Apple Quality Testing in Five Market Centers Using the MDT-1 Agricultural Penetrometer

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SUMMARY:

The Red Delicious has for many years represented the ideal apple and has been a symbol of consistent crispness and delicious flavor. However, changes in the way Red Delicious varieties are bred, distributed, and sold threaten to displace the Red Delicious apple from its central role in the industry. One important component in this shift is the trend in the last decade of breeding Red Delicious varieties for appearance rather than texture, flavor, or shelf life. Another component is the Washington State practice of selling last year's crop before selling the new crop, which delays selling of the new harvest until February. This requires that the majority of the apples sold in the early part of the season come from CA storage. Our research shows that these apples, often sold as "new crop," can be overripe and show other signs of poor management. Finally, poor stock rotation in the grocery store further erodes the likelihood that Red Delicious apples of consistently high quality will reach the consumer. Millions of dollars spent on industry advertisements touting the consistent quality of Washington Red Delicious apples, but without substantive change geared at making those claims a reality, have only served to further tarnish the reputation of the Red Delicious apple. As result, many consumers now consider the Red Delicious to be an apple that may not be worth buying and have lost confidence in apples in general as a fruit to bring home for the family to eat and enjoy.

The picture may not be as bleak as it seems, however. The results of a study we report in this article strongly suggest that although there may be some relatively undesirable varieties of Red Delicious, Red Delicious fruit now represented in the retail sector could be delivered to the consumer with consistently high quality if monitored, packed, and handled correctly.

Three different types of apples, Red Delicious, Braeburn and Gala apples were tested from grocery stores in California, Oregon, and Washington from November 2001 to July 2002. In Washington, market samples were made in Seattle, Spokane and the Tri-Cities (Kennewick, Richland, and Pasco). Samples were purchased from five major store chains in each market area in Washington on a regular basis and tested with the MDT Computerized Agricultural Penetrometer. Results of this study show that well-managed Red Delicious apples even near the end of the market season can be maintained at a higher Quality Factor index than the imported Gala or Braeburn apples that are placed on the market near the end of the year. This and other results highlight the potential that careful stock assessment and management could play in improving consumer confidence in Red Delicious varieties and increasing sales.

We also report data suggesting that isolated Magness-Taylor type firmness measurements grossly underestimate changes in fruit maturity, and are often unable to differentiate apples on the basis of quality. On the basis of these data, we propose the adoption of the MDT as an industry standard test device capable of differentiating apples on the basis of internal quality.

INTRODUCTION:

The Red Delicious has for many years represented the ideal apple; it has been a symbol of consistent crispness and delicious flavor. However, changes in the way Red Delicious varieties are bred, distributed, and sold have led to inconsistent retail quality and threaten to displace the Red Delicious apple from its central role in the industry. One important component in this shift is the trend in the last decade of developing Red Delicious varieties for appearance rather than texture, flavor, or shelf life. Another component is the practice in Washington state of selling last year's crop before selling the new crop, which delays selling of the new harvest until February. This requires that the majority of the apples sold in the early part of the season come from CA storage. Our research shows that these held-over apples, often sold as "new crop," can be overripe and of unacceptable quality. Finally, poor stock rotation in the grocery store further erodes the likelihood that Red Delicious apples of consistently high quality will reach the consumer.

Millions of dollars spent on industry advertisements touting the consistent quality of Washington Red Delicious apples, but without substantive change geared at making those claims a reality, have only served to further tarnish the reputation of the Red Delicious apple. As result, many consumers now consider the Red Delicious to be an apple that may not be worth buying.

The picture may not be as bleak as it seems, however. Here we report the results of a study which strongly suggests that although there may be some relatively undesirable varieties of Red Delicious, Red Delicious fruit now represented in the retail sector could be delivered to the consumer with consistently high quality if assessed, packed, and handled correctly.

Three different types of apples, Red Delicious, Braeburn and Gala apples were tested from grocery stores in California, Oregon, and Washington over the period of November, 2001 to July, 2002. In Washington State, market samples were made in Seattle, Spokane and the Tri-Cities (Kennewick, Richland, and Pasco). Samples were purchased from five major store chains in each market area in Washington on a regular basis and tested with the MDT fruit tester. Results of this study show that well-managed Red Delicious apples even near the end of the market season can be maintained at a higher Quality Factor index than the imported Gala or Braeburn apples that are placed on the market near the end of the year. This and other results highlight the potential that careful stock assessment and management could play in improving consumer confidence in Red Delicious varieties and increasing sales.

In this article, we summarize the study and report data suggesting that Red Delicious varieties, when managed in a consistent fashion, have the potential to reach the consumer with consistently high quality. The results of the study show that Braeburns, Galas and Red Delicious are all susceptible to poor handling practices and poor quality fruit of all varieties can be found on most grocery store shelves. We also present evidence that measurement of internal fruit quality with a device such as the MDT-1 can play an important role in accurate apple maturity assessment.

The MDT-1 Computerized Agricultural Penetrometer:

The instrument used in this study differs from industry standard firmness testers in several regards. The MDT-1 measures the firmness from the surface of an apple to its core during a constant rate test. Measurement of internal fruit pressure is important because external fruit pressure measured by standard firmness testers often has poor correlation to internal fruit structure. Constant rate testing allows tests to be precise and repeatable. Each test also includes a measure of the high-frequency tearing characteristics (or crispness) of the fruit material and the creep deformation of the fruit under constant pressure. The MDT-1 determines each of these important characteristics from approximately 5,000 firmness and displacement measurements. The purpose of each test is to provide a quantitative measure of those characteristics consumer experiences when he or she bites into an apple.

Figure 1 shows the cross section of an apple and the R1, R2 and R3 regions. R1 extends inward from the outer surface to a depth of 0.32 inches. This is the standard Magness-Taylor firmness measurement depth that is used by most mechanical and electronic firmness measurement tools that are currently available.

Region 2 (R2) runs from the boundary of R1 to a depth proportional to the radius of the fruit (0.6 for apples). The MDT computes the R2 boundary once it identifies the surface of the fruit and is able to computes the diameter. R3 is the core-region and runs from R2 to the center of the fruit.

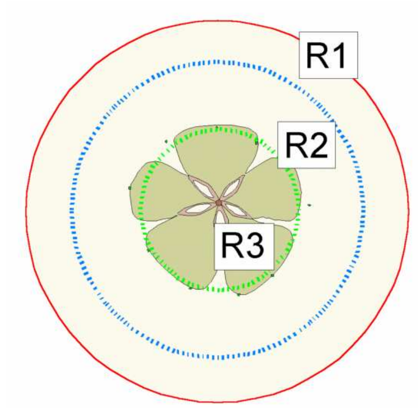

Figure 1 The MDT model of an apple showing R1, R2, and R3.

Texture and quality information gathered by the MDT-1 is best represented quantitatively by the Quality Factor (QF), a weighted sum of the results of the rigorous materials test routines discussed above. The QF is scaled between 0, representing Washington State Apple Commission minimum shipping requirements, and 100, representing the Apple Maturity Program's optimum picking guidelines. Currently, these values are based on Red Delicious varieties. In terms of consumer acceptability, QF values above 50 represent good apples. Consumer acceptability diminishes rapidly below QF values of 20. QF values below 0 represent very poor quality apples that in general would not be acceptable to most consumers. The QF is discussed in detail below.

Basic Concepts of The Quality Factor (QF):

The basic concept underlying the development of the QF is that the majority of the edible portion of the fruit should be included in any assessment of fruit maturity. Further, to make the measurement reliable and consistently accurate, the results of several independent types of tests should be combined. By comparison, the industry-standard Magness-Taylor style penetrometer measures only the maximum force in the outer 0.32 inches of a fruit. The Mohr Digi-Test unit considers the following items as part of the QF determination:

M1 = Maximum force in region R1, defined by the region of the apple from the surface to 0.32 inches depth. This test is done at a computer-controlled constant velocity.

C0 = Creep deformation is obtained through application of a constant force and movement of the plunger to keep the force constant as the apple material relaxes. The C0 measurement is made when the plunger first reaches a depth of R1. At this depth, the computer control switches from constant velocity testing to a constant load mode of operation, targets a constant plunger force specified in software, and maintains that load for the period of time specified in software. This is usually 0.5 seconds to a maximum of 2.5 seconds with a force of 10 pounds for apples. As the apple starts to age and break down due to the maturation process the C0 deformation will increase significantly.

A2 = Average Firmness in Region 2. After the creep test period is completed, the test is resumed with the same constant velocity trajectory used for the initial part of the test. The force readings obtained from moving the plunger from R1 to R2 are averaged and the average firmness in region 2 is used as one of the parameters to characterize the fruit quality. In a fresh apple A2 will be several pounds higher than M1.

E2 = Average of the Last 20 Firmness Readings in Region 2. The value of E2 in a crisp apple will be greater than both M1 and A2. As the maturation process of the fruit continues, the values of A2 and E2 drop significantly. The E2 measurement is made over the last 0.01907 inches of plunger travel, starting with 200 raw samples taken at 5000 Hz over 0.040 sec then downsampled to 20 readings. The plunger velocity is currently 0.4768 inches/sec.

CN = Crispness Measurement. The crispness measurement is made in the mid-region of the fruit during the constant velocity portion of the test as the plunger moves between R1 and R2. It is based on the 5000 Hz sampled force data that is treated to allow the Fourier Transform of the deviation from a least-squares cubic spline calculated as the best fit of the force data. This relatively high frequency change in force transmitted to the load cell by the plunger as it passes through the mid-region of the fruit is a good measure of the fruit crispness, or tearing characteristics. This measurement is in essence a quantification of the crunch that would be obtained when biting the fruit.

QF = Quality Factor. The five individual terms listed above are combined into a single term called the QF or quality factor. Relationships have been developed for each term based on test data from fresh fruit at the time of picking as defined by the Apple Maturity Program Handbook picking guidelines for starch, dissolved solids, and firmness in R1. The method for developing the QF is as follows. The apples from the database used for development that fit the criteria are sorted; those with the highest readings are given a scale value of 100 for each of the measurement categories. The value of zero is determined by recording the lowest values for each of the five terms that are found by apples that are nearing unacceptable maturity levels and which have poor texture. Linear correlations have been developed for each of the five terms that allow the measurements from the apple being tested to be converted into individual QF (Scale) terms of 0 to 100. The QF (Scale) terms are summed for the five values and averaged to give the overall Quality Factor (QF).

Typical Force and Displacement Plots For Red Delicious Apples:

Figure 2 shows a typical force versus displacement plot obtained by the unit for a plunger trajectory going from the surface to the center of the fruit. This figure shows constant velocity testing in R1, a creep test at the R1-R2 boundary, the resumption of constant velocity testing in R2, an additional creep test at the R2-R3 boundary, and finally the constant velocity test of R3 to the core of the fruit. The red line at the top of the plot represents the plunger movement during the creep test.

In this case the creep (C0) is about 0.008 inches for 2.5 seconds at the R1 boundary. The test time is shown on the top axis for time and the right hand axis for creep plunger movement. As the plunger continued testing to the center of the fruit, it encountered a soft seed pocket and the plunger force dropped to 10.5 lbs. The red dot shows the maximum force M1 in R1. The horizontal line is the average force in R2. There is a red dot in region 2 showing the maximum force in R2 and then the final red dot in R3 showing the maximum force in that region. The horizontal line in R3 shows the average firmness in that region.

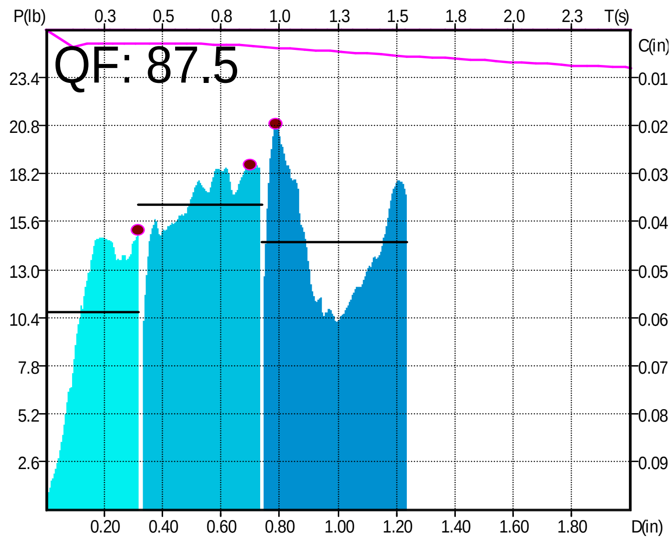

Figure 2. Graphic display of an apple with Quality Factor of 87.5 showing the Force P in (lbs) as a function of plunger depth D. The different colors are for forces in region R1, R2 and R3. The creep deflection C0 is also shown in red at the top of the figure for a 2.5 sec. creep test between R1 and R2.

There is a second creep test shown in Figure 2. The plunger movement during the second creep test (C1) is zero and as such does not show on the plot. Encountering a zero creep deformation was found to be the typical case and as a result the second creep tests was eventually taken out of the test protocol. The problems of hitting a seed pocket in the R3 region is shown by large dip in the force. The test trajectory that is currently used stops at the R2 boundary and does not go into the center of the fruit.

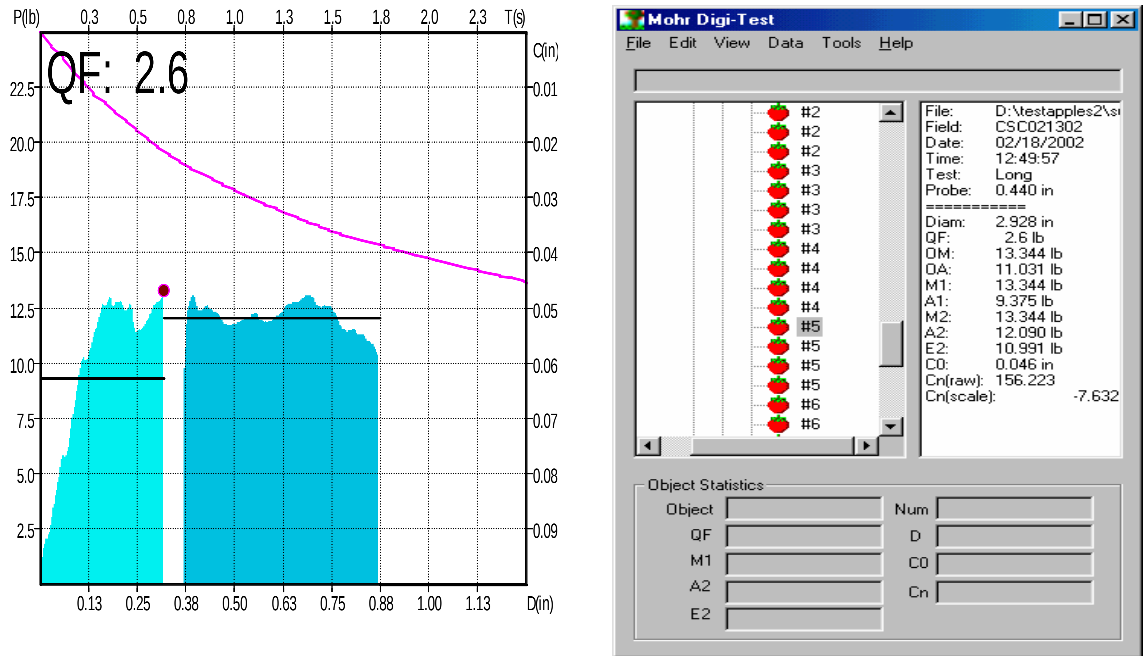

Figure 3. Red Delicious test results showing an apple with low firmness on the inside and low crispness. The data display on the right shows the test results from the MDT-1 software. There are four number 5 tests indicating that four tests were made on each side of the same apple. The results are from the first test on one side of apple No. 5.

Figures 3 and 4 shows the comparison of tests from two apples both having an M1 value of approximately 13.3 pounds. M1 is equivalent to the industry-standard Magness-Taylor penetrometer firmness measurement. The textures of the two fruits are completely different, which becomes apparent when the interior of the fruit is examined and the measured values are compared. The QF of 80.9 for the good apple and 2.6 for the poor apple provide a very good indication of how the two apples taste. The apple with QF of 80.9 was found to be a crisp, firm apple. The apple with a QF of 2.6 was found to be an undesirably ripe apple with poor texture, although would still probably be barely acceptable to most consumers. It is apparent that a Magness-Taylor firmness test would have had no power to distinguish between these two apples.

Comparison of Red Delicious Apple Condition Over Time:

The following figures document the general change in parameters as the apple continues to mature as a result of the aging process that is usually referenced to the time of picking. If picking is delayed or sun exposure is greater on one side, differences in maturity can greatly affect the quality of the apple that finally reaches the consumer. The examples found in this article were selected from apples obtained either from grocery stores or from packinghouses as part of an apple quality study. Samples were taken at the time of picking, at multiple stages of CA storage, and finally following 14 months or more of CA storage and retail distribution.

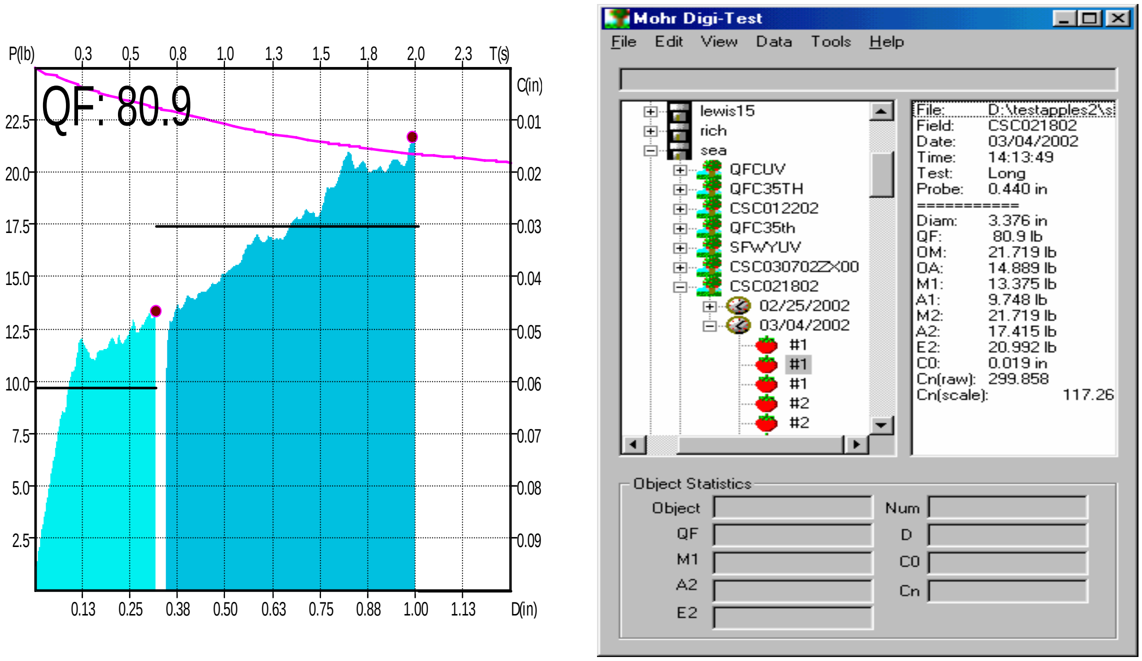

Figure 4. Test results for a good Red Delicious apple with good internal firmness and a very high crispness index. The data display on the right shows the test results from the MDT-1 software. The test number shows that three (3) all appear with the same number 1 indicating that three tests were made around the same apple. The results shown in this figure are from a test on one side of apple no.1. Creep deformation (C0) was in the medium range of 0.019 inches. The crispness number CN was very high and M1, used by the industry as the standard, is 13.375 pounds. The test date was 03/04/2002.

Figure 5 shows a typical force profile from a fresh picked Red Delicious apple. It can be seen that R3 was included in the test sequence, similar to Figure 2 . (Later tests do not include R3 data.). The QF number is computed in the same way for all of the test samples that are shown, regardless of the inclusion of R3.

The apple shown in Figure 5 has a QF of 122. This is an excellent apple. The raw crispness index (CN) is 333.46 and the QF scale factor for crispness is 146. The creep value is 0.000 inches and the M1 value is 18.414 lbs. All of these numbers indicate that this is a very good apple. It was tested on October 1, 1998, and had been picked and packed perhaps a week earlier. Figures 6 through 11 show the results of other tests not inclusive of R3. The data that are shown are characteristic of the firmness, crispness, and general texture found in the general population of apples that were tested. There is of course tremendous variability with individual tests. The variation around the apple from one side to the other as indicated by the test results from the four quadrants can be significant. We have performed a study of our test results as a function of circumferential variation in QF, the results of which will be discussed in a later paragraph.

One important thing to notice is that the various components of the QF change at different times in the maturation process. Figures 6 through 11 summarize the change in parameters associated with going from apples of QF 118 to a QF of -55.8. In terms of taste, the apple with a QF of 118 is crisp with a pleasing texture. In contrast, an apple with a QF of -55 is overripe with no measurable crispness, and has undesirable texture.

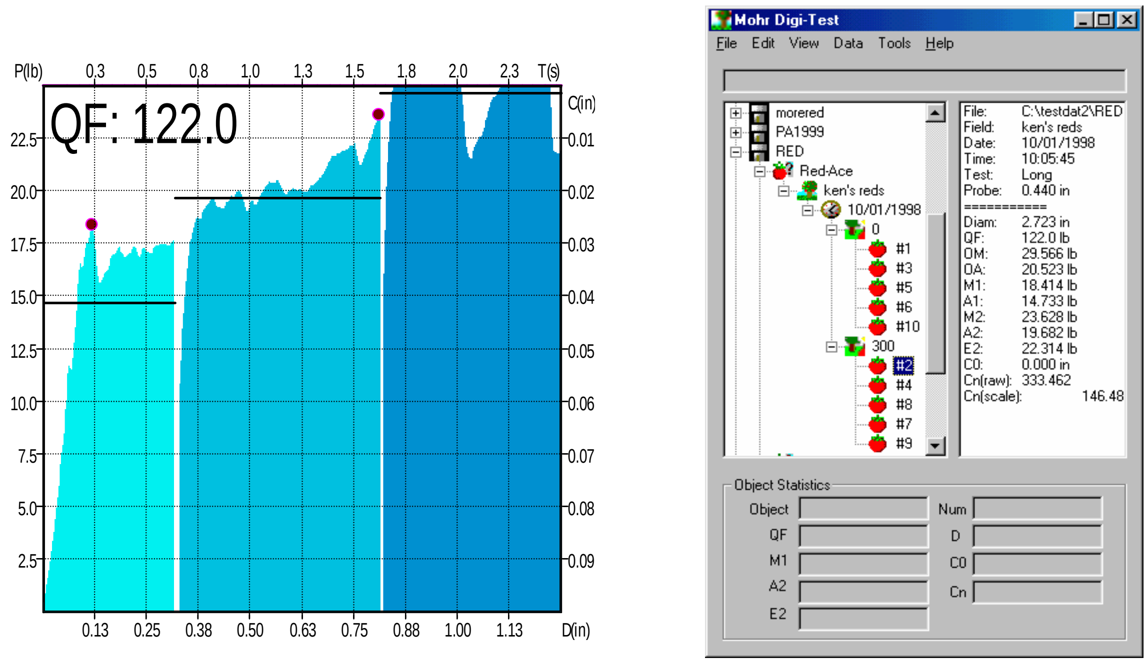

Figure 5. A typical firmness test profile for a crisp Red Delicious apple tested within a few days of picking time. (October 1, 1998) Note the test protocol for testing to the center of the apple was being used for this test. The Crispness index was very high, the creep was 0.000 and the force versus position curve showed a steady increase going to the center of the apple. This is an ideal apple firmness profile

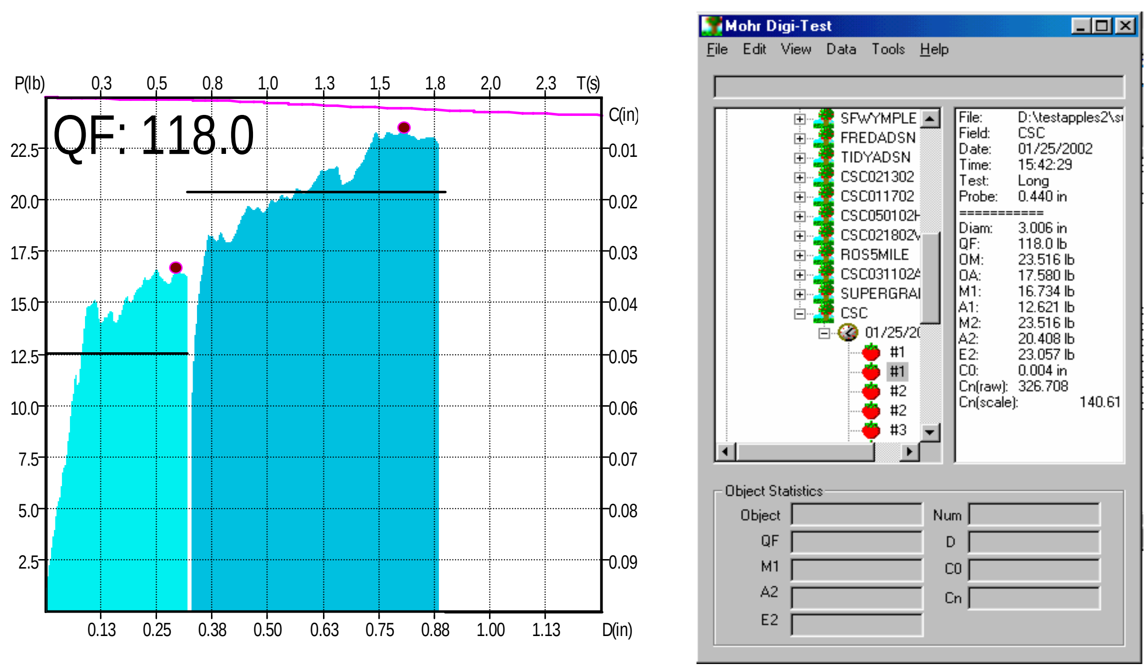

Figure 6. Plots and data for one of the best Red Delicious that has been tested taken from CA storage. The crispness index is high, the creep deformation is low and the firmness numbers are all very good. This is an example of a very good apple that would fall in the top 1 percentile of the apples tested. It was tested on 1/25/02 showing that wonderful tasting apples were available for market at that time.

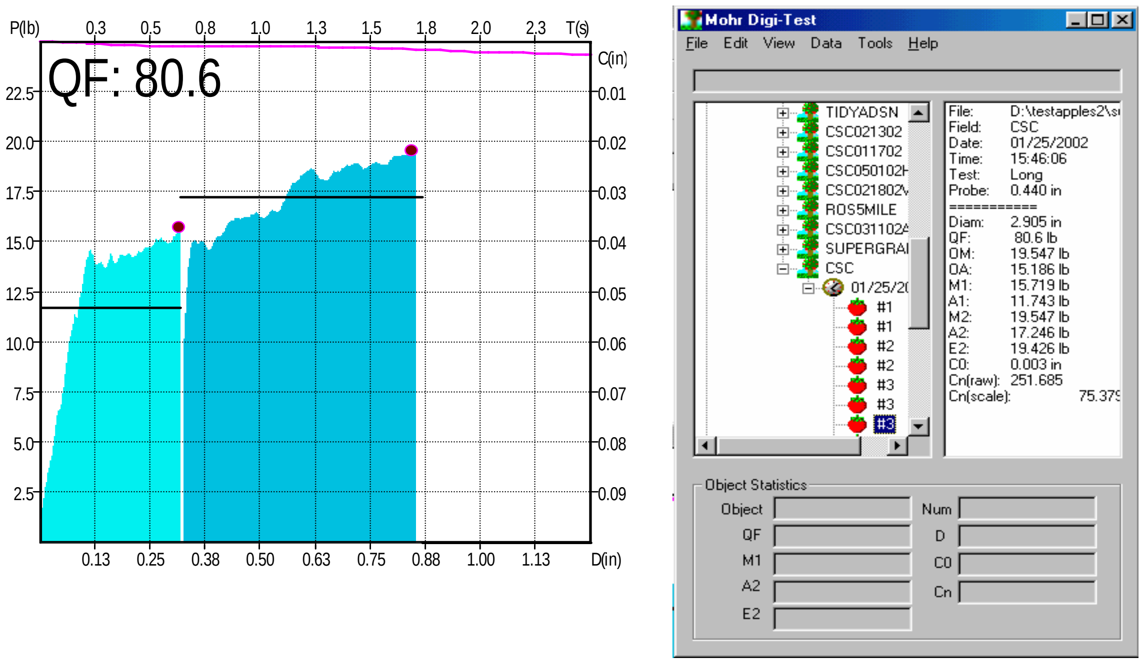

Figure 7. Red Delicious apple tested on 1/25/02 taken from CA storage as part of the 2001 crop. This range of quality is typical of many fresh picked apples.

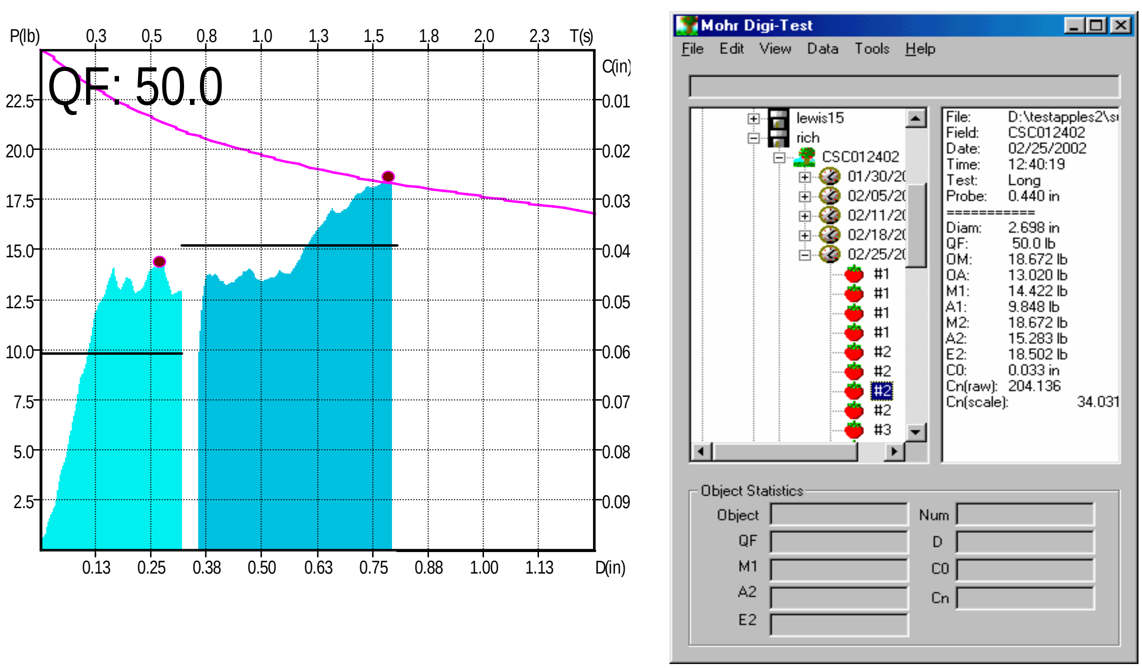

Figure 8. Red Delicious apple tested on 2/25/02 taken from CA storage as part of the 2001 crop year. This apple is starting to show signs of breaking down, the firmness readings are coming down and the creep deformation C0 is increasing accompanied by a significant drop in CN.

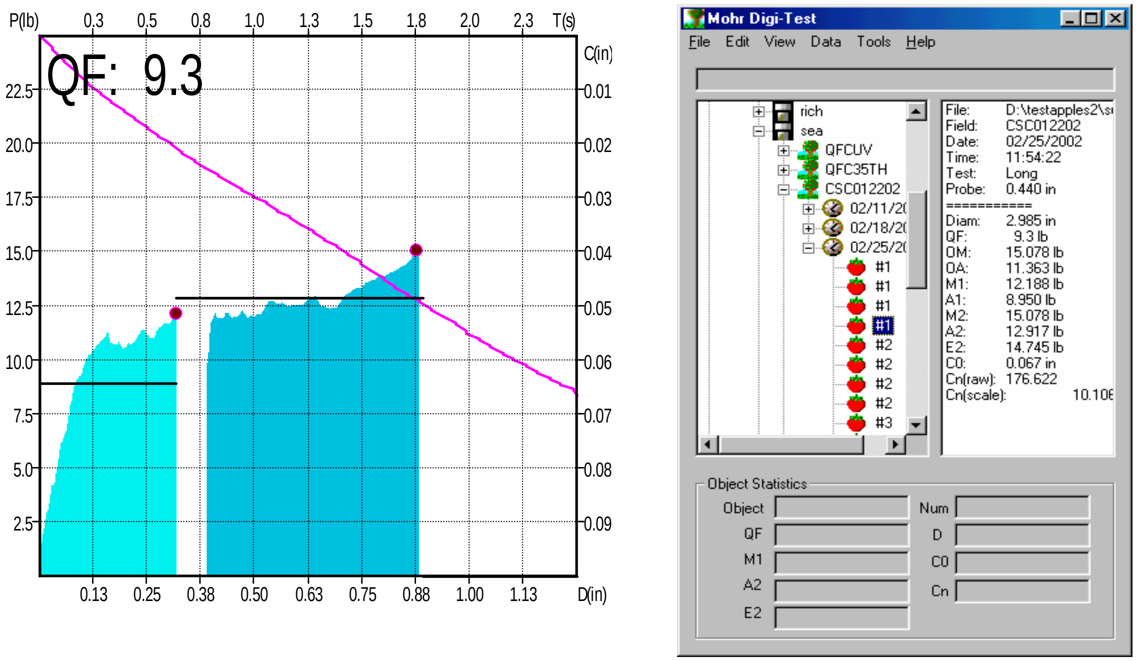

Figure 9. Red Delicious apple tested 2/25/02 which shows a significant reduction in texture properties. There is a significant reduction in crispness and a very significant increase in creep deformation (C0). The QF reading of 9.3 puts this apple very close to the limit of acceptable taste and texture.

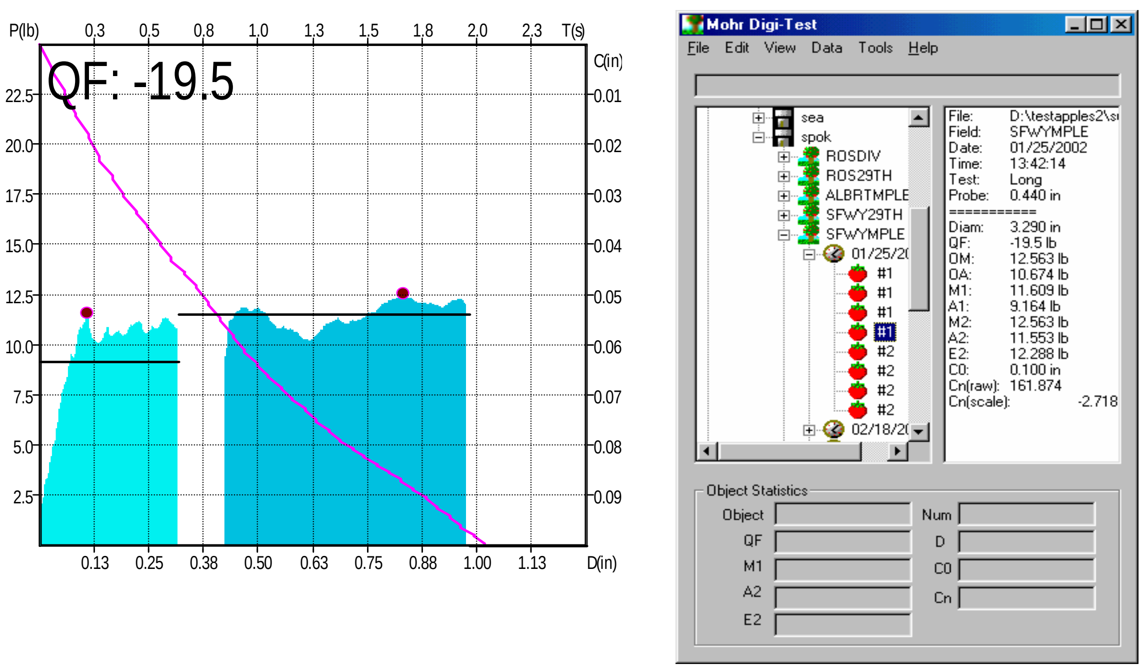

Figure 10. Red Delicious apple tested 1/25/02 showing very poor quality. This apple is most certainly a hold over from the 2000 crop that has been in CA storage. Creep number (CO) has hit the maximum and was terminated by software limits. The crispness term is very low and the firmness numbers are very low. It would be a very soft and mushy apple and not good to eat.

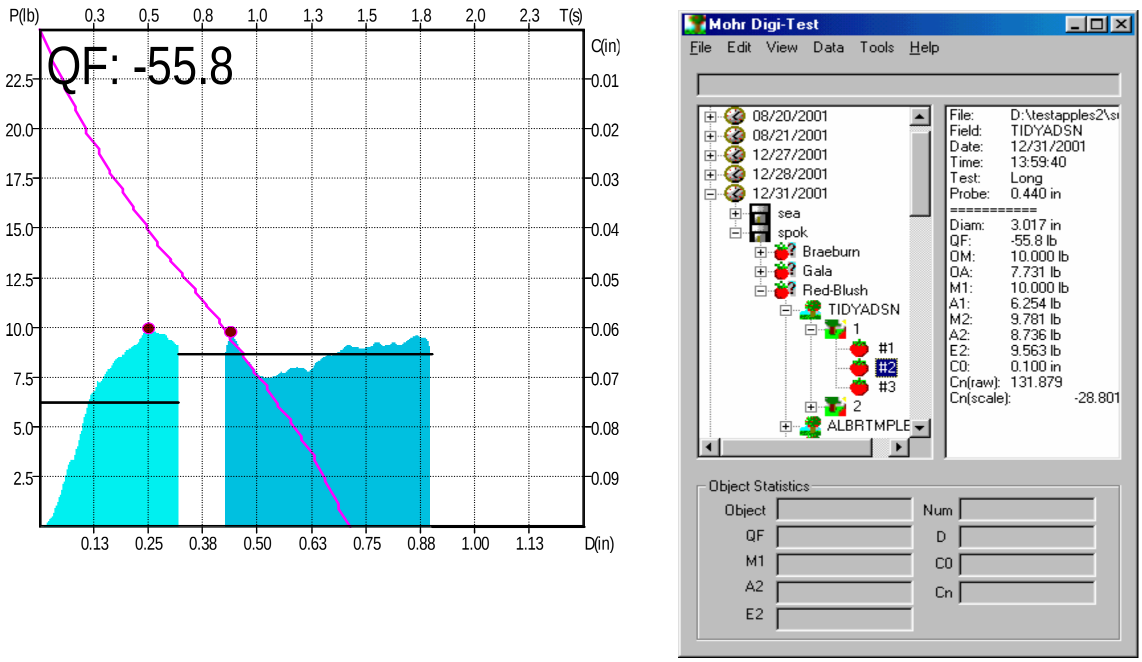

Figure 11. Red Delicious apple tested 12/31/01. This apple is from the 2000 crop year. It has no crispness, a very soft internal firmness and the creep deformation was limited by software at 0.1 inch of deformation. This apple would be very soft and mushy and bad tasting.

Table 1 summarizes the test data that is identified in the Figure 5 through Figure11. It is very interesting to compare the change in QF with the change in C0 the creep index term and CN the crispness index term.

TABLE 1

Relationship of Individual QF Terms During Maturation Process

QF	M1 (lbs)	A2 (lbs)	E2 (lbs)	C0 (in) Creep	CN (Crispness)
122	18.4	19.68	22.31	0.000	333.46
118	16.73	20.40	23.05	0.004	326.7
80.6	15.71	17.24	19.4	0.003	251.69
50	14.42	15.28	18.5	0.033	204.13
9.3	12.18	12.91	14.74	0.067	176.62
-19.5*	11.6	11.5	12.28	0.100 + (limit)	161.8
-55.8*	10.00	8.736	9.56	0.100 + (limit)	131.8
* Fruit from 2000 crop year held in CA storage					

STUDY OBJECTIVES:

This study had several objectives, the first of which was to carefully examine the quality of Red Delicious apples available to the consumer over time. We were particularly interested in the consistency of retail quality, both overall and between store chains. Further, we decided to make our examinations on the basis of percentile, so that it would be apparent what the general quality distribution was. Here we present evidence that Red Delicious consumer quality shows significant inconsistency, with discrete periods during which the majority of fruit is of poor quality. Percentile distributions, however, suggest that the highest quality Red Delicious apples are maintained at a consistently high level of quality throughout most of the year.

Comparison of newer varieties of apples such as Gala and Braeburn with Red Delicious in terms of consumer fruit quality was a second study objective. This was an important objective, because data showing inconsistent retail quality in more robust varieties such as Gala and Braeburn would strengthen the claim that a significant degree of blame rests with post-harvest handling methods rather than variety alone. If such were the case, more stringent post-harvest and retail handling guidelines could protect the large grower investment in Red Delicious varieties. We present data from this study showing that Gala and Braeburn apples do, in fact, suffer from inconsistent retail quality similar in fashion to Red Delicious apples.

A third study objective was to gather information on how well individual store chains are able to maintain fruit quality. It has been hypothesized that different retail chains consistently place differing amounts emphasis on preserving fruit quality prior to sale. We report data showing that this widely held view is in fact true, suggesting that part of the industry problem could be solved by adoption of more robust industry standard fruit handling guidelines, particularly if such guidelines included retail fruit handling practices.

A final objective of this study was to provide a comparison between simple external fruit pressure measurement (represented by the MDT-1 M1 value), such as that gathered by current firmness testing devices, and the rigorous materials test carried out by the MDT-1. Previous testing by Mohr and Associates has provided strong evidence that external fruit pressure alone can be a poor predictor of internal fruit quality, and that multiple measures of internal fruit structure are necessary for accurate and reliable maturity assessment. This study provides further evidence suggesting that industry adoption of the MDT-1 as a standard fruit maturity tool could help improve consumer apple quality, improve consumer confidence, and improve sales.

MATERIALS AND METHODS:

Tests were performed during the period from 11/29/01 to 6/24/02. Each apple was picked at random from the display stand at its respective store; most were tested within 0-3 hours of purchase. All tests were performed in four positions on each apple with skin removed. Red Delicious, Gala and Braeburn varieties were tested whenever possible. Starting in mid-May 2002, Gala and Braeburn imports from New Zealand and Chile were included in the test program in those stores that stocked them.

All tests performed by the MDT-1 were full tests, with measurement of constant-rate internal and external fruit pressure, creep measurement, and high-frequency crispness measurements. Data was analyzed and stored on the MDT-1 and later transferred to a desktop computer for graphic visualization and further analysis. The results of the several thousand tests were then sorted and results plotted and are shown in the following figures.

RESULTS:

Figures 12 to 23 summarize testing in California, Oregon and Washington. The first data points shown are from California and Oregon on day 0 (November 29, 2001); day 30 is the first test date which includes Washington apples. The Oregon and California test data represent fresh apples from the current crop year. The Washington test results were from held-over 2000 crop year apples. On the 59 and 60-day point (approximately 2/01/02) the 2001 crop was introduced into the Washington market for Red Delicious. Figure 12 shows a significant increase in QF at the 60-day point for Red Delicious compared with the test samples taken at the 27 and 30-day point from the Washington market.

The test data that are shown in Figures 12 to 17 show the parameters measured by the MDT for the top 33rd percentile for Red Delicious, Gala and Braeburn apples from the tri-state market. It can be seen that Red Delicious apples with QF greater than 50 can still be purchased at the end of the study – more than 200 days after testing began. A QF of 50 for Red Delicious represents a good apple with reasonably good crispness. The dips in the QF curves are the result of introduction of fruit damaged by poor handling practices, poor retail management, or both.

Consistently high-quality Braeburn apples were found in the tri-state markets. Crispness scores for Braeburn apples were much higher than for either Gala or Red Delicious throughout the season as is shown in Figure 15.

Figures 18 and 19 show QF and CN test results for Red Delicious apples at the top 5th, 33rd, 67th and 95th percentiles as a function of time. The test program was started as indicated below. The data points follow in sequence starting with the first five points in sequence as follows:

1) California and Oregon on November 29, 2001
2) Richland, Washington on December 29, 2001
3) Seattle, Washington
4) Richland, Washington
5) Spokane, Washington

By the fifth sample period the apples that were being sold in Washington were from the new crop (2001) as opposed to holdovers out of CA storage from the 2000 crop. Holdover 2000 Red Delicious apples remained in Washington stores until mid January 2002. The test results show that a crispness level of 200 and QF over 50 for the Red Delicious was held out as far as July 2002.

Of note is the fact that some variants of the basic Red Chief variety of Red Delicious were found to have desirable texture characteristics down to QF levels of 10 and 20. The texture of these Red Chief variants provide a firm white meat that has good cell structure, relatively low creep deformation (C0) and good crispness (CN). On the other hand, Scarlet Red Delicious were found to have bitter, tough skin and poor texture with green, bitter meat at a QF of 50, even though firmness was acceptable. Varietal differences can clearly make a difference on taste and consumer acceptability. Structural testing should be augmented with other means of evaluating quality within the variety.

Figures 20 and 21 show QF and CN for Gala apples in the 5^{th}, 33^{rd}, 67^{th}, and 95^{th} percentiles as a function of time. The QF values drop in mid-May, 2002, when the imported Galas reached the retail market. These imported apples are of lower quality than the high-quality Red Delicious available at the same time. The value of the Galas' CN at the 33^{rd} percentile also drops at this point. These imported Gala apples are soft with a poor texture, unlike Washington Gala apples that had been tested several weeks prior.

Figures 22 and 23 show test results for QF and CN for Braeburn apples at the top 5^{th}, 33^{rd}, 67^{th}, and 95^{th} percentiles as a function of time. The QF and CN values for every percentile range of Braeburns are higher than these ranges for Red Delicious or Gala varieties. The CN values remain in the 300-350 range to the end of the test period. This result is significantly higher than that obtained for either Gala or Red Delicious.

The variation in apple quality around the circumference of the apple can be significant. For a fresh picked Red Delicious near QF 100, the variation will be in the range of ± 10 or fewer points. By the time the apple has matured to an average QF 50, the circumferential variation in QF can approach ± 40 points. For apples with average QF of –20 to –50, this variation drops to approximately ± 5 points. As is well known, the effect of the "sun" side on accelerating the maturation process within the apple is significant. The test data from this study show that for selected samples, individual QF readings on an apple can be as high as 90 on one side and 10 on the other.

Skin strength was another factor that was measured. The MDT was used to measure the apple with the skin removed and then with the skin left on. Skin strength was derived from the difference between the maximum force in R1 generated during the two tests. Gala apples showed a skin strength of 4-7 lbs. Braeburn apples had a somewhat higher range of skin forces, in the 5-8 lb. range. Red Delicious of the Red Chief variety showed skin forces in the 6-9 lb. range, and the Scarlet variety of Red Delicious regularly had skin forces of 13-18 lbs. Apples with higher skin strength are generally less desirable than apples with lower skin strength.

Figures 24 through 28 show the QF (Quality Factor) by percentile for Red Delicious apples by store chain. These figures represent fruit taken from five major store chains in the tri-state area. Note that produce from store chain #5 was sampled in Oregon, Washington, and California. The last sample period reported represents samples take in June from the chain #5 Oregon store. The second to last data point was for samples tested from a store in Richland, WA.

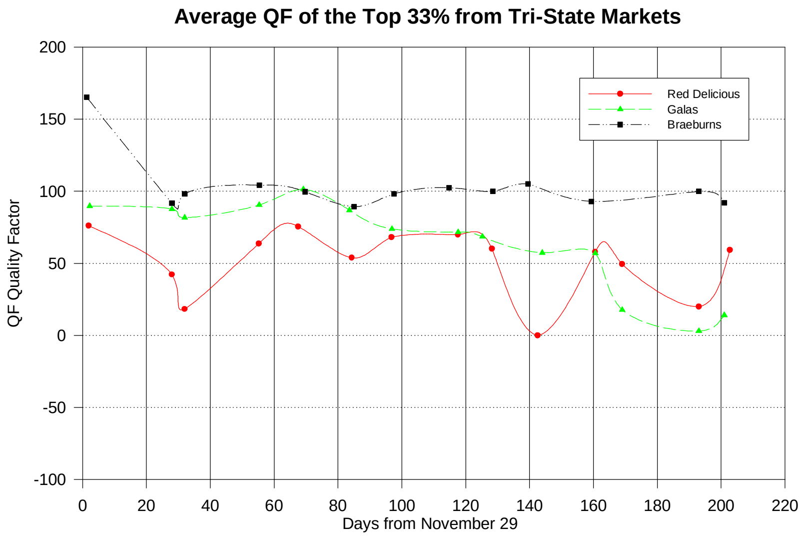

Figure 12. Average QF for the top 33% for Red Delicious, Braeburn and Gala apples for test period November 29, 01 to June 24, 02.

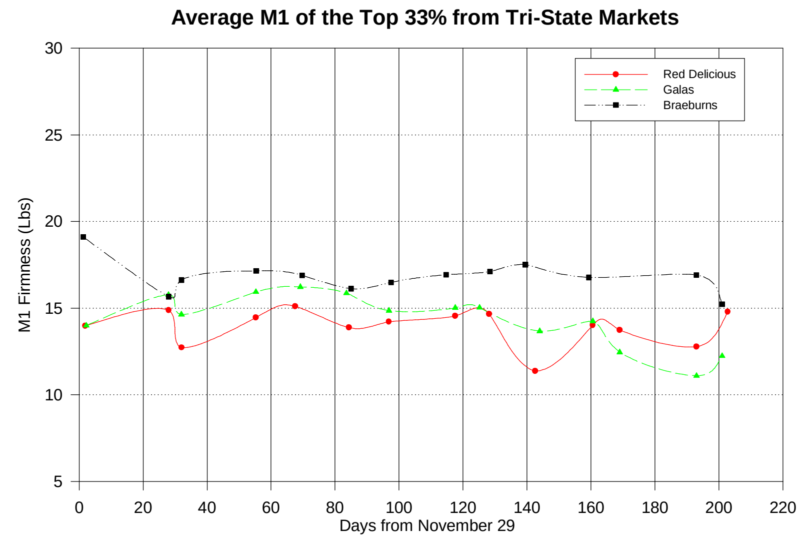

Figure 13. Average M1 firmness for the top 33% for Red Delicious, Braeburn and Gala apples for test period November 29, 01 to June 24, 02.

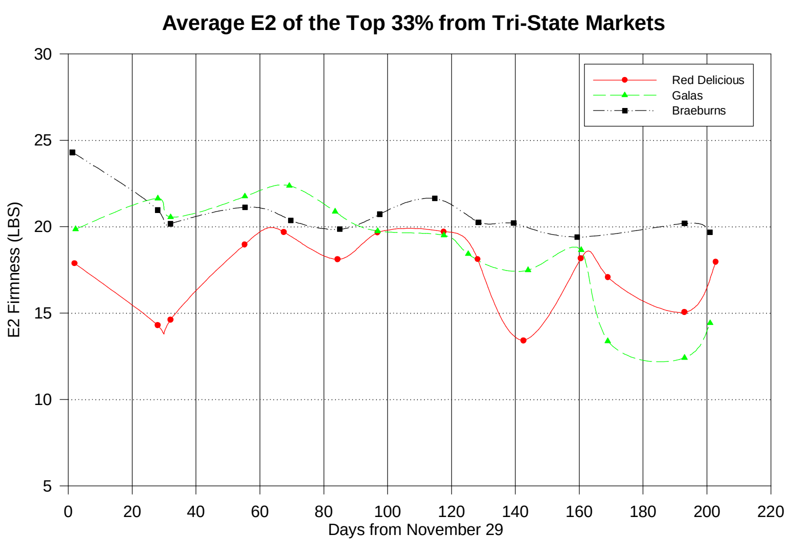

Figure 14. Average E2 firmness for the top 33% for Red Delicious, Braeburn and Gala apples for test period November 29, 01 to June 24, 02.

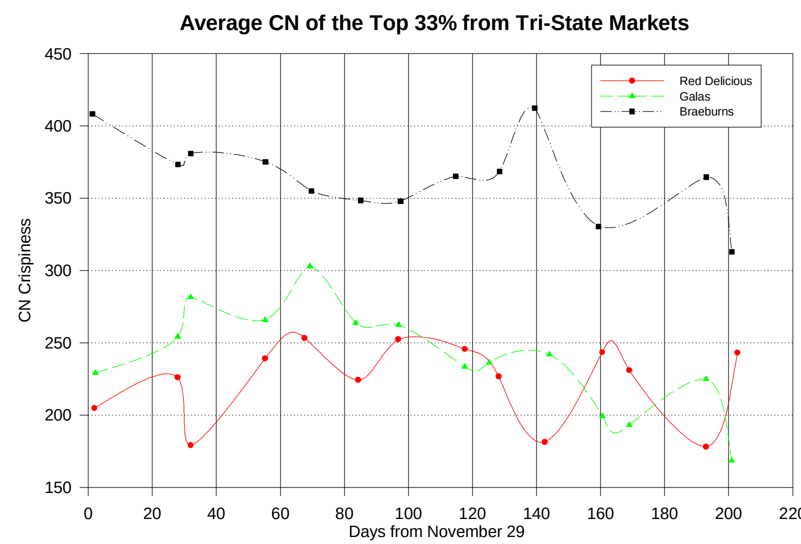

Figure 15. Average CN Crispness for the top 33% for Red Delicious, Braeburn and Gala apples for test period November 29, 01 to June 24, 02.

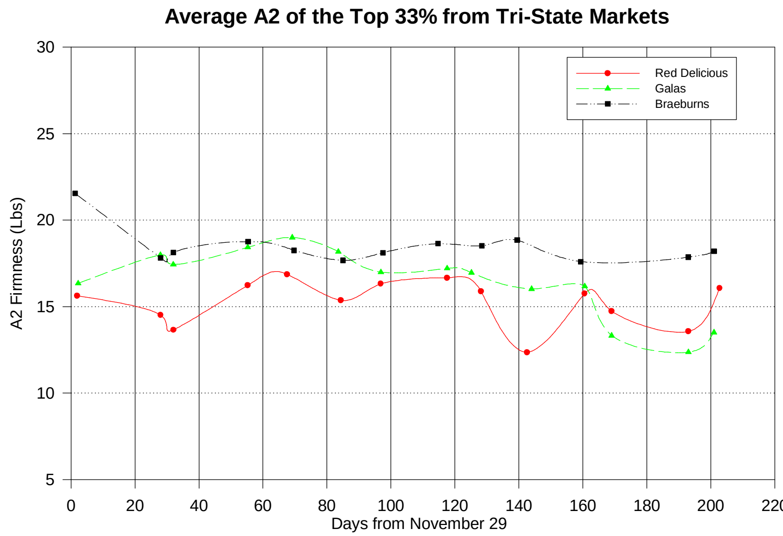

Figure 16. Average A2 firmness for the top 33% for Red Delicious, Braeburn and Gala apples for test period November 29, 01 to June 24, 02.

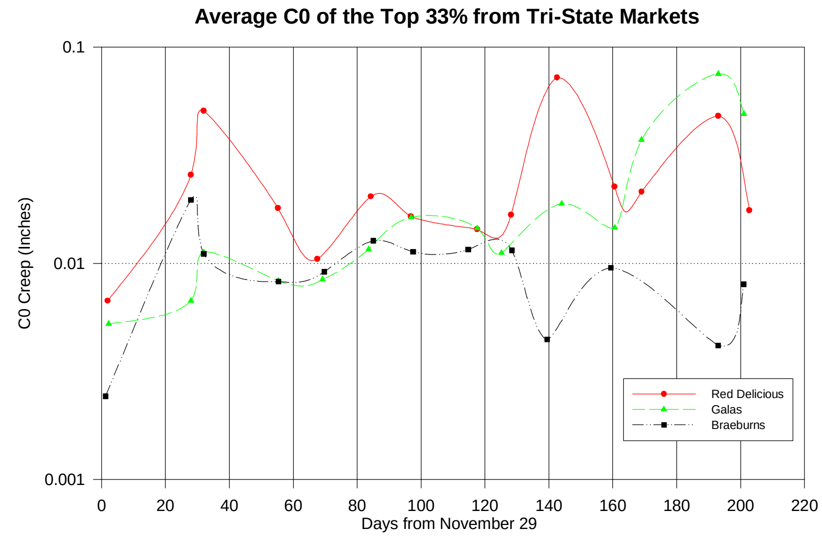

Figure 17. Average C0 creep deformation for the top 33% for Red Delicious, Braeburn and Gala apples for test period November 29, 01 to June 24, 02.

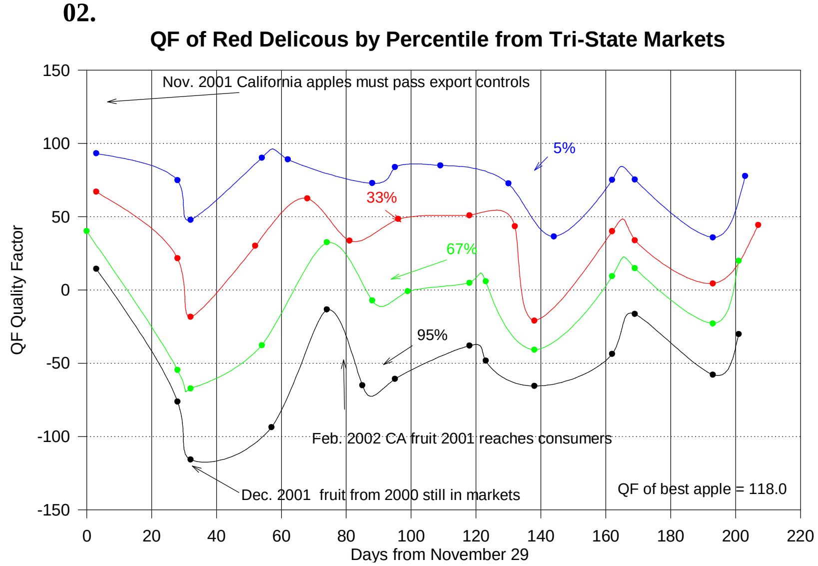

Figure 18. QF Quality Factor by percentile for Red Delicious, apples for test period November 29, 01 to June 24, 02.

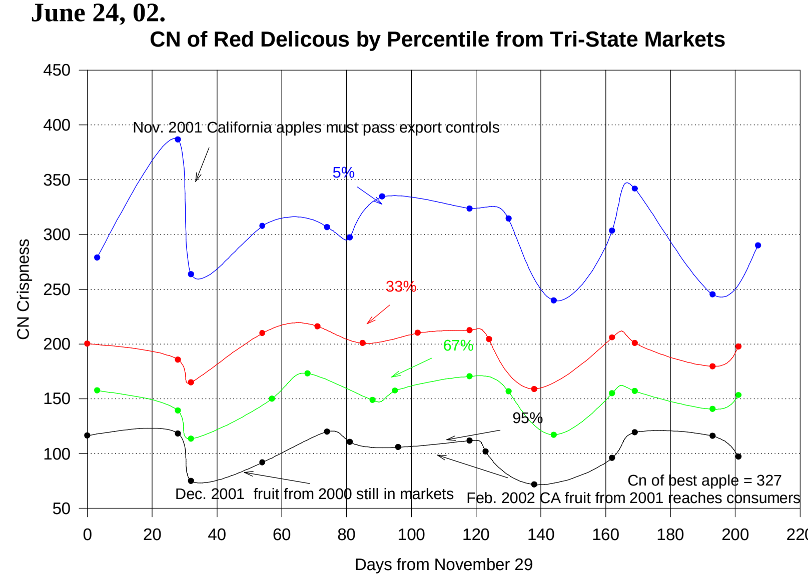

Figure 19. CN crispness index by percentile for Red Delicious for test period November 29, 01 to June 24, 02.

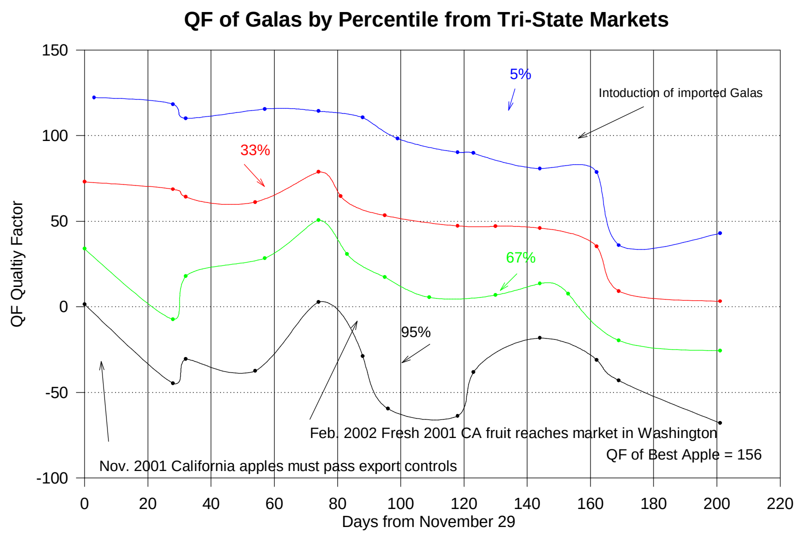

Figure 20. QF Quality Factor by percentile for Gala apples for test period November 29, 01 to June 24, 02.

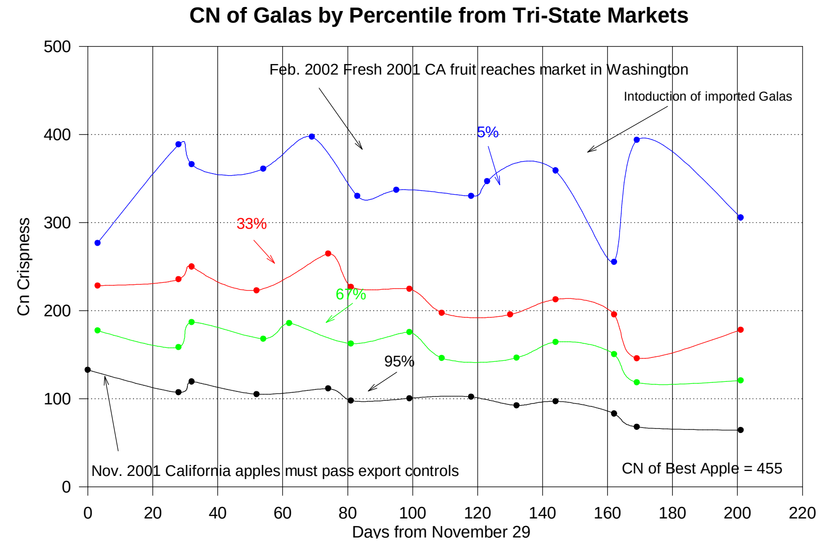

Figure 21. CN Crispness by percentile for Gala apples for test period November 29, 01 to June 24, 02.

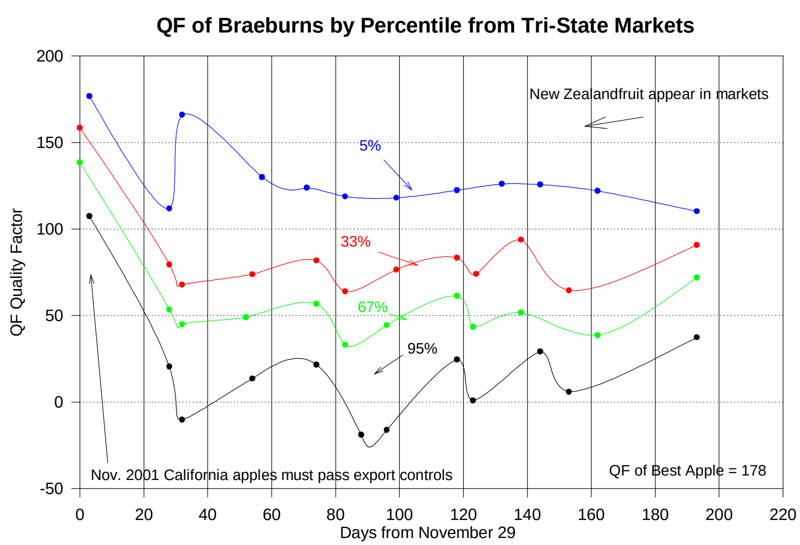

Figure 22. QF Quality Factor by percentile for Braeburn apples for test period November 29, 01 to June 24, 02.

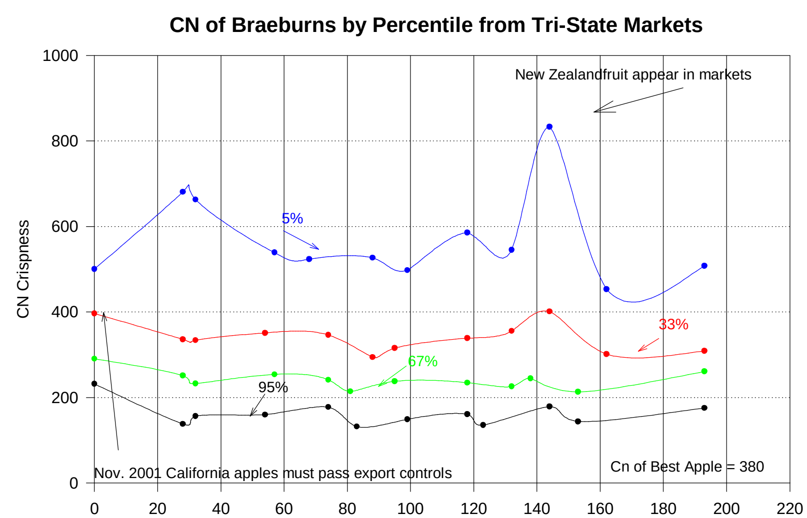

Figure 23. CN Crispness by percentile for Braeburn apples for test period November 29, 01 to June 24, 02.

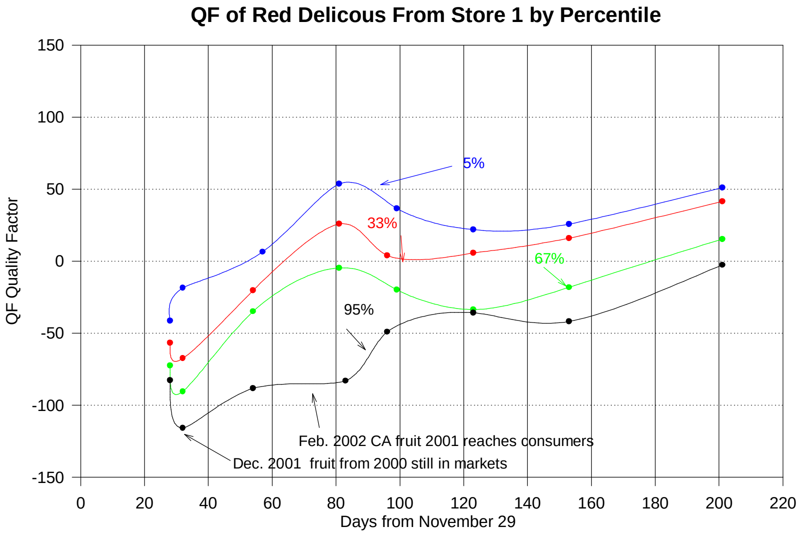

Figure 24. QF Quality Factor by percentile for store chain No 1 for Red Delicious, apples for test period Nov 29, 01 to June 24, 02.

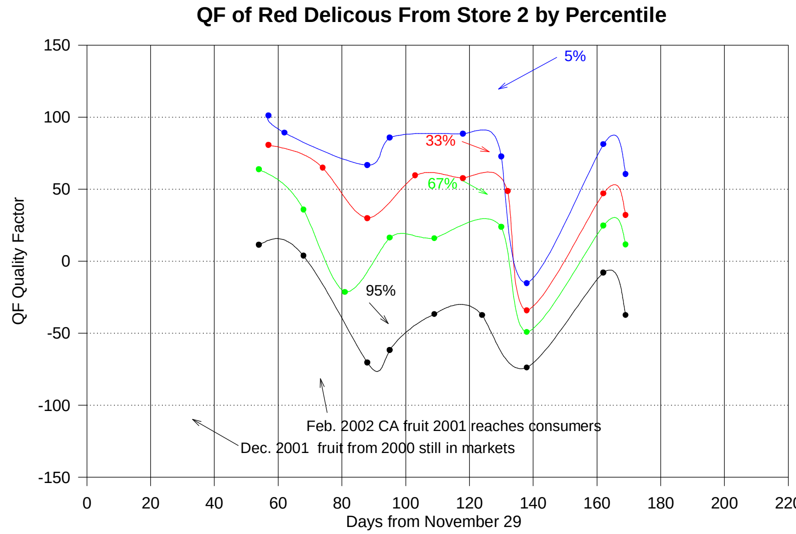

Figure 25. QF Quality Factor by percentile for store chain No 2 for Red Delicious, apples for test period Nov 29, 01 to June 24, 02.

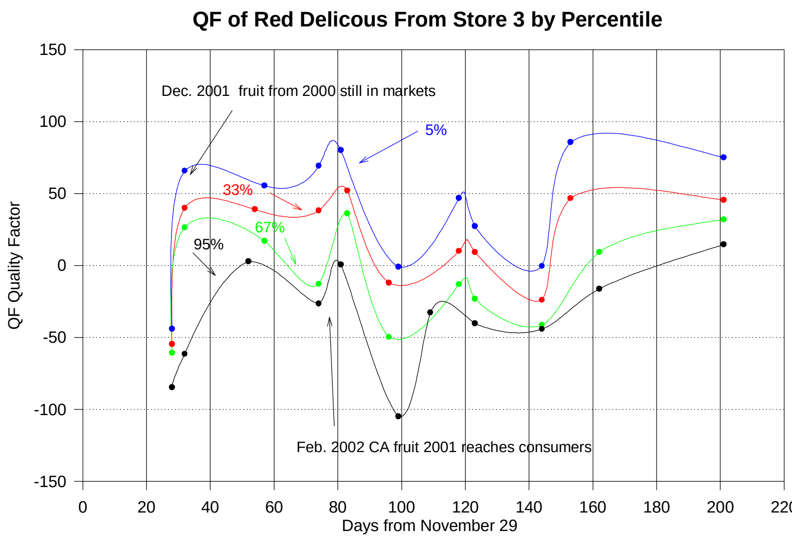

Figure 26. QF Quality Factor by percentile for store chain No 3 for Red Delicious, apples for test period Nov 29, 01 to June 24, 02.

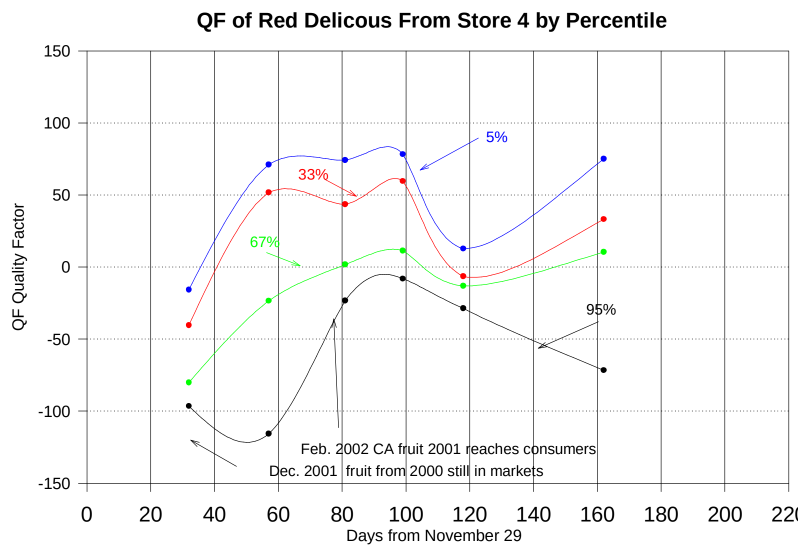

Figure 27. QF Quality Factor by percentile for store chain No 4 for Red Delicious, apples for test period November 29, 01 to June 24, 02.

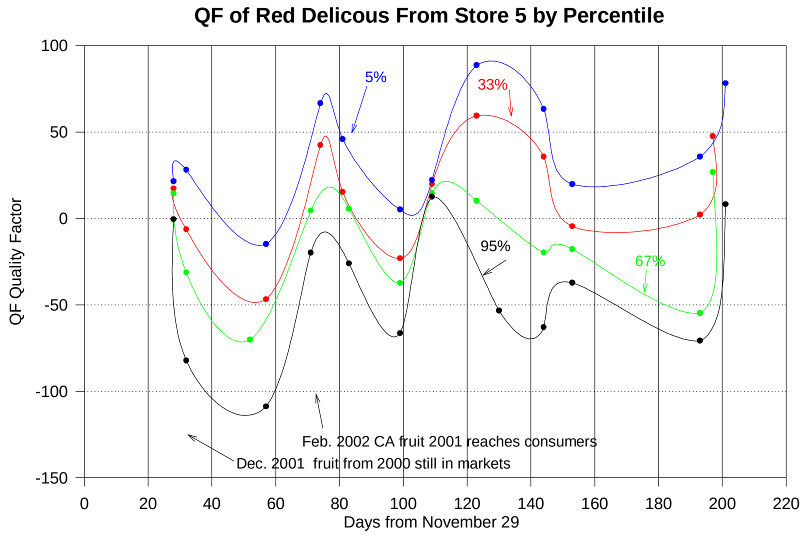

Figure 28. QF Quality Factor by percentile for store chain No 5 for Red Delicious, apples for test period Nov 29, 01 to June 24, 02.

DISCUSSION:

This study clearly shows that high-quality Red Delicious apples were able to reach the consumer throughout most of the year; this quality was not consistent, however. High-quality Red Delicious apples were available at least through July of the year following harvest. Figures 12 and 15, which record QF and CN for Red Delicious, Braeburn and Gala apples, show that the Red Delicious at the 33 percentile range were of higher quality than the imported Gala apples as the study period drew to a close. In fact, Figure 18 shows that Red Delicious QF values of 50 and above were found during every time-point of the study. Figure 12 highlights the problem with inconsistent quality, however. It is our assertion that Red Delicious apples in the 5th percentile (and certainly the 33rd percentile) represent the kind of quality that could be consistently delivered to the consumer with more efficient handling guidelines and with an improved, standardized QA measurement system. Some other features of Red Delicious varieties are also important in this quality determination, and are discussed further below.

Other apple varieties were also examined. Braeburn apples were the most crisp and were maintained at the highest QF level of the three varieties (see Figure 12 and 15). This is not surprising, since Braeburns are known to be robust, age well and have a long shelf life. This fact is shown by the consistent QF values from all study time-points. Figure 22 shows that the QF for Braeburns at the 67th percentile is near 50 for the entire study period. Braeburns are thus relatively insensitive to problems in handling and retail. However, poor Braeburns were found sporadically – the variety is not immune to mistreatment.

Gala apples, on the other hand, are more susceptible to poor handling practices. Figure 12 shows that early in the year, top quality Galas rivaled Braeburns. However, the Galas, with a starting QF above 85, soon began a gradual decline to approximately QF 55 just prior to the introduction of imported apples from Chile and New Zealand. Introduction of these imported apples caused a marked drop in Gala apple quality to a top 33rd percentile level near QF 0, well below Red Delicious apples that ended the sample period with a QF of near 50.

The breakdown by percentile for the Gala test series is shown in Figure 20. It shows that the QF for the 67th percentile of domestic Galas was approximately 10, which for a Gala is barely acceptable in terms of firmness and texture. The worst Gala apples (shown by the 95th percentile line) showed significant swings to levels below QF -50. Apples in this range are very poor tasting and have undesirable texture. For Gala apples reaching the consumer near or below QF 0, it is clear that CA storage planning was suboptimal, subsequent packing and hold times prior to sale were too long, and/or the stock rotation at the point of sale was lax. This set of conditions allowed a large quantity of apples that were not fit to eat to reach the consumer.

In comparison to the Gala and Braeburn apples that were tested, the Red Delicious apples generally had a lower initial QF. This may be offset by unpublished data we have collected which suggests that Red Delicious apples maintain acceptable texture levels at lower QF values than some other varieties. Even so, Figure 12 and 18 show that the Red Delicious crop faced suboptimal management.

In Figure 18, note that apples tested in California and Oregon (first time-points) had a much higher post-harvest QF than apples that are available in Washington shortly thereafter. Even at the 33rd percentile level there were major swings in QF throughout the season, indicating that the problem was not with the Red Delicious variety but with the way the apples were managed and handled prior to sale. Figure 18 illustrates that at selected times it was possible to purchase Red Delicious at the 67th percentile range with a QF of 20 to 50. Red Delicious apples in the QF 20 to 50 range are good apples with acceptable texture. Red Delicious apples near or below QF 20 will still be quite acceptable to most consumers.

This study results also highlight retail store practices. Figures 24 through Figures 28 show the test results for five of the major store chains that were sampled. Store chain #1 showed poor buying practice at the start of the season, consistently buying lower quality apples than the other four chains. As the season progressed, chain #1 was able to buy better apples and eventually reached parity in terms of apple quality at the end of the study period of 200 days. Store chain #1 did not have any days with QF at or above 50 at the 33rd percentile level.

Store chain #2 had 60 days of sampling with QF greater or equal to 50 at the 33rd percentile level. Store chain #3 had approximately 45 days with a QF of 50 or greater at the 33rd percentile level. Store chain #4 had approximately 30 days with a QF of 50 or greater at the 33rd percentile level. Store chain #5 had approximately 20 days with a QF of 50 or greater at the 33rd percentile level.

These stores represent markets in five different locations and in three different states, and are therefore subject to local market conditions. All of the stores sustained very large swings in Red Delicious quality at a time when it was obviously possible to purchase good apples, as evidenced by consistently high 5th percentile apple quality. We surmise that either the packers playing a role in the supply chain or the retail buyers were not aware of or unable to influence the quality of product reaching the consumer. It goes without saying that in many cases the consumer was sold inferior product. Such an outcome can only serve to decrease consumer confidence in the apple industry in general and Red Delicious varieties in particular.

Finally, this study illustrates how a test device such as the MDT could significantly improve the apple industry QA process. In selected cases, such as in Figures 3 and 4, the MDT's test capabilities are clearly necessary to differentiate fruit quality differences. These apples have similar M1 values but vastly different internal quality. Standard Magness-Taylor testing, even if done perfectly by an automated device, would have no power to differentiate these two apples in terms of storage potential or consumer acceptability. The sophisticated internal test capabilities of the MDT are therefore useful in differentiating between individual apples.

In the population sense, these capabilities are just as important. Consider Figures 12 and 13, taking notice of the first 3 time-points. During the interval between the first and third time-points, the net change in M1 was ~ 1 lb. (7%). During the same period of time, however, the net change in E2 was ~3.2 lbs. (17%), and the change in QF was ~ 50 points (66%). An isolated M1 measurement would grossly underestimate fruit maturity changes in this case.

As another example, consider Table 1. A drop of M1 from 15.71 to 14.42 lbs. represents an 8% change. During the same interval, the apples represented by these two samples underwent a 19% change in CN, a 1000% change in C0, an 11.4% change in A2, and a 38% change in overall fruit quality (QF).

For both of these examples, M1 grossly underrepresented fruit maturity changes. Any system of management is only as good as the system of measurement that is used to direct it. It is unlikely that any method of bringing consistently high-quality apples to the consumer will be successful until the industry adopts a standard QA tool similar to the MDT that can accurately and reliably measure changes in fruit maturity.

It is useful to mention a potentially far-reaching implication of MDT technology -- the ability to quantify crispness in the form of CN, a component of fruit texture separate from firmness. Although crispness or "crunch" has been widely touted as perhaps the most important component of the consumer's apple-eating experience, there has been no way to usefully quantify it until now. Management of crispness is a natural extension of industry trends toward improved quality control and has the potential to result in increased consumer confidence and market share.

CONCLUSIONS:

1) High-quality Red Delicious apples were found throughout the study period.
2) Red Delicious varieties suffer from inconsistent retail quality. This suggests that improved handling guidelines can restore Red Delicious retail quality and protect grower's investments in this important variety.
3) Braeburn apples are more robust and a higher percentage of apples with QF greater than 50 can be purchased throughout the market year than with either Red Delicious or Gala apples.
4) Red Delicious with a QF greater than Gala apples can be purchased near the end of the market year after imported Gala apples are introduced to the market.
5) Braeburn, Gala, and Red Delicious are all potentially susceptible (Red > Gala >> Braeburn) to poor storage, packing, handling, and stock rotation practices. Poor quality examples of all varieties were found in all states, particularly Washington. This suggests that newer varieties are not immune to poor handling practices, and that poor handling and subsequent poor retail quality has the capacity to reduce market share and destroy consumer confidence in apples for all varieties, not just Red Delicious.
6) Certain store chains are more effective than others at preserving retail apple quality. This suggests that stores with poor handling practices can improve apple quality significantly by emulating those stores with better practices. This would be of particular value if made along with the adoption of a robust method of maturity assessment.
7) The loss of market share and a general loss of consumer confidence in Red Delicious and apples in general can be attributed to the inconsistent quality of apples presented to the consumer.
8) Standard external fruit firmness testers, even electronic devices with constant-rate testing, are not able to accurately characterize apple maturity, and may grossly underestimate changes in maturity.
9) Measurement of internal fruit structural properties, such as crispness (CN), creep (C0), and internal fruit firmness (A2 and E2) is necessary to differentiate changes in fruit maturity accurately and reliably.

10) The MDT-1 can accurately measure the crispness of apples, an important element of fruit texture that the fruit industry until now has been unable to measure.