COMPARISON OF POME FRUIT FIRMNESS TESTING INSTRUMENTS1

Eugene Kupferman,
Washington State University
1100 North Western Ave
Wenatchee WA 98801

Nairanjana Dasgupta
Program in Statistics
Washington State University
Pullman WA 99164

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In the fall of 1999, commercial and developmental instruments that determine the firmness of apples and pears were compared. All instruments measure firmness based on the system developed by Magnus and Taylor using an 11-mm wide probe inserted into the pared flesh of a fruit to a distance of 7.9 mm.

The instruments were tested as provided by the manufacturer. Changes in hardware and software could make an instrument more attractive. Please contact the manufacturer for the most recent product information.

The instruments that were evaluated are listed below and pictured on pages 2 through 4:

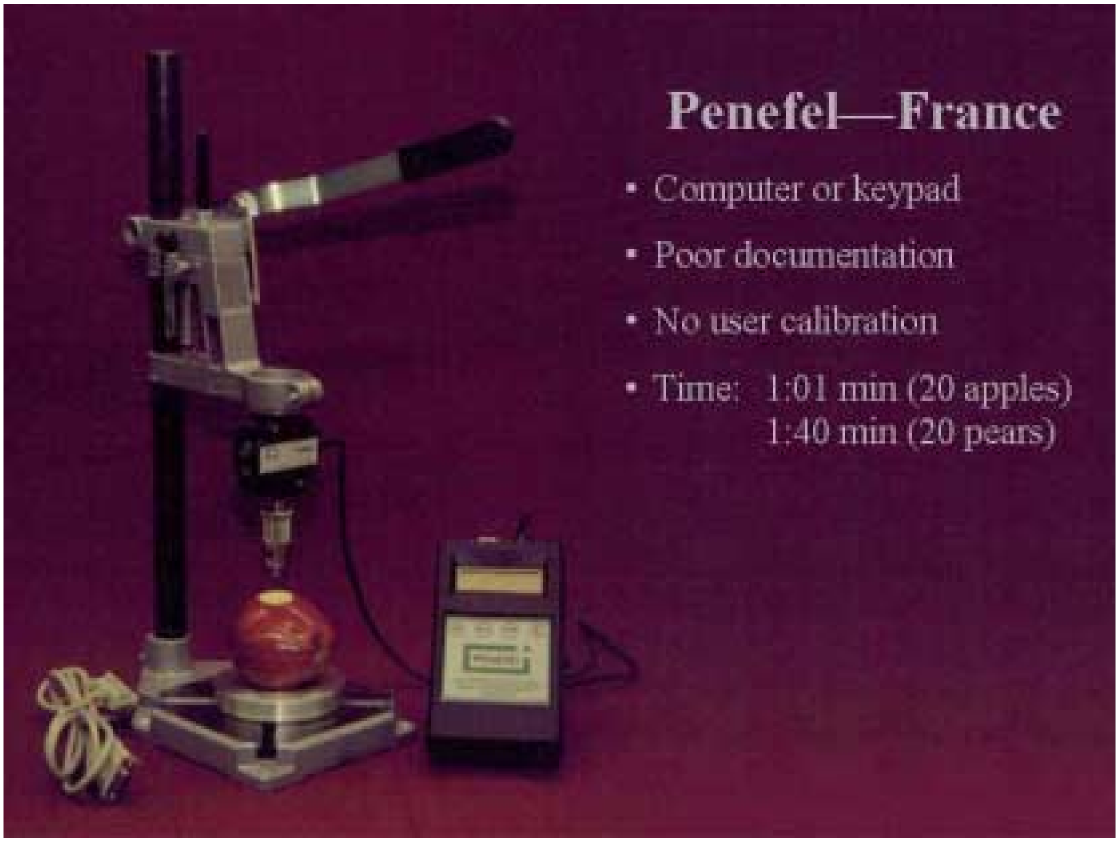
1. FQT-Fruit Quality Tester manufactured by Geo-Met Instruments, Nova Scotia, Canada; www3.geo-met@ns.sympatico.ca
2. PFL-Penefel manufactured by Copa-Technolgie, St. Etienne du Gris, France; Fax: 33 04 90 49 05 33
3. Digitest-manufactured by Digitest and Associates, Richland, Washington; bDigitest@comtch.iea.com
4. FTA-Fruit Texture Analyzer, manufactured in South Africa by Guss; www.gusstoday.com
5. Effegi-manufactured in Italy and widely available.
6. EPT-manufactured by Lake City Technical Products, Kelowna , British Columbia; Lakecity@okanagan.net.

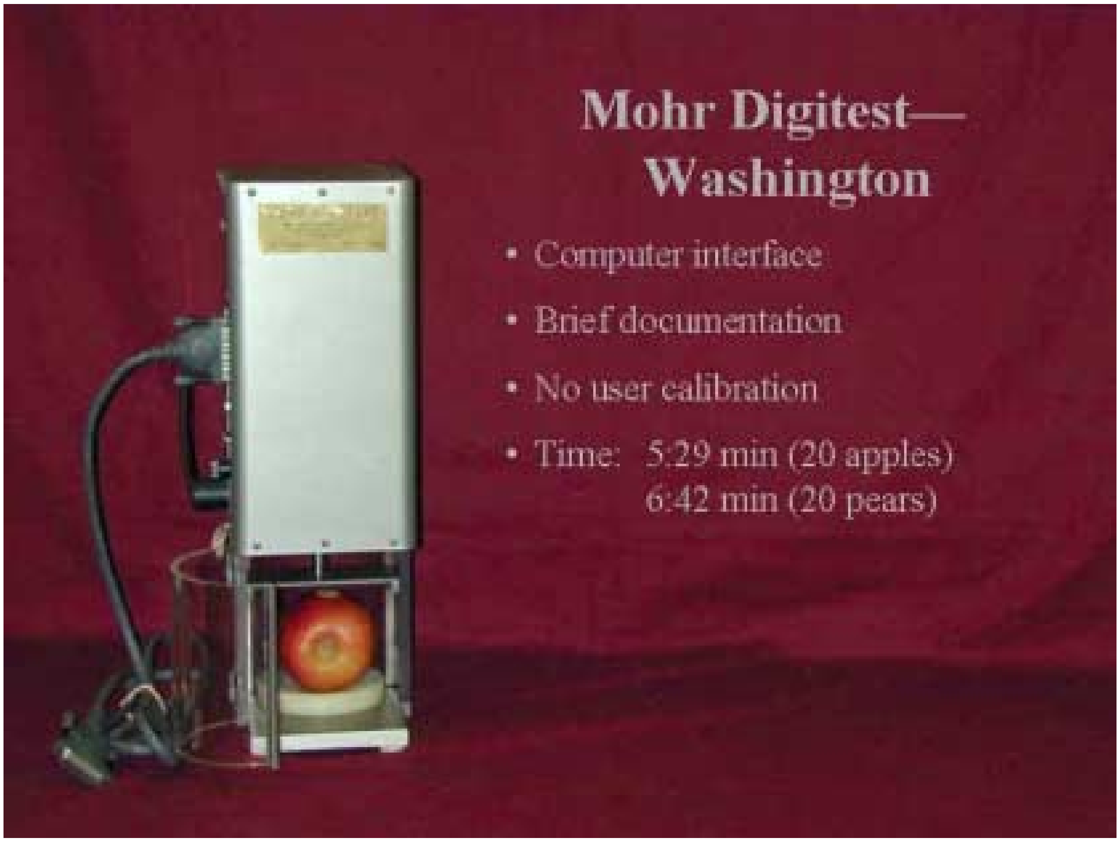
Each instrument was evaluated both subjectively and objectively three ways:

1. **Ease of use** (clarity of instructions, computer requirements, calibration procedure, help availability, safety)
2. **Firmness measurement** (accuracy, precision, speed, operator effect, portability/ robustness, cleaning)
3. **Data handling** (readout, programming, data transfer, data modification and error correction).

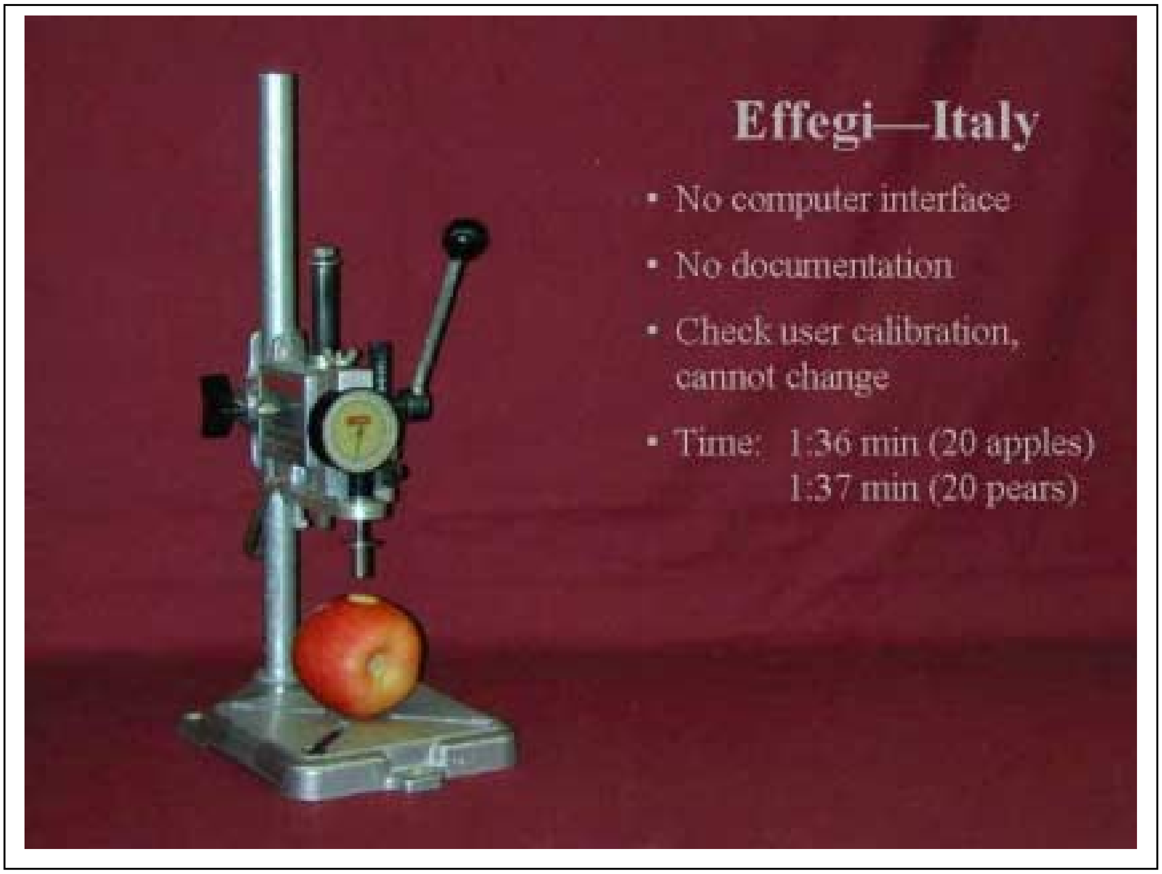
[1] Thanks to the Washington Tree Fruit Research Commission for partial funding, Nancy Buchanan and Chris Sater for technical work and the manufacturers for the loan of the instruments.

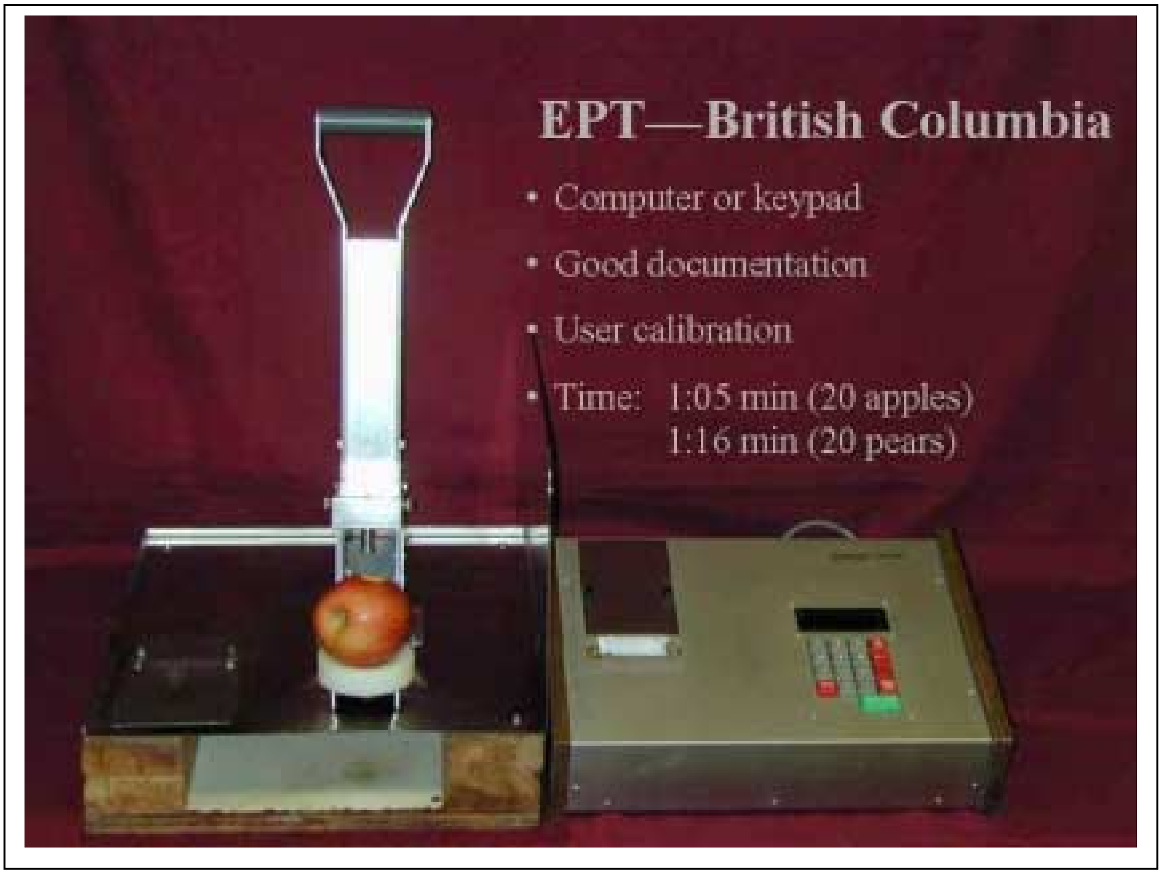

Fruit Quality Tester—Nova Scotia
• Computer interface
• No documentation
• Check user calibration, cannot change
• Time: 1:27 min (20 apples)
2:05 min (20 pears)


Penefel—France
• Computer or keypad
• Poor documentation
• No user calibration
• Time: 1:01 min (20 apples)
1:40 min (20 pears)


Mohr Digitest—
Washington
• Computer interface
• Brief documentation
• No user calibration
• Time: 5:29 min (20 apples)
6:42 min (20 pears)


Fruit Texture Analyzer—
South Africa
• Computer or keypad
• Good documentation
• User calibration
• Time: 2:01 min (20 apples)
2:20 min (20 pears)


Effegi—Italy
• No computer interface
• No documentation
• Check user calibration, cannot change
• Time: 1:36 min (20 apples)
1:37 min (20 pears)


EPT—British Columbia
• Computer or keypad
• Good documentation
• User calibration
• Time: 1:05 min (20 apples)
1:16 min (20 pears)

I. SETTING UP THE INSTRUMENTS

The amount and quality of written instructions varied greatly with each instrument (Table 1). The documentation with the FTA and EPT instruments was sufficient to set up the hardware and software. The only instrument in which one can both check and easily change calibration is the EPT.

Table 1. Summary of information provided by manufacturers.

Instrument	Instrument Set Up			Computer Required
	Written Instructions	Calibration	Help Resources	
1-FQT	None	Can check, but not change	E-mail, Web site	Yes
2-PFL	Poorly translated	Not by user	None	Yes/No*
3-Digitest	Very brief	Not by user	Personal visits, e-mail	Yes
4-FTA	Well done	Can check, but not easily change	E-mail, Web site	Yes/No*
5-Effegi	None	Can check, but not easily change	None	No
6-EPT	Well done	By user	E-mail	No**

* Can be configured to provide direct readout on LCD keypad
**Software is available for use with a computer

II. TAKING MEASUREMENTS

a) Experimental Design

Experimental designs such as BIBD (Harker et al 1996) and Repeated Measures (Lehman-Salade 1996) have been used to compare the effects of multiple users on a single instrument, or multiple firmness instruments. Since fruit from different orchards vary in terms of firmness, each fruit (apple or pear) was used as the experimental unit keeping the fruits as homogenous as possible by standardizing variety, strain and length of storage.

A single punch per fruit was taken half way between the sunny side and shady side on the right side of the fruit with the sunny side facing up. The fruit were 70 ºF when tested and the instruments turned on for at least 0.5 hours prior to each test. Each instrument was carefully calibrated (where possible). The technician practiced using each instrument with fruit of similar firmness prior to the test.

In a pilot study to determine the number of fruit to be tested and whether the order of testing played a role in final firmness numbers, a Completely Randomized Design, CRD (see for example Neter, Kutner, Nachtsheim and Wasserman, 1996) was used with a single operator on all instruments. Using power analysis of the type proposed by Saltveit (1978) with results from a pilot study, it was decided that 20 fruits per instrument were to be used for a power of about 0.80. Results indicated that the order in which the instruments were used or "order-effects" were not significant.

In the first experiment 140 randomly assigned fruits were tested on each of the instruments. Each instrument was used to test several types of apples and pears. Very hard round apples (Granny Smith), hard elongated apples (Red Delicious directly out of CA), soft elongated apples

(Red Delicious following ripening), hard pears (d'Anjou pears directly out of CA) and softened pears (d'Anjou pears following ripening) were tested. Results from these experiments for a single user is provided in Table 2.

Because the EPT can measure firmness in two modes, it is presented in the tables as instrument 6-EPT and 7-EPT MT. In EPT mode (6-EPT), the depth of the probe tip penetration does not matter. The EPT unit reports the highest firmness, regardless of probe depth. In MT mode, the operator must control the depth the probe tip enters the fruit (7.9 mm). The firmness at the 7.9-mm depth is recorded. MT mode is required to measure the firmness of soft fruit.

Table 2. Average firmness values for each type of fruit as determined by the firmness instruments.

Instrument	Apples			Pears	
	Red Delicious Firm	Red Delicious Soft	Granny Smith Firm	Anjou Soft	Anjou Firm
5-Effegi	13.05 a*	10.82 a	18.50 a	3.90 a	9.15 a
1-FQT	13.13 a	11.15 a	17.25 b	3.91 a	9.98 a
2-PFL	12.46 a	12.47 b	18.38 a	3.98 a	10.76 b
3-Digitest	12.89 a	10.96 a	17.93 a	4.27 a	10.30 b
4-FTA	13.84 a	11.48 a	19.49 a	4.13 a	10.70 b
6-EPT	14.23 a	13.02 b	18.36 a	6.09 b	11.53 b
7-EPT MT	14.70 b	12.62 b	19.05 a	5.01 b	11.79 b

* Numbers followed by 'b' denotes statistically different than those obtained with the Effegi, while those followed with 'a' denotes statistically indistinguishable from Effegi. For each fruit variety the overall $\alpha = 0.05$. The other six instruments were not compared to each other.

b) Accuracy

It is difficult to determine the true firmness of the fruit since there is no way of obtaining an accurate value without a known standard. Because the Effegi is the current industry standard, the results from the six instruments were compared to that instrument. This was conducted using Dunnett's comparison to control multiple comparison technique (see for example Hsu, 1996) keeping the overall Type I error (a-level) fixed at 0.05. Analysis was conducted using MINITAB Version 12© using the Dunnett option in ANOVA. Normality and equal variance was checked via Anderson-Darling's and the Bartlett's test respectively (for details see MINITAB Version 12 © HELP menu). Individual standard deviations are provided in Table 3. The equal variance assumptions were satisfied by four of the fruits (soft Red, firm Red, firm Granny Smith, firm pears) under study at the 0.05 level.

Soft pears indicated some marginal unequal variance (p-value=0.018). Data were log transformed to correct for this problem; however, there were no changes in the results in terms of instrument comparison from those without transformation. Hence, only the results from the untransformed data are reported. Table 2 summarizes the findings for comparing the six instruments to the Effegi.

The variety of fruit played a role in the firmness values (Table 2). When testing firm Red Delicious apples the EPT in the MT mode gave higher readings than the Effegi. The other instruments were not statistically distinguishable from the Effegi. For soft Red Delicious the

PFL, EPT, EPT in MT mode were higher than Effegi. With firm Granny Smith the FQT gave values lower than the Effegi whereas the others are indistinguishable from Effegi. When testing soft pears EPT and EPT-MT gave higher values than Effegi, whereas the others are not statistically different than Effegi. For firm pears FQT gave lower values than the Effegi whereas the others are again indistinguishable from the Effegi.

c) Precision

Precision is the amount of variability in firmness is indicated by the standard deviation of the samples. If there is a great deal of scatter in the data in one instrument compared to the others, then that instrument is less precise and the standard deviation will be higher. Using Bartlett's test there was no significant difference in the standard deviation values for any of the instruments on any of the apples tested and for the hard pears (Table 3). As reported above there were some marginal differences for soft pears. However, these differences were not significant using Levene's test.

Table 3. Estimated Standard Deviations obtained for the seven instruments under study.

Instrument	Apples			Pears	
	Red Delicious Firm	Red Delicious Soft	Granny Smith Firm	Anjou Soft	Anjou Firm
1-FQT	1.81	1.81	1.48	0.12	0.73
2-PFL	1.62	1.40	1.22	0.12	1.07
3-Digitest	1.67	1.73	1.60	0.17	1.04
4-FTA	1.73	1.98	1.49	0.12	1.00
5-Effegi	1.40	1.58	1.59	0.22	0.93
6-EPT	1.98	1.58	1.06	0.13	1.25
7-EPT MT	1.45	1.44	1.10	0.10	1.30

d) Performance by Multiple Users

In a second study firm Red Delicious and Granny Smith apples were used in a Randomized Block design with the five operators as blocks and 20 fruits per operator and instrument combination. For each operator, 120 fruits were randomly assigned to the 6 six instruments (20 fruits per instrument, per operator). The replication allowed us to study block-treatment interactions.

The results indicate operator-instrument interaction effects were significant in both cases (p-values of 0.005 Red Delicious and 0.001 for Granny Smith). This indicates that there may be a relationship between the type of instrument and the individual operator (Figure 1). The data show that Operator B's firmness values are different than other operator's using Effegi and FQT. Removing this operator from the study greatly reduces this interaction. For the Red Delicious data (without Operator B) there are no interactions (p-value = 0.42) or operator effects (p-value = .31). At $\alpha = .05$, PFL, EPT and EPT in the MT mode are different from the Effegi. Incidentally, this result is identical to those obtained for the single operator for firm Red Delicious

For the Granny Smith apples even without Operator B, there appears to be marginally significant interactions. Thus interpreting main effects is not possible. The means and standard deviations for the instruments and operators are found in Tables 4 and 5.

Figure 1. Operator Interaction Plot for Red Delicious.

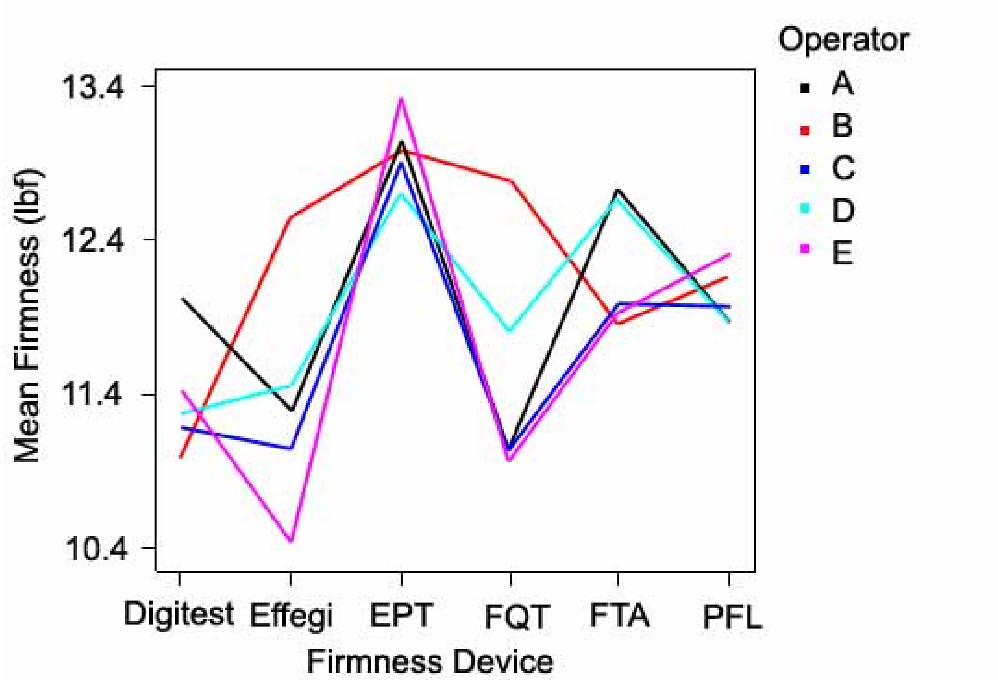


Table 4. Means and Standard Deviations for the 6 instruments over all 5 operators.

Instrument	Means		Standard deviations	
	Red Delicious Firm	Granny Smith Firm	Red Delicious Firm	Granny Smith Firm
1-FQT	11.54	15.14	1.691	1.502
2-PFL	12.04	15.93	1.567	1.228
3-Digitest	11.38	15.70	1.642	1.086
4-FTA	12.24	16.94	1.841	1.232
5-Effegi	11.36	15.81	1.778	1.406
6-EPT	12.99	16.36	1.418	1.413

Table 5. Means and Standard Deviations for the 5 operators over all 6 instruments.

Operator	Means		Standard deviations	
	Red Delicious Firm	Granny Smith Firm	Red Delicious Firm	Granny Smith Firm
A	12.01	15.96	1.60161	1.30629
B	12.22	16.06	1.87672	1.51411
C	11.69	16.30	1.76890	1.33941
D	11.96	15.58	1.77496	1.53817
E	11.74	16.00	1.71313	1.35336

This analysis implies that the differences amongst the instruments is related to the type of fruit being used, hardness of the fruit, and also to a smaller extent the operator who uses these instruments. There was no one instrument that was consistently different than the standard Effegi. As far as precision was concerned, there were no clear 'winners' and precision depended upon the variety and firmness.

d) Suitability by Location

All of the instruments could be easily used in a laboratory. If testing is desired at a warehouse receiving station or in a packing room any of the instruments except the Digitest tester would be suitable. The Digitest instrument is too slow to be used in a commercial situation (Table 6). If an instrument were to be used in the orchard by growers, only the Effegi would be suitable because it does not require a computer or electricity. The PFL might be used in the orchard but it must be repacked into its case for transport and is not watertight or rugged.

Table 6. Time to administer one punch per 20 fruit by a trained operator or technicians with varying levels of experience.

Instrument	Trained Operator (Avg. min:sec)	Technicians* (Avg. min:sec)
1-FQT	1:27	1:55
2-PFL	1:01	1:28
3-Digitest	5:29	5:19
4-FTA	2:01	1:59
5-Effegi	1:36	1:43
6-EPT	1:05	1:31
7-EPT MT	1:15	NA

* Average of 5 technicians

e) Messiness and Cleaning

There were differences in how messy each instrument was to use and keep clean. The following comments illustrate the differences.

1. The FQT has a sample collection cup that catches some of the juice from the puncture. This juice sample can be used for SS or acidity readings. However, a fair amount of the juice ends up on the floor.
2. The PFL does not have a drain hole and juice collects in the apple support plate, which needs to be wiped up on a regular basis. Since the PFL is not watertight, extreme caution must be used when cleaning.
3. The Digitest does not have a drain hole and juice collects in the support plate. The probe picks the apple up off the support plate at the end of the test and drops in down into the juice as the probe is raised. Juice also collects under the support plate. Access to areas that need cleaning is difficult.
4. The FTA is very clean to work with. Juice clean up and access is easy.
5. The Effegi mounted on the drill press does not have a support plate that collects juice, so there is no splashing. The drill press can easily be rinsed and wiped with a sponge.

6. The EPT has a drain hole that allows the juice to be removed from the testing area. Juice does tend to collect on the stand but can be wiped up with a sponge. Two knurled thumbscrews must be removed to clean the testing head after use. Caution must be used not to get too much water into the head when cleaning.

III. DATA REPORTING AND HANDLING

a) Data Handling

Each instrument had a very different method of reporting firmness. All the instruments were digital except the Effegi. All of the digital instruments recorded data directly to a computer or printer. The Effegi required recording data by hand. The read-out accuracy of the instruments ranged from 0.5 to 0.001 lb/force. In some cases the instruments were programmable (lb/force vs. kg/force vs. Newton) and in others it was not (Table 7).

Table 7. How the firmness testers handled data.

Instrument	Accuracy lb/force	Units	Ease of transfer to spreadsheet	Hard copy print out	Program flexibility	Readout
1-FQT	0.01	lb/kg/N	Easy	No	Easy	Digital
2-PFL	0.1	lb/kg	Difficult	No	Difficult	Digital
3-Digitest	0.001	programmable	Moderate	No	Very Difficult	Digital
4-FTA	0.01	programmable	Easy	No	Easy	Digital
5-Effegi	0.5	lb/kg	Hand entry	No	N/A	Analog
6-EPT	0.01	lb/kg/N	Hand entry	Yes	None	Digital

b) Error Replacement

FQT and FTA allowed for the replacement of an erroneous reading any time during testing. The user can highlight the suspect firmness and retest. The new reading then replaced the old one in the same location in the spreadsheet. PFL does not allow for the replacement of erroneous readings during testing; it must be done in the spreadsheet. Digitest and EPT users can only replace an erroneous reading immediately after the reading has been taken. If the error is not noticed right away the erroneous reading can be deleted, but the new reading will not be replaced in order in the spreadsheet.

IV. SUBJECTIVE EVALUATION

The principal technician and each of the five participating technicians were asked about their experience with each instrument.

1. **FQT-**The FQT did not come with instruction booklet and the help file was very sparse. There was not enough detail about where to set parameters in software and what all the boxes on the screen are for. Calibration is checked using a scale or weights. It is difficult to judge how much force to use when pushing the fruit onto the probe. Tip comes loose with use and needs to be checked often.

2. **PFL-**The instructions for using the PFL were very confusing. This instrument was the most difficult to learn to use. Setting instrument up involved using arrow keys to select letters (e.g., press arrow key 26 times for the letter z) rather than a keyboard. Cannot view all data on screen at the same time to know what the trends are. Battery operated so it can be used in the field. There is a minimum threshold of 1.6 kg. When testing softer

fruit you must change to a lower value. When using the higher sensitivity many false readings can be obtained because any bumping of the handle against the top of the instrument can provide a false reading. Instrument is not shock resistant and must be transported in its case.

3. **Digitest-**The software for the Digitest must be rewritten for each computer it is used with. There are too many file name layers to go through. The 'Enter' key does not work and the mouse must be clicked for each sample. A button on the instrument would be more convenient and would keep juice off the keyboard. The wizard does not work on the second sample and causes the program to crash. The file can be renamed on the screen, but it is difficult to do. The software tends to crash often. The instrument cannot be user calibrated and visual clearance is poor. It is difficult to line up fruit with the probe since the fruit tend to roll around so the pared area does not remain lined up with the tip. One must resort to using a rubber band to hold the door open, and hold the fruit with your hand while testing occurs. This is not a very safe practice. The way the instrument is designed does not allow for the testing of large fruit since clearance is about 4 inches. The testing takes too long to make it feasible in a warehouse situation, but the extra 'creep' data might be a useful area for research. Changing between the apple and pear tip would be easier if they weren't so long. The instrument needs to be placed higher than a regular lab bench in order to make access less difficult.
4. **FTA-**The instructions with the FTA are very hard to follow on first reading. After playing with the program, the instructions begin to make sense. The testing depth must be set every time since the software doesn't save this parameter. Data are automatically saved and when a series of samples are tested it is easy to name next file. Positioning the apple is simple and quick and visual clearance is good. Since one can't continue testing until you acknowledge the previous reading is out of bounds helps prevent missing a bad reading. The user sets the warning limits. Clean up is quick and simple.
5. **Effegi-**The Effegi on the drill stand is very easy to use and clean up. However, reading the dial can be difficult because of the size of the numbers. Since only every only other pound tick mark is labeled, it is easy to misread the dial. Dial only shows readings to the 0.5 lb. thus rounding the numbers is also a challenge. Speed and depth of penetration are not controlled mechanically. There is a quick learning curve. Calibration is questionable. Simple to use.
6. **EPT-**Calibration can be performed by user. EPT is easy to learn to use. Gives audible error messages for bad readings. Clean up is moderate. This is the only instrument that gives an immediate hard copy of the data. We did not have the most recent software, which we understand interfaces with a computer and helps manage data. One must change mode for use on the softer apples.

b) Ranking by Technicians

After both a familiarization period and use period, technicians were invited to rate instruments as to which instruments they would like to use in a lab. The FTA instrument was ranked highest, the Effegi and ETP ranked intermediate and the other instruments were ranked the least preferable.

Table 8. Ranking by technicians following use on Red and Granny Smith apples. Does not include an evaluation of data handling capabilities.

Instrument	Operator					Average Score
	A	B	C	D	E	
1-FQT	5	5	6	3	4	4.6
2-PFL	3	4	5	6	6	4.8
3-Digitest	4	6	4	5	5	4.8
4-FTA	1	2	2	1	1	1.4
5-Effegi	2	3	3	2	3	2.6
6-EPT	6	1	1	4	2	2.8

Subjective ranking with 1 = best and 6 = least.

V. SUMMARY AND DISCUSSION

R. O. Sharples determined that the speed and depth of compression greatly influenced the firmness measurement. Consequently one would expect that an instrument with a motorized plunger (or moveable platform) would provide the most consistent readings. This would be especially true when several operators used the same instrument. However, in this study this was not shown to be the case. Instead each instrument was equally accurate with either one technician or several. In some sense this is not surprising since the instruments work on the same principal.

There was little significant difference in the accuracy or precision of these instruments. There was slightly more difference when operator/instrument interaction was considered. In the pear trials the EPT gave higher readings than the others, while the Effegi gave the lowest readings. In one trial there was no difference.

If price and portability are the most important factors, the Effegi mounted on a drill press stand is the instrument of choice. However, modern warehouses need rapid access to data on many lots of fruit, so an instrument that can log information directly on the computerized database is desirable. The instrument of choice is the FTA which is reliable, robust (well built), simple to operate and the data manipulation features are superior to that provided by the other instruments. It is suitable for laboratory or commercial packinghouse use. The readings are as reliable and accurate as the other instruments.

The Digitest instrument provides an interesting measurement of "creep". Creep is an engineering term that may provide additional information about fruit quality and firmness. It was beyond the scope of this project to investigate this new way of measuring fruit firmness. We were obviously not using the full capability of this instrument.