20.39	4	E	B	40.28	1.415	27.94	7	E	B	27.17	1.422	19.16
1	S	T	23.07	1.099	12.68	4	S	T	23.49	1.148	13.44	7	S	T	22.34	1.163	12.95
1	S	M	26.25	1.169	15.33	4	S	M	25.23	1.159	14.61	7	S	M	25.71	1.174	14.95
1	S	B	30.44	1.258	19.01	4	S	B	27.43	1.630	22.51	7	S	B	28.78	1.370	19.67
1	W	T	26.35	1.175	15.49	4	W	T	25.57	1.200	15.20	7	W	T	24.40	1.095	13.34
1	W	M	24.40	1.191	14.50	4	W	M	27.16	1.332	17.92	7	W	M	23.52	1.246	14.59
1	W	B	27.35	1.499	20.30	4	W	B	29.79	1.454	21.56	7	W	B	25.75	1.108	14.17
2	N	T	22.50	1.332	14.94	5	N	T	23.15	1.269	14.62	8	N	T	24.43	1.406	17.28
2	N	M	23.42	1.386	16.04	5	N	M	22.62	1.218	13.72	8	N	M	21.40	1.155	12.27
2	N	B	25.57	1.306	16.66	5	N	B	32.85	1.409	22.78	8	N	B	24.84	1.583	19.31
2	E	T	25.39	1.328	16.69	5	E	T	23.02	1.105	12.72	8	E	T	22.44	1.322	14.88
2	E	M	22.74	1.278	14.44	5	E	M	20.15	1.144	11.42	8	E	M	23.22	1.066	12.40
2	E	B	33.33	1.382	22.75	5	E	B	29.81	1.401	20.70	8	E	B	25.88	1.662	21.55
2	S	T	21.30	1.280	13.68	5	S	T	23.17	1.245	14.35	8	S	T	22.09	1.299	14.46
2	S	M	23.33	1.460	17.06	5	S	M	22.45	1.261	14.10	8	S	M	24.05	1.400	17.05
2	S	B	20.94	1.270	13.19	5	S	B	27.83	1.356	18.82	8	S	B	25.02	1.508	18.79
2	W	T	23.96	1.306	15.56	5	W	T	21.98	1.172	12.85	8	W	T	26.21	1.236	16.18
2	W	M	22.49	1.261	14.13	5	W	M	21.11	1.080	11.33	8	W	M	28.15	1.511	21.25
2	W	B	27.63	1.288	17.64	5	W	B	27.85	1.458	20.21	8	W	B	23.73	1.502	17.54
3	N	T	20.62	1.021	10.50	6	N	T	25.65	1.121	14.25	9	N	T	21.30	1.204	12.76
3	N	M	21.50	1.089	11.71	6	N	M	23.40	1.228	14.30	9	N	M	21.63	1.354	14.56
3	N	B	30.17	1.302	19.59	6	N	B	29.08	1.483	20.92	9	N	B	25.48	1.176	14.80
3	E	T	25.50	1.138	14.31	6	E	T	26.39	1.199	15.74	9	E	T	27.53	1.271	17.40
3	E	M	24.27	1.230	14.87	6	E	M	25.50	1.338	17.02	9	E	M	25.00	1.400	17.42
3	E	B	30.42	1.210	18.14	6	E	B	31.94	1.193	18.78	9	E	B	27.77	1.622	22.28
3	S	T	26.25	1.105	14.44	6	S	T	21.91	1.090	11.86	9	S	T	27.97	1.223	16.95
3	S	M	26.06	1.245	16.01	6	S	M	20.98	1.152	12.07	9	S	M	24.28	1.300	15.65
3	S	B	31.02	1.322	20.49	6	S	B	23.16	1.331	15.27	9	S	B	27.74	1.617	22.36
3	W	T	20.89	0.884	9.18	6	W	T	23.18	1.233	14.29	9	W	T	22.67	1.024	11.52
3	W	M	23.52	1.014	11.92	6	W	M	21.37	1.300	13.77	9	W	M	23.65	1.270	14.94
3	W	B	29.09	1.430	20.45	6	W	B	23.75	1.178	13.96	9	W	B	21.43	1.098	11.68

Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area
10	N	T	23.63	1.185	13.93	13	N	T	23.09	1.188	13.58	16	N	T	24.11	1.261	15.10
10	N	M	25.10	1.196	14.87	13	N	M	21.66	1.077	11.62	16	N	M	23.34	1.468	16.82
10	N	B	31.30	1.333	20.58	13	N	B	30.29	1.344	19.99	16	N	B	26.23	1.191	15.42
10	E	T	26.68	1.154	15.27	13	E	T	29.05	1.051	15.14	16	E	T	18.68	1.080	10.11
10	E	M	27.08	1.232	16.56	13	E	M	24.88	1.176	14.44	16	E	M	21.91	1.389	15.10
10	E	B	33.39	1.468	24.31	13	E	B	30.29	1.165	17.18	16	E	B	29.60	1.381	20.35
10	S	T	26.04	1.225	15.85	13	S	T	27.27	1.054	14.31	16	S	T	23.00	1.383	15.75
10	S	M	25.07	1.142	14.21	13	S	M	27.16	1.103	14.92	16	S	M	23.72	1.294	15.29
10	S	B	29.13	1.389	19.65	13	S	B	30.12	1.413	20.89	16	S	B	26.74	1.492	19.88
10	W	T	26.19	1.029	13.33	13	W	T	26.30	1.016	13.29	16	W	T	25.06	1.206	15.12
10	W	M	27.21	1.117	15.11	13	W	M	26.31	1.288	17.00	16	W	M	24.57	1.231	14.99
10	W	B	30.96	1.460	22.19	13	W	B	25.51	1.054	13.37	16	W	B	26.62	1.274	16.87
11	N	T	20.29	1.424	14.48	14	N	T	23.81	1.176	13.92	17	N	T	24.80	1.104	13.64
11	N	M	21.81	1.343	14.57	14	N	M	22.78	1.367	15.46	17	N	M	27.60	1.214	16.57
11	N	B	24.52	1.531	18.68	14	N	B	35.16	1.322	22.90	17	N	B	37.22	1.302	23.64
11	E	T	23.03	1.247	14.27	14	E	T	20.44	1.131	11.58	17	E	T	25.34	1.419	17.55
11	E	M	21.34	1.199	12.71	14	E	M	19.75	1.119	11.05	17	E	M	28.08	1.371	19.02
11	E	B	27.33	1.322	17.86	14	E	B	31.95	1.402	22.03	17	E	B	39.21	1.438	27.61
11	S	T	24.26	1.305	15.78	14	S	T	24.46	1.235	14.95	17	S	T	27.23	1.191	16.18
11	S	M	22.58	1.424	15.99	14	S	M	22.74	1.298	14.80	17	S	M	25.00	1.219	15.27
11	S	B	30.72	1.292	19.53	14	S	B	29.80	1.541	22.69	17	S	B	30.76	1.550	23.38
11	W	T	22.85	1.184	13.54	14	W	T	24.40	1.139	13.72	17	W	T	29.40	1.411	20.57
11	W	M	21.57	1.421	15.34	14	W	M	22.38	1.339	14.91	17	W	M	24.12	1.327	15.89
11	W	B	27.96	1.300	17.91	14	W	B	33.42	1.374	22.36	17	W	B	33.30	1.580	25.95
12	N	T	23.39	1.251	14.58	15	N	T	18.99	1.118	10.64	18	N	T	22.99	1.339	15.28
12	N	M	21.27	1.247	13.23	15	N	M	18.08	1.156	10.48	18	N	M	22.63	1.305	14.69
12	N	B	24.28	1.414	17.14	15	N	B	24.53	1.294	15.72	18	N	B	31.60	1.368	21.25
12	E	T	23.82	0.934	10.96	15	E	T	22.14	0.970	10.73	18	E	T	27.62	1.231	16.75
12	E	M	21.63	1.071	11.57	15	E	M	24.40	1.089	13.31	18	E	M	23.63	1.127	13.26
12	E	B	28.91	1.181	16.63	15	E	B	25.64	1.448	18.60	18	E	B	37.26	1.643	30.55
12	S	T	23.87	1.139	13.55	15	S	T	24.64	1.211	14.87	18	S	T	23.63	1.360	15.98
12	S	M	27.20	1.374	18.63	15	S	M	22.10	1.238	13.62	18	S	M	25.09	1.528	19.03
12	S	B	36.61	1.209	21.55	15	S	B	26.40	1.257	16.49	18	S	B	30.53	1.597	24.05
12	W	T	24.91	1.079	13.29	15	W	T	19.44	0.944	9.10	18	W	T	22.38	1.115	12.49
12	W	M	23.22	1.142	13.22	15	W	M	21.27	1.033	10.96	18	W	M	20.81	1.177	12.34
12	W	B	39.67	1.291	25.02	15	W	B	27.49	1.119	15.21	18	W	B	29.58	1.378	20.14

Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area
19	N	T	20.13	1.104	11.16	22	N	T	20.42	1.266	12.92	25	N	T	26.16	1.238	16.24
19	N	M	16.55	0.936	7.80	22	N	M	22.66	1.675	18.90	25	N	M	24.74	1.432	18.08
19	N	B	24.85	1.243	15.48	22	N	B	27.78	1.400	19.29	25	N	B	30.77	1.576	23.71
19	E	T	18.34	1.121	10.30	22	E	T	21.38	1.275	13.65	25	E	T	24.07	1.174	14.13
19	E	M	17.89	1.163	10.44	22	E	M	17.07	1.402	11.96	25	E	M	26.80	1.534	20.38
19	E	B	24.26	1.251	15.05	22	E	B	22.86	1.491	16.54	25	E	B	32.92	1.424	22.81
19	S	T	24.90	1.350	17.13	22	S	T	19.26	1.079	10.38	25	S	T	18.40	1.254	11.53
19	S	M	23.60	1.155	13.59	22	S	M	19.17	1.210	11.53	25	S	M	23.00	1.171	13.46
19	S	B	25.93	1.162	15.07	22	S	B	25.40	1.581	20.10	25	S	B	26.85	1.551	20.57
19	W	T	21.12	1.000	10.46	22	W	T	21.38	1.196	12.71	25	W	T	23.51	1.390	16.22
19	W	M	22.35	1.274	14.06	22	W	M	25.44	1.514	19.09	25	W	M	24.42	1.412	17.06
19	W	B	28.37	1.346	18.98	22	W	B	32.44	1.528	24.60	25	W	B	28.70	1.473	20.72
20	N	T	24.70	1.229	15.02	23	N	T	25.93	1.198	15.46	26	N	T	21.38	1.008	10.80
20	N	M	21.67	1.232	13.30	23	N	M	26.74	1.341	17.86	26	N	M	22.37	1.230	13.71
20	N	B	27.58	1.496	20.33	23	N	B	30.89	1.578	24.03	26	N	B	26.55	1.162	14.88
20	E	T	21.25	1.176	12.40	23	E	T	25.71	1.262	16.30	26	E	T	21.37	1.037	11.13
20	E	M	19.04	1.128	10.67	23	E	M	25.88	1.392	17.85	26	E	M	22.82	1.084	12.34
20	E	B	32.34	1.302	20.87	23	E	B	30.91	1.335	20.29	26	E	B	30.93	1.310	19.97
20	S	T	25.63	1.675	21.64	23	S	T	29.13	1.153	16.82	26	S	T	16.91	0.978	8.15
20	S	M	27.37	1.429	19.24	23	S	M	29.39	1.280	18.79	26	S	M	21.86	1.324	14.54
20	S	B	31.93	1.535	24.00	23	S	B	33.15	1.405	22.82	26	S	B	27.81	1.214	16.54
20	W	T	19.20	1.201	11.48	23	W	T	31.23	1.377	21.26	26	W	T	22.47	1.113	12.41
20	W	M	17.23	1.147	9.96	23	W	M	27.06	1.325	17.85	26	W	M	19.62	1.053	10.41
20	W	B	29.35	1.197	17.41	23	W	B	33.27	1.361	22.17	26	W	B	27.62	1.257	17.30
21	N	T	20.78	1.122	11.72	24	N	T	19.28	0.989	9.52	27	N	T	24.41	1.386	16.80
21	N	M	21.40	1.082	11.66	24	N	M	19.98	1.083	10.64	27	N	M	20.83	1.186	12.25
21	N	B	24.64	1.232	15.13	24	N	B	21.52	1.137	12.17	27	N	B	30.29	1.497	22.41
21	E	T	18.84	1.109	10.52	24	E	T	22.46	1.126	12.59	27	E	T	24.63	1.257	15.38
21	E	M	19.43	1.264	12.25	24	E	M	20.42	1.366	13.80	27	E	M	23.04	1.197	13.73
21	E	B	27.46	1.193	16.17	24	E	B	22.25	1.196	13.17	27	E	B	30.18	1.523	22.69
21	S	T	27.44	1.276	17.50	24	S	T	25.40	1.238	15.77	27	S	T	32.96	1.353	21.92
21	S	M	26.67	1.314	17.33	24	S	M	22.66	1.148	12.83	27	S	M	27.60	1.284	17.50
21	S	B	32.10	1.303	20.84	24	S	B	25.85	1.293	16.47	27	S	B	35.97	1.750	30.66
21	W	T	25.50	1.255	15.99	24	W	T	14.23	1.051	7.44	27	W	T	26.06	1.174	15.12
21	W	M	26.13	1.301	16.93	24	W	M	19.63	1.178	11.43	27	W	M	26.34	1.397	18.27
21	W	B	37.76	1.460	27.18	24	W	B	22.14	1.371	15.89	27	W	B	33.72	1.383	22.83

Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area
28	N	T	20.68	1.243	12.85	31	N	T	20.69	1.290	13.31	34	N	T	22.33	1.294	14.27
28	N	M	22.49	1.694	19.04	31	N	M	20.29	1.424	14.36	34	N	M	23.57	1.261	14.77
28	N	B	25.21	1.677	20.91	31	N	B	23.00	1.087	12.51	34	N	B	31.81	1.399	21.71
28	E	T	16.99	1.194	10.11	31	E	T	26.81	1.219	16.32	34	E	T	23.61	1.209	14.19
28	E	M	20.48	1.359	13.88	31	E	M	23.90	1.273	15.09	34	E	M	24.83	1.398	17.35
28	E	B	25.91	1.429	18.38	31	E	B	28.67	1.542	21.82	34	E	B	23.32	1.166	13.41
28	S	T	21.21	1.371	14.52	31	S	T	25.62	1.214	15.46	34	S	T	25.15	1.484	18.36
28	S	M	20.36	1.478	14.99	31	S	M	23.54	1.488	17.40	34	S	M	23.06	1.260	14.45
28	S	B	27.61	1.370	18.98	31	S	B	35.61	1.611	28.28	34	S	B	29.73	1.575	23.05
28	W	T	24.49	1.385	16.98	31	W	T	20.45	1.078	11.02	34	W	T	24.99	1.210	15.14
28	W	M	21.90	1.542	16.93	31	W	M	23.18	1.499	17.22	34	W	M	21.49	1.387	15.04
28	W	B	26.83	1.359	18.01	31	W	B	28.68	1.342	19.04	34	W	B	28.65	1.553	21.93
29	N	T	25.22	1.225	15.24	32	N	T	27.64	1.336	18.27	35	N	T	22.51	1.296	14.53
29	N	M	26.23	1.247	16.18	32	N	M	24.97	1.297	16.17	35	N	M	22.77	1.331	15.00
29	N	B	36.92	1.536	27.95	32	N	B	33.58	1.263	20.83	35	N	B	26.53	1.163	15.33
29	E	T	25.81	1.059	13.65	32	E	T	30.86	1.455	22.36	35	E	T	25.88	1.190	15.47
29	E	M	26.79	1.268	16.79	32	E	M	26.47	1.483	19.60	35	E	M	22.76	1.015	11.54
29	E	B	36.05	1.398	24.63	32	E	B	29.43	1.145	16.68	35	E	B	25.65	1.119	14.28
29	S	T	31.78	1.237	19.40	32	S	T	26.73	1.203	16.02	35	S	T	25.62	1.359	17.41
29	S	M	31.96	1.475	23.37	32	S	M	30.63	1.519	23.04	35	S	M	25.08	1.420	17.63
29	S	B	38.31	1.589	30.31	32	S	B	31.66	1.251	19.83	35	S	B	26.64	1.124	14.71
29	W	T	28.53	1.080	15.26	32	W	T	25.31	1.172	14.74	35	W	T	33.37	1.282	21.17
29	W	M	24.55	1.083	13.21	32	W	M	25.80	1.215	15.56	35	W	M	25.91	1.125	14.34
29	W	B	34.65	1.261	21.28	32	W	B	29.03	1.279	18.33	35	W	B	37.50	1.213	22.67
30	N	T	23.11	1.280	14.79	33	N	T	24.01	1.199	14.29	36	N	T	22.08	1.262	13.79
30	N	M	25.65	1.350	17.31	33	N	M	23.26	1.376	15.79	36	N	M	26.03	1.606	20.82
30	N	B	29.75	1.502	22.06	33	N	B	31.66	1.399	21.48	36	N	B	28.31	1.531	21.06
30	E	T	23.54	1.103	12.96	33	E	T	25.01	1.253	15.58	36	E	T	24.39	1.172	14.08
30	E	M	23.51	1.135	13.38	33	E	M	20.61	1.356	14.63	36	E	M	26.76	1.232	16.27
30	E	B	28.33	1.403	19.66	33	E	B	31.90	1.426	22.29	36	E	B	28.95	1.229	18.01
30	S	T	21.51	1.254	13.49	33	S	T	25.03	1.264	15.60	36	S	T	21.14	1.499	15.85
30	S	M	23.86	1.455	17.32	33	S	M	24.35	1.271	15.40	36	S	M	24.38	1.337	16.24
30	S	B	28.13	1.359	18.88	33	S	B	33.55	1.636	26.78	36	S	B	31.42	1.393	21.52
30	W	T	28.03	1.340	18.55	33	W	T	22.49	1.168	12.99	36	W	T	27.60	1.273	17.37
30	W	M	23.51	1.240	14.56	33	W	M	25.94	1.476	18.95	36	W	M	29.89	1.427	21.25
30	W	B	30.08	1.329	19.94	33	W	B	34.55	1.480	24.87	36	W	B	40.11	1.773	34.68

Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area
37	N	T	24.11	1.252	14.98	40	N	T	28.13	1.009	14.27	43	N	T	22.69	1.099	12.39
37	N	M	24.46	1.283	15.61	40	N	M	28.66	1.306	18.96	43	N	M	21.00	1.193	12.58
37	N	B	30.66	1.291	19.36	40	N	B	29.64	1.216	17.63	43	N	B	29.28	1.199	17.37
37	E	T	27.48	1.137	15.45	40	E	T	25.83	1.020	13.02	43	E	T	19.70	1.136	11.19
37	E	M	29.22	1.513	21.80	40	E	M	27.36	1.133	15.35	43	E	M	20.68	1.151	11.86
37	E	B	29.20	1.333	19.14	40	E	B	34.69	1.309	22.30	43	E	B	25.84	1.468	18.74
37	S	T	27.64	1.184	16.13	40	S	T	23.48	1.030	12.00	43	S	T	22.44	1.133	12.65
37	S	M	24.55	1.257	15.31	40	S	M	22.28	1.131	12.60	43	S	M	20.70	1.271	13.17
37	S	B	31.67	1.420	22.13	40	S	B	30.52	1.270	19.01	43	S	B	19.42	1.411	13.33
37	W	T	24.27	1.191	14.38	40	W	T	26.61	1.180	15.57	43	W	T	18.78	1.056	9.85
37	W	M	23.60	1.232	14.43	40	W	M	25.13	1.195	14.98	43	W	M	21.37	1.197	12.81
37	W	B	25.08	1.338	16.55	40	W	B	29.79	1.331	19.62	43	W	B	25.58	1.348	17.04
38	N	T	26.64	1.362	18.04	41	N	T	23.29	1.120	12.82	44	N	T	22.49	1.284	14.35
38	N	M	22.80	1.469	16.63	41	N	M	25.72	1.438	18.22	44	N	M	22.22	1.273	14.12
38	N	B	29.84	1.541	22.43	41	N	B	33.25	1.435	23.69	44	N	B	30.19	1.115	16.56
38	E	T	23.54	1.232	14.31	41	E	T	25.01	1.047	13.16	44	E	T	23.45	1.117	13.02
38	E	M	25.70	1.228	15.78	41	E	M	29.04	1.516	21.81	44	E	M	23.26	1.036	12.06
38	E	B	27.39	1.309	17.68	41	E	B	34.22	1.345	22.74	44	E	B	27.71	1.182	16.11
38	S	T	27.23	1.144	15.44	41	S	T	29.92	1.275	18.78	44	S	T	21.31	0.996	10.51
38	S	M	22.70	1.350	15.30	41	S	M	28.13	1.451	20.15	44	S	M	18.39	1.035	9.50
38	S	B	29.40	1.540	22.26	41	S	B	38.25	1.427	26.62	44	S	B	30.14	1.312	19.66
38	W	T	30.01	1.294	19.40	41	W	T	29.03	1.184	16.68	44	W	T	25.34	1.126	14.31
38	W	M	28.23	1.283	18.06	41	W	M	30.56	1.490	22.38	44	W	M	18.73	1.098	10.38
38	W	B	37.45	1.639	30.48	41	W	B	35.00	1.525	26.42	44	W	B	29.20	1.266	18.34
39	N	T	20.61	1.248	12.85	42	N	T	26.15	1.087	14.01	45	N	T	21.73	1.096	11.88
39	N	M	20.96	1.156	12.17	42	N	M	24.20	1.097	13.31	45	N	M	22.60	1.445	16.38
39	N	B	28.98	1.463	21.00	42	N	B	32.91	1.319	21.39	45	N	B	31.23	1.395	20.94
39	E	T	21.33	1.053	11.14	42	E	T	23.19	1.206	13.80	45	E	T	22.67	1.140	12.84
39	E	M	17.83	0.985	8.76	42	E	M	25.82	1.176	15.22	45	E	M	22.16	1.111	12.32
39	E	B	29.16	1.258	17.93	42	E	B	27.65	1.242	16.86	45	E	B	26.31	1.187	15.43
39	S	T	22.30	1.104	12.24	42	S	T	26.22	1.156	14.95	45	S	T	18.16	1.018	9.20
39	S	M	20.25	1.072	10.79	42	S	M	25.46	1.097	13.81	45	S	M	21.52	1.109	11.92
39	S	B	28.66	1.270	17.84	42	S	B	29.68	1.272	18.62	45	S	B	24.23	1.203	14.32
39	W	T	19.45	1.007	9.80	42	W	T	28.50	1.393	19.74	45	W	T	23.94	1.164	13.81
39	W	M	19.89	1.102	10.94	42	W	M	24.61	1.121	13.60	45	W	M	24.10	1.378	16.45
39	W	B	25.23	1.390	17.55	42	W	B	31.22	1.612	24.67	45	W	B	29.30	1.352	19.61

Sample #	Direction	Layer	BY Force	BY Disp	BY Area	Sample #	Direction	Layer	BY Force	BY Disp	BY Area
46	N	T	27.80	1.300	17.83	49	N	T	29.37	1.326	19.29
46	N	M	27.49	1.433	19.44	49	N	M	26.42	1.354	17.96
46	N	B	40.65	1.424	28.28	49	N	B	34.76	1.262	21.44
46	E	T	26.69	1.364	18.05	49	E	T	24.36	1.198	14.48
46	E	M	25.32	1.454	18.43	49	E	M	17.95	1.020	9.10
46	E	B	30.80	1.505	22.70	49	E	B	27.58	1.088	14.87
46	S	T	29.30	1.304	18.92	49	S	T	21.17	1.108	11.94
46	S	M	27.75	1.538	21.10	49	S	M	21.37	1.025	10.97
46	S	B	33.19	1.448	23.63	49	S	B	28.73	1.195	17.01
46	W	T	33.04	1.514	24.63	49	W	T	24.24	1.120	13.54
46	W	M	29.87	1.567	23.10	49	W	M	21.06	1.227	12.87
46	W	B	37.38	1.529	27.99	49	W	B	26.61	1.108	14.47
47	N	T	24.87	1.154	14.36	50	N	T	22.94	1.260	14.39
47	N	M	23.92	1.160	13.78	50	N	M	20.92	1.159	12.00
47	N	B	27.88	1.389	18.93	50	N	B	26.53	1.149	15.03
47	E	T	29.95	1.224	18.28	50	E	T	21.22	1.234	12.96
47	E	M	28.31	1.048	14.60	50	E	M	19.44	1.294	12.59
47	E	B	29.28	1.257	18.15	50	E	B	26.79	1.571	20.59
47	S	T	28.26	1.102	15.31	50	S	T	23.12	1.115	12.84
47	S	M	26.54	1.110	14.62	50	S	M	22.41	1.228	13.70
47	S	B	30.00	1.173	17.39	50	S	B	21.21	1.272	13.26
47	W	T	18.08	0.913	8.28	50	W	T	23.89	1.153	13.67
47	W	M	24.04	1.055	12.53	50	W	M	21.49	1.308	13.99
47	W	B	36.91	1.437	26.00	50	W	B	27.81	1.544	21.00
48	N	T	24.50	1.287	15.72						
48	N	M	25.04	1.420	17.59						
48	N	B	32.39	1.276	20.34						
48	E	T	26.42	1.232	16.04						
48	E	M	27.77	1.409	19.56						
48	E	B	27.95	1.342	18.45						
48	S	T	23.55	1.252	14.64						
48	S	M	23.29	1.308	15.11						
48	S	B	26.22	1.241	16.16						
48	W	T	19.66	0.935	9.21						
48	W	M	23.28	1.358	15.66						
48	W	B	30.18	1.285	19.21						

REFERENCES

Ababneh, H. A. 2002. Development of a mechanical probe for nondestructive apple firmness evaluation. Unpublished Ph.D. Thesis. *Michigan State University*, East Lansing, MI.

Abbot, J. A. and R. Lu. 1996. Anisotropic mechanical properties of apples. *Transactions of the ASAE* 39(4): 1451-1459.

Abbott, J. A., R. Lu, B. L. Upchurch, and R. L. Stroshine. 1997. Technologies for Nondestructive Quality Evaluation of Fruits and Vegetables. Horticultural Reviews 20: 1-120. John Wiley & Sons, Inc., New York, NY.

Abbott, J. A. and D. R. Masie. 1995. Nondestructive dynamic force/deformation measurement of Kiwifruit firmness. *Transactions of the ASAE* 38(6): 1809-1812.

Abbott, J. A., D. R. Massie, B. L. Upchurch, and W. R. Hruschka. 1995. Nondestructive sonic firmness measurement of apples. *Transactions of the ASAE* 38(5): 1461-1466.

Abbott, J. A., A. E. Watada, and D. R. Massie. 1976. Effe-gi, Magness-Taylor, and Instron fruit pressure testing devices for apples, peaches, and nectarines. *J. Am. Soc. Hort. Sci.* 101: 698-700.

ASAE. 2000. ASAE Standard S368.4: Compression test of food materials of convex shape. *ASAE,* St. Joseph, MI.

Chen, P. and Y. Tjan. 1996. A low-mass impact sensor for high-speed firmness sensing of fruits. *AgEng 96 Paper 96F-003,* Madrid, Spain

Clevenger, Jr. J. T. and D. D. Hamann. 1968. The behavior of apple skin under tensile loading. *Transactions of ASAE* 11(1): 34-37.

De Baerdemaeker, J. and L. J. Segerlind. 1976. Determination of the viscoelastic properties of apple flesh. *Transactions of the ASAE* 19(2): 346-348, 353.

Delwiche, M. J., S. Tang, and J. J. Mehlschau. 1989. An impact force response of fruit firmness sorter. *Transactions of the ASAE* 32(1): 321-326

Harker, F. R., J. H. Maindonald, and P. J. Jackson. 1996. Penetrometer measurement of apple and kiwi firmness: Operator and instrument differences. *J. Am. Soc. Hort. Sci.* 121(5): 927-936.

Harker, F. R., R. J. Redgwell, I. C. Hallet, and S. H. Murray. 1997. Texture of fresh fruit. In Horticultural Reviews 20: 121-224 (ed. by J. Janick). John Wiley & Sons, Inc., New York, NY.

Holt, C. B. 1970. Measurement of Tomato Firmness with a Universal Testing Machine. *J. Textures Studies* 1: 491-501.

Jeong, S. 1997. A rheological model of apple flesh failure during the Magness-Taylor puncture test. M.S. Thesis. *Michigan State University*, East Lansing, MI.

Lu, R., 2004. Multispectral imaging for predicting firmness and soluble solids content of apple fruit. Postharvest Biolology and Technology 31: 147-157.

Lu, R., D. E. Guyer, and R. M. Beaudry. 2000. Determination of firmness and sugar content of apples using near-infrared diffuse reflectance. *J. Texture Studies* 31(6): 615-630.

Lu, R., A. K. Srivastava, and H. A. A Ababneh. 2006. Finite element analysis and experimental evaluation of bioyield probes for measuring apple fruit firmness. Transactions of the ASABE 49(1): 123-131.

Lu, R., A. K. Srivastava, and R. M. Beaudry. 2005. A New Bioyield Tester for Measuring Apple Fruit Firmness. *Applied Engineering in Agriculture* 21(5): 893-900.

Magness, J. R. and G. F. Taylor. 1925. An improved type of pressure tester for the determination of fruit maturity. *USDA Cir.* 350. 8 pp.

McGlone, V. A. and S. Kawano. 1998. Firmness, dry-matter and soluble-solids assessment of postharvest kiwifruit by NIR spectroscopy. Postharvest Biolology and Technology 13: 131-141.

Mohsenin, N. N., H. E. Cooper, J. R. Hammerle, S. W. Fletcher, and L. D. Tukey. 1965. "Readiness for harvest" of apples as affected by physical and mechanical properties of the fruit. Bulletin 721. University Park, Pa.: Pennsylvania State University Agricultural Experiment Station.

Mohsenin, N. N. 1986. *Physical Properties of Plant and Animal Materials*. Gordon and Breach Science Publishers, New York. 891pp.

Peng, Y. and Lu, R. Improving apple fruit firmness predictions by effective correction of multispectral scattering images. Postharvest Biology and Technology 41(3): 266-274. 2006.

Perry, J. S. 1977. A nondestructive firmness (NDF) tester for fruit. *Transactions of the ASAE* 20(4): 762-767.

Prussia, S. E., J. J. Astleford, B. Hewlett, and Y. C. Hung. 1994. Non-destructive firmness measuring device. U.S. Patent #5,372,030.

Reid, M. S. 2002a. Maturation and Maturity Indicies. Postharvest Technology of Horticultural Crops: Third Edition. 55-62. (ed. by A. A. Kader) Regents of the University of California: Publication 311.

Reid, M. S. 2002b. Ethylene in Postharvest Technology. Postharvest Technology of Horticultural Crops: Third Edition. 149-162. (ed. by A. A. Kader) Regents of the University of California: Publication 311.

Ruiz-Altisent, M. and J. Ortiz-Canavate. 2005. Instrumentation and procedures for commercial non-destructive determination of firmness of various fruits. ASAE Paper No. 056176. St. Joseph, MI.

Schomer, H. A., and K. L. Olsen, 1962. A mechanical thumb for determining firmness of apples. *J. Am. Soc. Hort. Sci.* 81: 61-66.

Segerlind, L. J. and I. D. Fabbro. 1978. A failure criterion for apple flesh. ASAE Paper No. 78-3556. *ASAE*, St. Joseph, MI.

Seymour, G. B., J. E. Taylor, and G. A. Tucker 1993. *Biochemistry of fruit ripening.* Chapman & Hall, London.

Shmulevich, I., N. Galili, M. S. Howarth. 2003. Nondestructive dynamic testing of apples for firmness evaluation. Postharvest Biology and Technology 29: 287-299.

Steffe, J. F. 1996. Chapter 5: Viscoelasticity. Rheological Methods in Food Process Engineering. 294-349. Freeman Press, East Lansing, MI.

Takao, H. and S. Ohmori. 1994. Development of a device for nondestructive evaluation of fruit firmness. *JARQ* (Japan). 28(1): 36-43.

USDA Agricultural Marketing Service. 2002. USDA Quality Standard 51.300 – 51.321: United States Standards for Grades of Apples. Washington, D.C.

USDA Agricultural Research Service. 2004. Agricultural Handbook Number 66: The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. Washington, D.C.

Vincent, J. F. V. 1989. Relationship between density and stiffness of apple flesh. *J. Sci. Food Agric.* 47: 443-462.