# The Mohr Digi-Test (MDT) Computerized Agricultural Penetrometer as an Apple Maturity Tool

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## 1.0 Introduction

Fruit maturity testing is an essential element in growing, storing, packing, and ultimately selling quality fruit. Unfortunately, current fruit testing practices may not adequately track the subtle changes in fruit maturity and texture that influence consumer acceptability. This article describes some of the problems with current testing methods and how a new instrument, the Mohr Digi-Test (MDT) computerized agricultural penetrometer, addresses them.

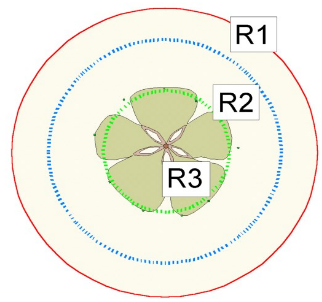


Figure 1: The MDT divides the apple into 3 regions: R1, R2, R3. R1 is currently tested by manual pressure testers. R2 contains the bulk of edible material. R3 is the core region.

This article will use the MDT nomenclature when referring to the apple. In this system, the apple radius is divided into three regions from the skin to the core: Region 1 (R1), Region 2 (R2), and Region 3 (R3) (see Figure 1). R1 extends from the skin to a 0.320 inch depth, the same region tested by manual pressure testers. R2 is the meat region of the fruit, where most of the edible portion of the apple resides, and is between the 0.320 inch boundary and a variable R3. R3 is the core region, and is proportional to the apple radius.

Simple experimental results from R1, R2, and R3 are currently divided into averages and maximums: Ax and Mx, where x is the numeral designation of the region (1, 2, or 3). For instance, M1 refers to the maximum hardness of R1; M1 therefore replaces Magness-Taylor type pressure tester readings. A2 designates the average hardness of R2, and is a good indicator of the structural maturity of the interior of the fruit. Creep, Crispness, and other quantities that can be determined from MDT data, such as starch and watercore correlations, will also be discussed.

## 2.0 Inadequacies of Common Test Methods

Penetrometer-type pressure testing is a widely-used method to measure fruit maturity changes because fruit pressure (fruit firmness) is a direct measure of apple structure, and is therefore useful in determining the fitness of fruit for picking and distribution. However, commonly used penetrometer test devices are sub optimal in several ways, discussed below.

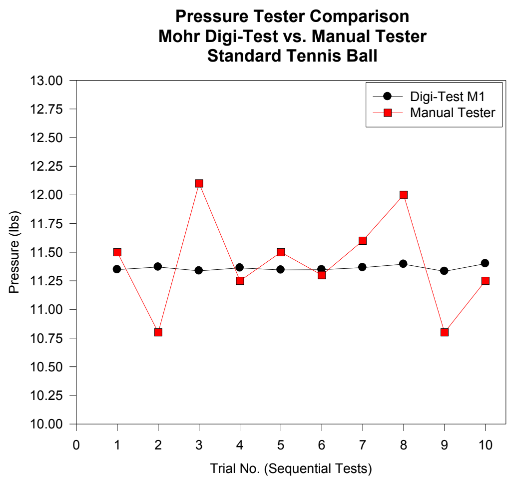


Figure 2: Standard manual pressure testers suffer from a sensitivity to testing rate, as this figure demonstrates. The manual tester, in red, was depressed to a carefully calibrated stop at different test velocities, producing a wide range of readings. The MDT, on the other hand, tested at a fixed rate to the same depth, producing considerably more precise readings.

## 2.1 Testing Rate Error

Commonly-used manual and electronic pressure testers are susceptible to changes in testing rate. Because of this, variations in test velocity between operators and/or individual tests can skew results. Slow rates allow the fruit material to relax (or creep) during testing, producing low pressure readings. Higher testing rates conversely produce higher readings. A constant-rate test is ideal, but is not possible with a hand-powered testing device.

Figure 2 illustrates this principle. A tennis ball was pressure-tested multiple times with both a MDT unit and a manual pressure tester fixed on a drill press stand. The results, manual tester in red and M1 in black, give an idea of the relative precision of each method. The manual pressure tester was depressed to a carefully calibrated stop (0.320 in.) during each test, but at slightly different rates, producing varying results. The MDT unit depressed itself to the same depth, but kept a constant rate to within 1:32,000. The firmness values it produced are accurate to better than 0.015 lb, varying only because of the partial decompression of the ball during each test.

The importance of such a comparison is important to recognize — it suggests that a manual tester must be used many times and the results averaged to approach the level of precision of a single test with a constant rate device like the MDT. If the operator of the manual tester uses consistently high or low testing velocities, his results will be consistently inaccurate as well as imprecise.

## 2.2 Internal Fruit Pressure

Currently used penetrometer test devices, regardless of their accuracy or precision, do not show internal fruit maturation reliably, since they measure external fruit pressure (R1) and essentially ignore R2 and R3, which represent the bulk of the edible material present in the fruit. Our research suggests that external fruit pressure can remain relatively constant while internal fruit pressure (and texture) continues to decline. This can be troublesome, since fruit that has reached a plateau in terms of external fruit pressure readings will continue to soften internally, as evidenced by R2 and R3 readings.

Figure 3 shows this phenomenon in a group of Mid-Columbia Red Chief apples tested with the MDT prior to picking. In this figure, external fruit pressure (M1) slows in its rate of decline over time. In contrast, internal fruit pressure (A2) continues its former rate of decline. Testing

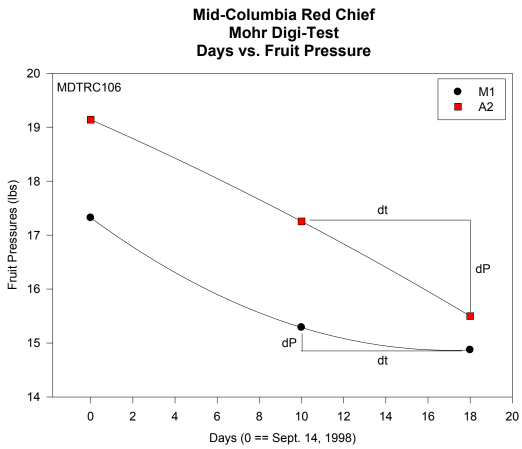


Figure 3: External fruit pressure can be misleading, as this figure representing a group of Mid-Columbia Red Chief apples shows. External fruit pressure (M1) shows little change past day 10, but the interiors of these fruit were still maturing, as their A2 readings show. Picking before day 10 would have produced fruit with better texture and greater longevity

only external fruit pressure leaves growers and distributors blind to the internal condition of their fruit. Our research has confirmed this same result in several other apple varieties.

## 2.3 Limitations of Constant-Rate Penetrometer Pressure Testing

Even constant-rate penetrometer pressure tests including the interior of a fruit are not always useful in tracking maturity changes. For example, Fuji apples are felt to be structurally robust enough to be held on the tree longer prior to harvest to increase color and/or produce watercore.

Late in the season, the pressure measurements have reached a plateau, and starch readings are of limited value. While it may appear that fruit structure has reached a plateau also, our research shows that changes are occurring in fruit structure that are readily measurable with the MDT.

One method that allows growers and distributors to measure previously subtle changes in their fruit is the Creep relaxation test. Creep relaxation (described in more detail later) is the amount the fruit material relaxes or gives way under a constant load. When full testing mode is selected, a Creep test segment is embedded within an MDT test at the beginning of R2.

Figure 4 illustrates Creep test data from a group of Mid-Columbia striped Fuji apples tested during the last few weeks before final picking. M1 and the Creep relaxation of the fruit, CP, are plotted with respect to time prior to picking. In this figure, the external fruit pressure, M1 remains relatively constant while Creep (the amount the fruit material relaxes under constant load) increases dramatically. This same dramatic change can be used as a diagnostic to carefully monitor apple maturity when other methods fail.

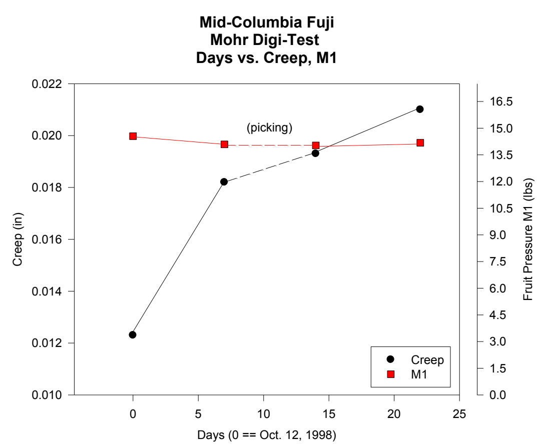


Figure 4: Fruit pressure testing is not sensitive in soft fruit that has reached a pressure plateau, as in this group of Mid-Columbia Fuji apples. The MDT *Creep* test, on the other hand, provides a reproducible method for tracking maturity in such fruit.

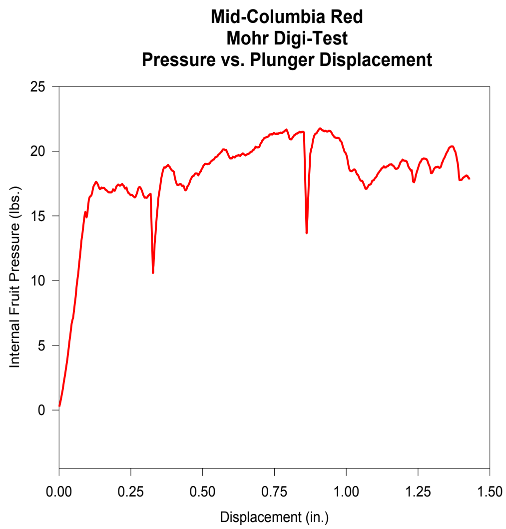


Figure 5: Fruit pressure profile through the radius of a Mid-Columbia Red Delicious apple. This profile represents a constant-rate test with two optional interspersed Creep test segments (spikes present at 0.32 inch and 0.83 inch displacement).

## 3.0 The MDT Test Record

Electronic records have the potential to become increasingly complex as increasingly complex testing methodologies are employed. Because of this, a specific design goal for the MDT has been to present potentially complex data in a format that is easily interpretable. The contents of the MDT electronic record and important correlations are discussed below.

## 3.1 Test Identifiers and General Info

These include time, date, database categories, fruit diameter. The operator may choose to enter any of a number of other characteristics prior to or after the test. Options allowing easy entry of data with a bar-code scanner and/or GPS unit are available.

## 3.2 Fruit Pressure

This data includes information from throughout the fruit – skin region (R1), meat region (R2), and core (R3).

Figure 6 is an example of a pressure history (a stress-strain curve) through an apple. This figure represents pressure samples taken at a fixed sampling rate throughout the test. The test plunger proceeds to the core and then retreats. Approximately 30,000 pressure samples are taken during a test.

### 3.2.1 External Fruit Pressure

As mentioned previously, maximum external fruit pressure (M1) correlates to current Magness-Taylor type penetrometer test values.

### 3.2.2 Internal Fruit Pressure

Internal fruit pressure (values from R2

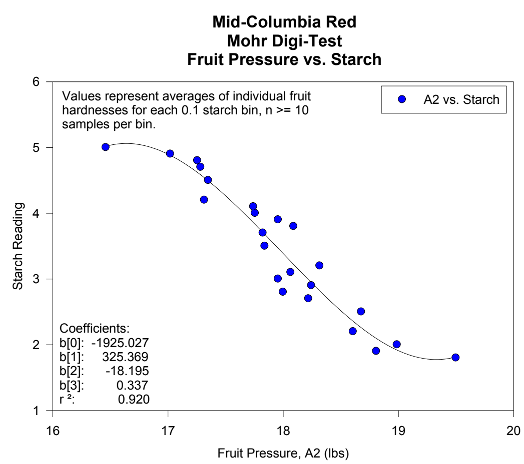


Figure 6: In this figure, starch is plotted with respect to *A2* for a group of Red Chief and Silver Spur apples. The resultant curve can be used to estimate starch. Such estimation could reduce the need for starch testing.

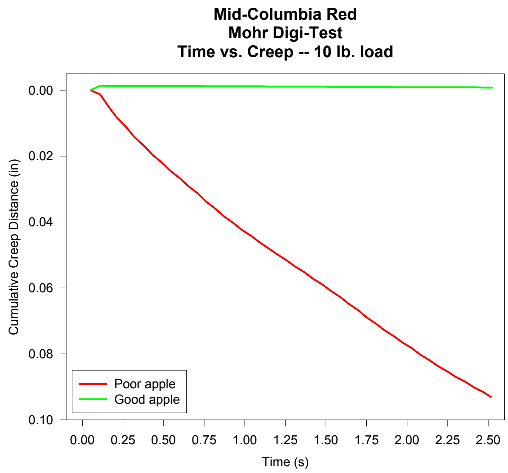


Figure 7: This figure shows the Creep curves of two individual fruits. Poor apple shows an unacceptable Creep displacement, while Good apple shows little displacement. Creep tests are capable of showing subtle changes in fruit maturity, particularly if the group of fruit being tested have M1 < 16 lbs.

and R3) have a number of important correlations, some discussed previously. Another interesting correlation is that of A2 with starch. A sample correlation is shown in Figure 7. The blue markers represent pressure and starch averages of 10 apples with similar starch readings.

## 3.3 Creep Test

This portion of the MDT test represents a software adjustable amount of time given to a constant load test segment that measures the relaxation rate of fruit material. As mentioned previously, creep can be used to measure maturity changes that are otherwise subtle or impossible to detect. Excessive Creep rates signal that the fruit being tested is nearing undesirable maturity levels.

Figure 7 shows the difference in Creep curves between a high-pressure, firm-texture apple and a low-pressure, poor-texture apple. In the figure, the displacement of the test plunger is plotted with respect to time for a constant load of 10 lbs, starting at the R1-R2 boundary. The undesirable apple shows an obvious creep displacement, while the less mature apple shows no displacement. Creep strain becomes more apparent as fruit pressure declines.

## 3.4 Crispness Test

The MDT's data acquisition electronics can sample pressure thousands of times during a single test. A mathematical transform of some of these data produce a measure of the average energy released at different frequencies during the test. This measure is theoretically similar to the energy released during a bite, and has therefore been termed the Crispness measure.

There is an empiric relationship between Crispness and pressure. Figure 8, which

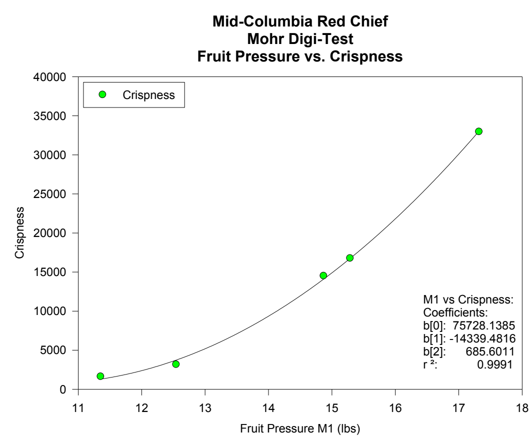


Figure 8: Crispness values serve several purposes. First, they provide a high-fidelity glimpse at the maturation of firm fruit, since subtle changes will produce relatively large changes in Crispness values. Second, they provide a confirmation of pressure readings. Third, they may be useful in the estimation of watercore, as discussed later.

represents the relationship between M1 and Crispness for a group of Mid-Columbia apples, shows that apple Crispness falls off sharply with fruit pressure. For instance, a 14 lb apple is 3 to 4 times higher in Crispness than a 12 lb apple, as is shown in the figure. This suggests that relatively small pressure differences can add up to big differences in texture and therefore in consumer satisfaction.

Apart from acting as a measure to quantify the texture of fruit, our research suggests that Crispness test results can be used in some instances to predict watercore levels in apples with similar pressure readings. The MDT could allow a more accurate look at what fruit is developing watercore, and when.

Figure 9 shows the relationship between Crispness and watercore for a group of Mid-Columbia Fuji apples with relatively similar pressure values. The ability to predict average watercore values as a matter of routine large-scale sampling could prove valuable to the grower.

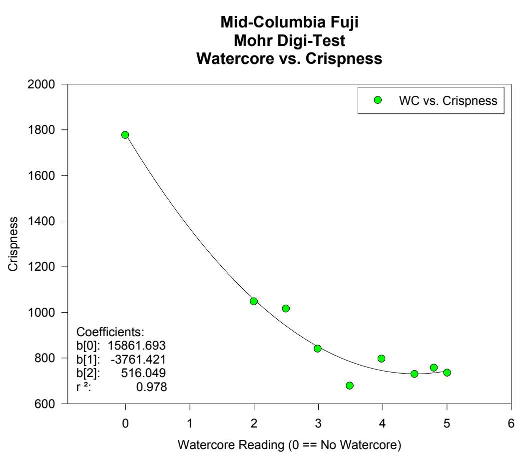


Figure 8: This figure shows Fuji apples with similar pressure values. High watercore (WC) readings associate with low *Crispness* values. Results like this suggest that *Crispness* may be used to estimate watercore levels.

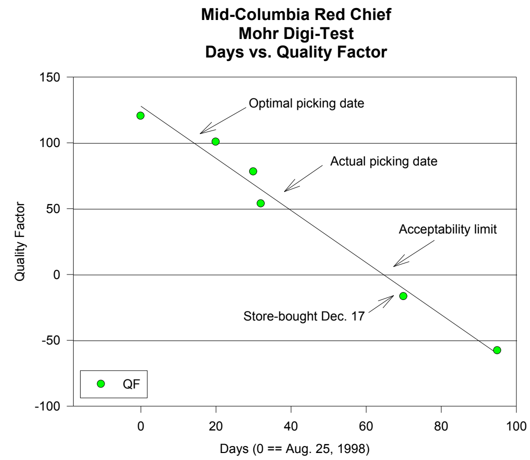


Figure 10: The QF is a comprehensive value that incorporates all MDT data. Each factor that goes into the QF (M1, A2, A3, Creep, and Crispness) has a weighting factor that is specific to fruit type. For this group of fruit, the QF could have been used to optimize picking and shipping dates.

## 3.5 Quality Factor

The Quality Factor is a weighted sum of MDT results, and is designed to provide an easily-interpretable measure of consumer acceptability. Scaled between 0 and 100, the QF identifies fruit that is reaching optimal picking maturity (QF 100) or falling below the pre-shipping acceptability limit (QF 0).

Figure 10 shows typical *QF* values for a group of Mid-Columbia Red Chief apples before and after picking. Note that picking should probably have been accelerated. However, in this case, most of the QF drop occurred in the post-CA distribution channels, resulting in sub-par fruit for the consumer. Monitoring the Quality Factor of the fruit would have been an easy way to optimize the time of picking and shipping, and also to monitor the effectiveness of CA storage parameters.

## 4.0 Convenience and Speed

The MDT has been designed with field use in mind. The MDT contains an internal CPU and rechargeable batteries. It is housed in a rugged ABS plastic enclosure and has a side handle for portability. The MDT can be placed under a faucet for easy cleanup.

When operating in Magness-Taylor compatibility mode, the MDT can test up to 20 fruit per minute. When operating in full test mode, the MDT can test up to 10 fruit per minute.

## 5.0 Conclusion

The Mohr Digi-Test is a computerized agricultural penetrometer designed for fruit maturity testing that addresses limitations in current fruit maturity test devices. Besides providing increased precision and accuracy with currently used testing methods, the MDT introduces user-modifiable novel testing strategies that have improved sensitivity to changes in fruit maturity.

Design goals of ease-of-use, portability, and speed have resulted in a device that is an excellent choice for both the field and the laboratory.

## 6.0 Specifications

Penetrometer
- Probes: all standard sizes available; 4.7, 8, and 11 mm tips standard
- With non-standard probes, automatic correction to standard values is provided in software -- e.g., accidentally testing a pear with an apple plunger does not influence test results

Test Characteristics
- Tests are user-programmable
- Example test profiles:
  - Standard Magness-Taylor replacement test + diameter testing -- 20 tests/min
  - Full test with internal fruit pressure, constant pressure, and high-frequency measurement segments -- 10 tests/min
- Constant pressure and constant rate segments are fully user-programmable

Penetrometer Electronics
- Displacement sensitivity: 0.001 mm
- Testing rate: 0-38 mm/s
- Load cell sensitivity: 6.8 g
- Load cell range: 0-30 kg, user-modifiable
- Data acquisition rate: 5 kHz
- Time resolution: 1 msec

Dimensions
- 6.5” (16.5 cm) W
- 5.5” (14.0 cm) L
- 14.9” (37.8 cm) H

Weight
- portable -- 10.9 lb. (4.9kg)
- desktop – 10.5 lb. (4.7 kg)
- heavy-duty – 17.0 lb. (7.7 kg)

Battery storage
- 6-10 hours continuous use
- >1 week intermittent use
- internal NiMH batteries

Data storage
- 16 MB standard, enough for 1,200 raw-data records or 65,000 results-only records
- Up to 100 GB optional

Optional Features
- GPS module
- Barcode module
- Calibration fixture

Availability and Pricing
- Contact us for availability and the latest affordable pricing. Also, ask about leasing options.

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