NON-DESTRUCTIVE FIRMNESS INSTRUMENT TESTING: APPLES AND PEARS

July 2007

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INTRODUCTION

This report summarizes the results of two experiments in which benchtop models of the Sinclair Internal Quality-Firmness Tester (Sinclair), the Greefa intelligent Firmness Detector (Greefa) and Aweta Acoustical Firmness Sensor (Aweta) were used to non-destructively test the firmness of apples and pears.

Non-destructive and destructive firmness measurements of apples from the 2003 harvest were used in conjunction with consumer tests conducted by Washington State University and Oregon State University. The tests were designed to determine consumer "willingness to buy" apples of different firmness and soluble solids levels. Anjou pears from the 2003 harvest were tested both 1 day and 5 days after removal from storage with the non-destructive and destructive firmness instruments. No consumer work was performed on these pears. Results from each non-destructive instrument were compared to each other and to penetrometer (destructive) firmness measurements.

APPLES: MATERIALS AND METHODS

In April 2004, Gala and Red Delicious apples were obtained from several packinghouses and either placed in RA storage or moved to room temperature for a period to provide very soft fruit for consumers to rate. Gala apples were sorted for sweetness using a commercial near-infrared (NIR) sorter. Fruit with the lowest (< 12.9 %brix) and highest (> 14.1 %brix) soluble solids (SS) levels were used for the consumer evaluations to ensure a wide range in sweetness. Red Delicious apples were not sorted for sweetness prior to testing.

A wide range of firmnesses of both Gala (24 to 64 *i*FD units) and Red Delicious (32 to 60 *i*FD) apples were selected for the consumer test using the Greefa. Each apple was individually numbered then tested using each non-destructive firmness instrument (Aweta, Greefa and Sinclair). The apples were tested according to manufacturers' recommendations:

- Aweta (FI units): 3 taps per fruit, **average** calculated by program
- Sinclair (IQ units): 4 taps per fruit, **median** calculated by user
- Greefa (*i*FD units): 13 taps per fruit, **median** calculated by program

On April 17 and 18, 2004, consumer taste evaluations were conducted at an outside public venue, the Portland Saturday Market. Galas were tested on Saturday, April 17, with 487 consumers participating. The Red Delicious test on Sunday drew 290 consumers. Prior to the consumer evaluating the apple, one-half of each apple was tested destructively for firmness

(penetrometer) and for soluble solids (SS) (digital refractometer). The other half of the apple was used for taste evaluation.

The objective of the consumer tests was to provide data that could be used for a predictive model to determine the relationship between apple firmness or sweetness to the probability of consumer willingness to buy the apple. Consumer ratings included scaled liking ratings, acceptability for apple firmness and sweetness, and willingness to purchase at specific price points. Consumer demographic and apple eating habits were also obtained.

APPLES: RESULTS

Gala Apples Instrument Correlations:

None of the three non-destructive firmness instruments tested on Gala apples correlated well with the penetrometer firmness. The Sinclair had the best correlation with the penetrometer firmness measurement ($r^2 = 0.3183$). The Aweta showed no correlation with the penetrometer for Gala apples ($r^2 = 0.0216$). See Table 1.

Table 1. Correlation coefficients (r^2) for non-destructive and destructive firmness testing on Gala apples (487 fruit tested).

Instrument	Greefa	Sinclair	Penetrometer
Aweta	0.4797	0.3154	**0.0216**
Greefa		0.5824	**0.2419**
Sinclair			**0.3183**

Gala Apples Consumer Willingness to Buy:

- Most apples (80%) were rated by consumers as having acceptable firmness.

- Apple firmness level (measured by penetrometer) was the only measure that significantly affected consumer purchase decisions. As Gala apple firmness increased, there was a significant increase in the number of consumers willing to buy the fruit.

- The non-destructive firmness measures obtained from the Aweta, Greefa or Sinclair instruments did not relate to consumer willingness to buy in a consistent way (Figures 1 to 3). The destructive firmness provided a better prediction of consumer buying response than its non-destructive counterparts (Figure 4).

Figures 1 through 4 are histograms generated by dividing the data into discrete groups of numbers ('bins': e.g., FI units of 12-13, 13-14, etc. in Figure 1) then determining the percent of fruit that consumers considered they were willing to buy vs. not willing to buy. Thus, one can observe that when the firmness is low there are less fruit that people are willing to buy than if the firmness is high. This is not a valid statistical approach but does provide a visual way of evaluating the results. Note: the number of fruit in a given 'bin' will vary depending on the range in fruit firmness. See Appendix A for the number of fruit in each firmness bin for Figures 1 to 4.
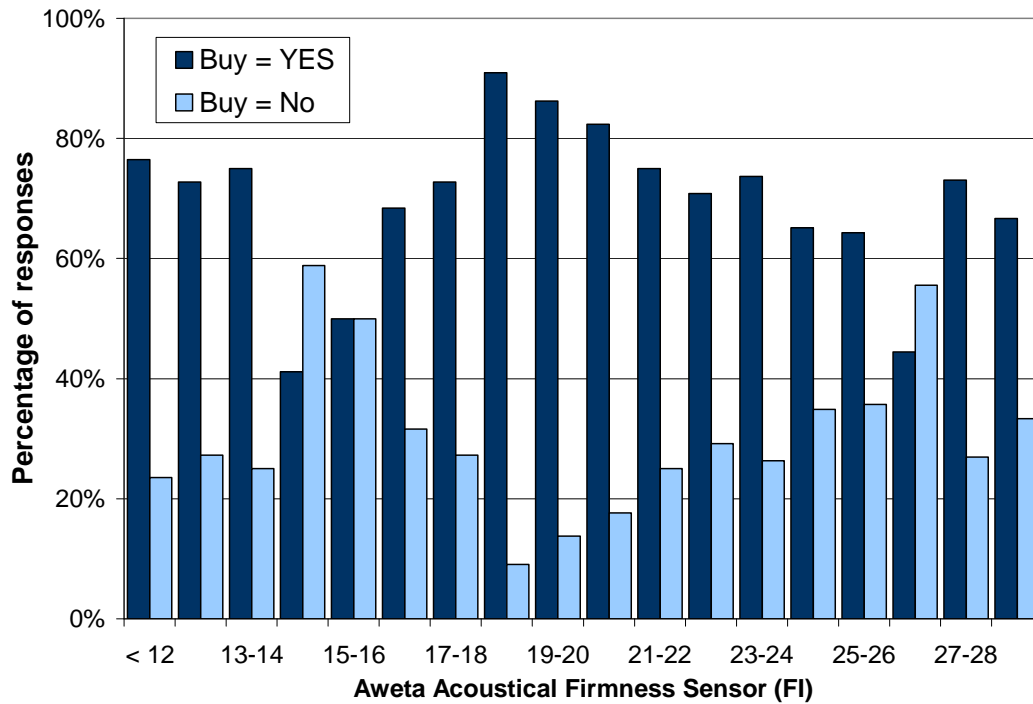
Figure 1. Consumer willingness to buy Gala apples (487 total responses) at different non-destructive firmness levels as measured by the Aweta Acoustical Firmness Sensor.
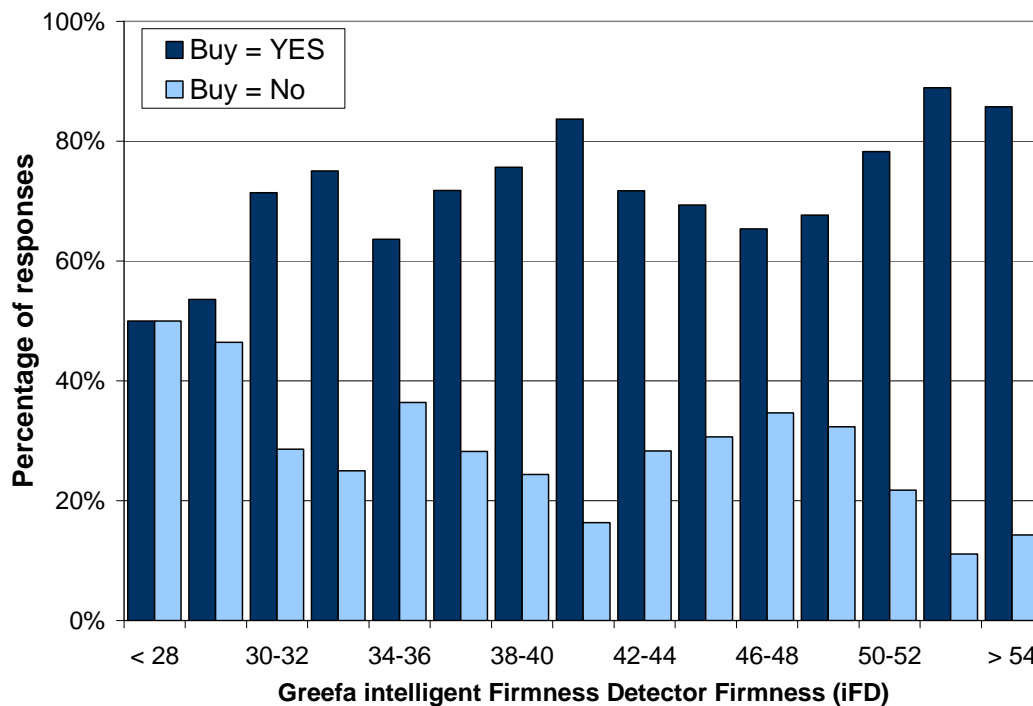

Figure 2. Consumer willingness to buy Gala apples (487 total responses) at different non-destructive firmness levels as measured by the Greefa intelligent Firmness Detector.
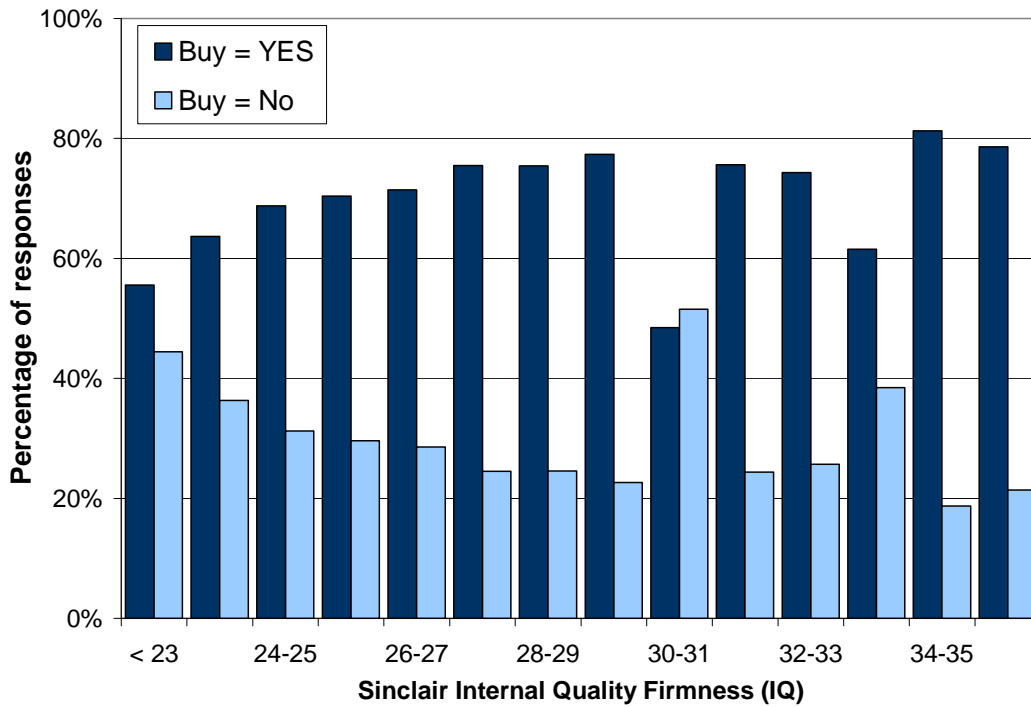
Figure 3. Consumer willingness to buy Gala apples (487 total responses) at different non-destructive firmness levels as measured by the Sinclair Internal Quality Firmness Tester.
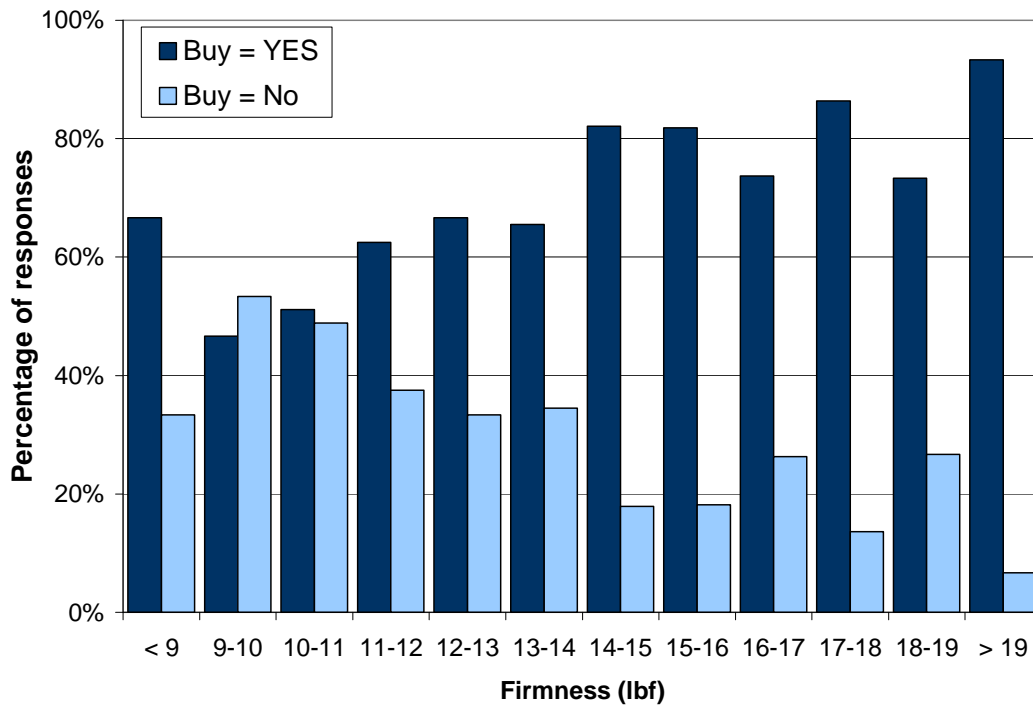

Figure 4. Consumer willingness to buy Gala apples (487 total responses) at different firmness levels as measured destructively by the penetrometer.

Red Delicious Apples Instrument Correlations:
As with the Gala apples, none of the three non-destructive firmness instruments tested on Red Delicious apples correlated well with the penetrometer. The Aweta had the best correlation with the penetrometer firmness measurement ($r^2 = 0.4189$). The Greefa showed no correlation with the penetrometer for Red Delicious apples ($r^2 = 0.0202$). See Table 2.

Table 2. Correlation coefficients (r^2) for non-destructive and destructive firmness testing on Red Delicious apples (290 fruit tested).

Instrument	Greefa	Sinclair	Penetrometer
Aweta	0.0018	0.2282	**0.4189**
Greefa		0.1258	**0.0202**
Sinclair			**0.2951**

Red Delicious Apples Consumer Willingness to Buy:

- Most apples (77%) were rated by consumers as having acceptable firmness.

- As Red Delicious apple firmness (measured by penetrometer) increased, there was a significant increase in the number of consumers willing to buy the fruit.

- Two non-destructive firmness measurements, Aweta (Figure 5) and Sinclair (Figure 7), appeared to provide a weak relationship to consumer willingness to buy. Greefa, the other non-destructive firmness instrument, did not relate in a consistent way to consumer willingness to buy (Figure 6). The penetrometer measure provided a better prediction of consumer response than the Aweta or Sinclair non-destructive firmness measures (Figure 8).

Figures 5 through 8 are histograms generated by dividing the data into discrete groups of numbers ('bins': e.g., FI units of 20-21, 21-22, etc. in Figure 5) then determining the percent of fruit that consumers considered they were willing to buy vs. not willing to buy. Thus, one can observe that when the firmness is low there are less fruit that people are willing to buy than if the firmness is high. This is not a valid statistical approach but does provide a visual way of evaluating the results. Note: the number of fruit in a given 'bin' will vary depending on the range in fruit firmness. See Appendix A for the number of fruit in each firmness bin for Figures 5 to 8.
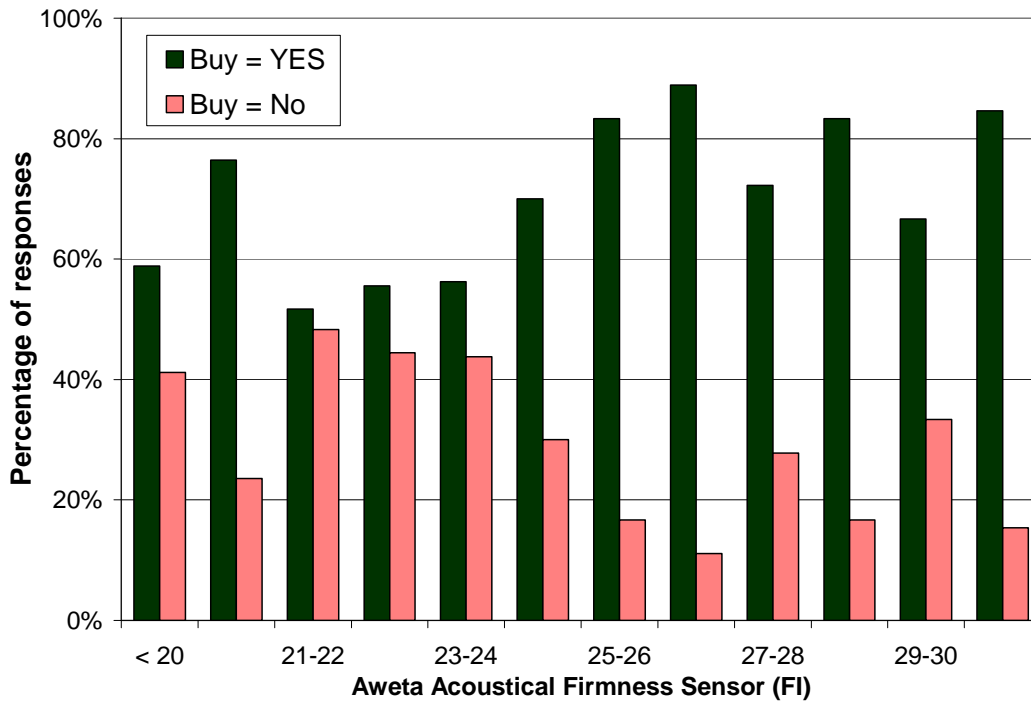
Figure 5. Consumer willingness to buy Red Delicious (290 total responses) at different non-destructive firmness levels as measured by the Aweta Acoustical Firmness Sensor.

Figure 6. Consumer willingness to buy Red Delicious (290 total responses) at different non-destructive firmness levels as measured by the Greefa intelligent Firmness Detector.
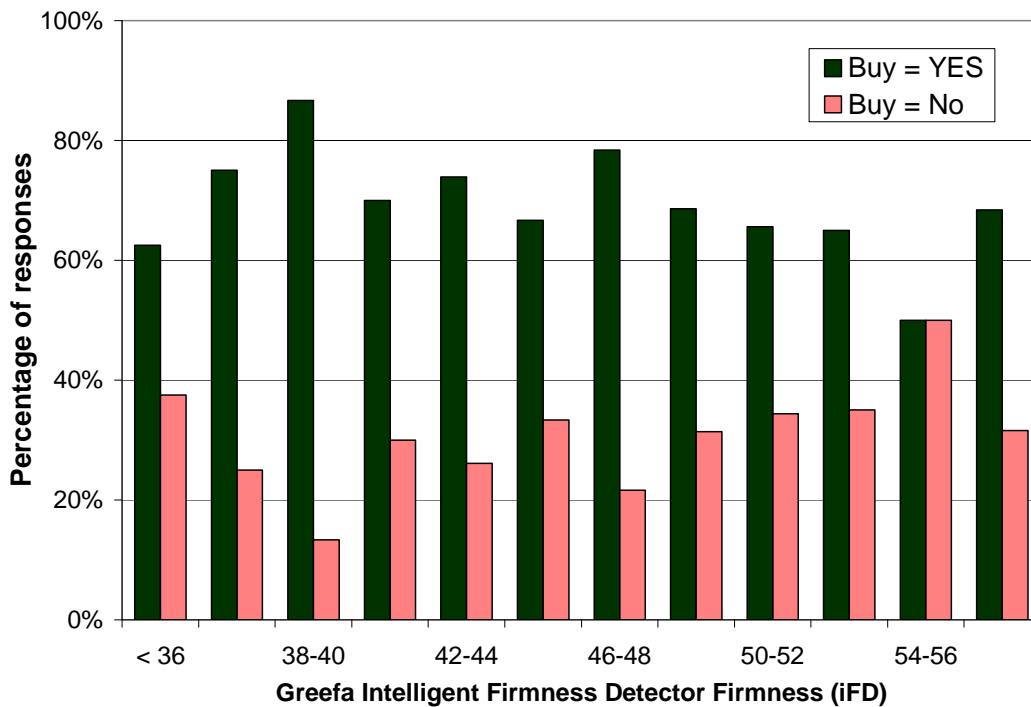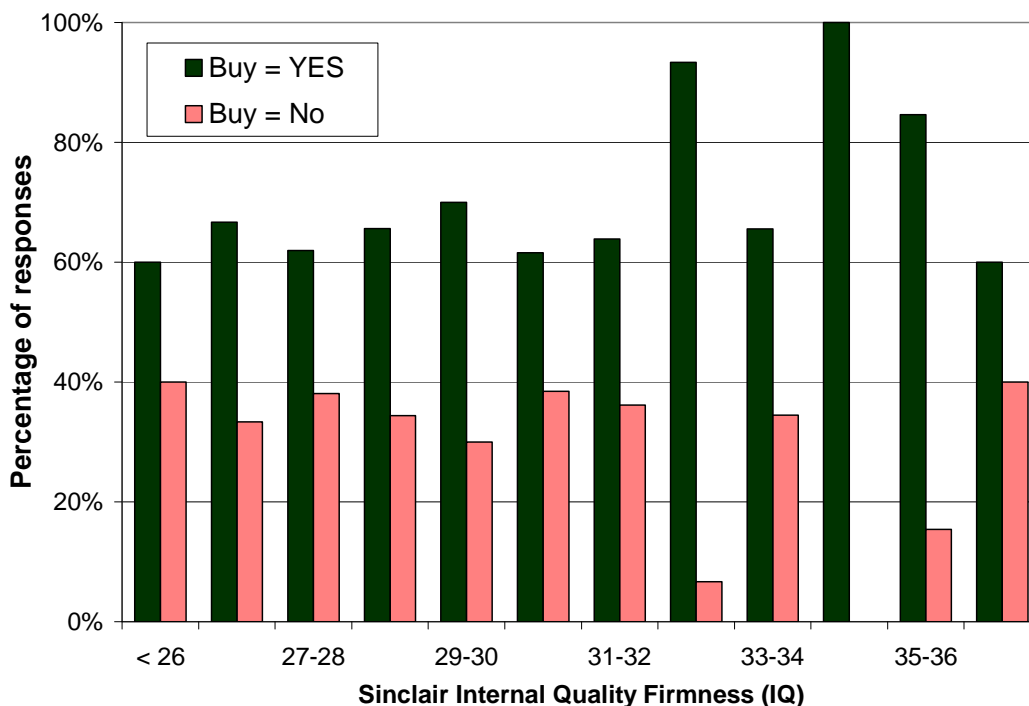
Figure 7. Consumer willingness to buy Red Delicious a (290 total responses) at different non-destructive firmness levels as measured by the Sinclair Internal Quality Firmness Tester.
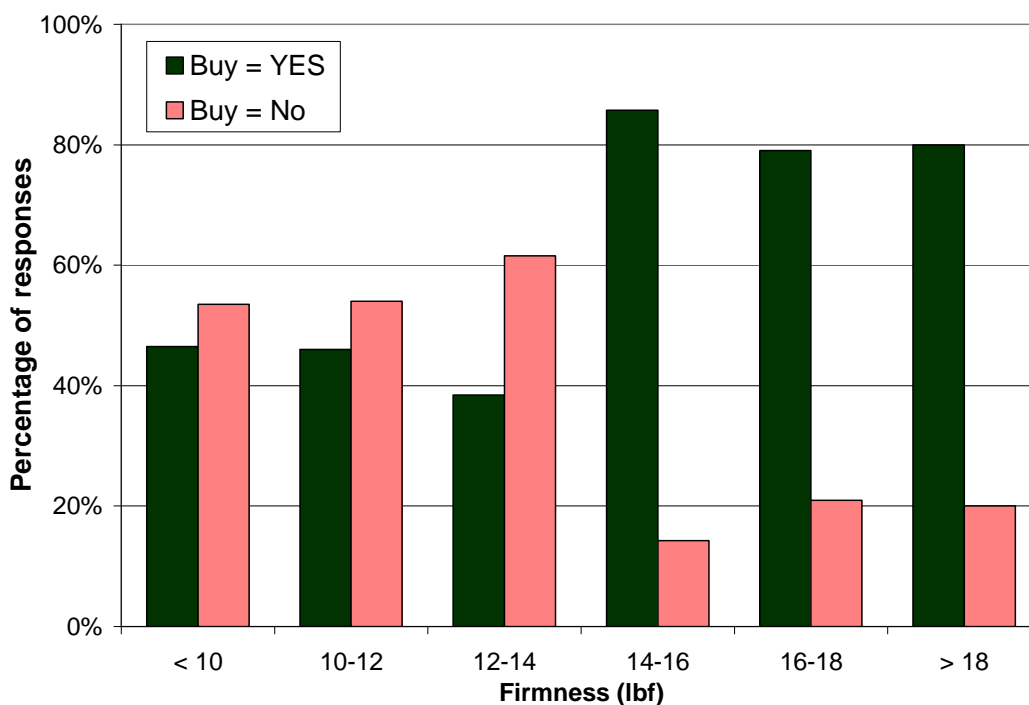

Figure 8. Consumer willingness to buy Red Delicious (290 total responses) at different firmness levels as measured destructively by the penetrometer.

APPLES: CONCLUSIONS

Correlations of non-destructive firmness instruments with the penetrometer were unsatisfactory in all cases. Dr. Marvin Pitts (Department of BioSystems Engineering, WSU), who has a long history of working with nondestructive instruments used to measure apple firmness, was invited to analyze firmness data from these two varieties as well as data from these and other varieties obtained from previous experiments. His analysis demonstrated that there was no correlation between the readings obtained using any of the non-destructive devices and the penetrometer when used on the same apple (Appendix B).

Correlations between consumer willingness to buy and any of the devices tested were also very weak. In viewing the data obtained by graphing the results as histograms, there emerges a general pattern of increasing willingness to buy with increased firmness. This is not a valid statistical approach and so it can only be an observation.

It is interesting to note that the percent of the consumers that considered their fruit to be acceptable was high (80% for Gala, 77% for Red Delicious). This was despite our attempts at providing very soft fruit (below 10 lbf) as well as firm fruit. Does this demonstrate that apples firmness is not a commercial problem? I don't think so since a fairly sizeable number of people at the market were unwilling to participate when Red Delicious were served, stating that they had tasted enough mealy, soft Red Delicious from their supermarkets in the past.

PEARS: MATERIALS AND METHODS

An experiment was performed to determine whether packed Anjou pears would retain quality better when stored on pallets covered with polyethylene hoods. We decided to use this fruit to evaluate the potential of the non-destructive firmness instruments on softening Anjou pears. There was no consumer component to this experiment.

Trials were done with fruit from regular storage (RA) and controlled atmosphere (CA) in the hopes that they might have less shrivel and decay than those stored on non-hooded pallets. The fruit used in this experiment came from five growers that had been packed throughout October 2003. Fruit was stored in RA for 76 days or CA for 139 days.

After each storage period, the fruit was randomly divided into two groups: the first group of fruit was tested one day after storage (+1 day) and the second group of fruit was allowed to ripen at room temperature for five days prior to testing (+5 days). Testing included non-destructive firmness on each instrument (Aweta, Greefa and Sinclair), followed by destructive firmness testing using the Fruit Texture Analyzer (FTA) penetrometer. Approximately 2000 pears were tested using each instrument.   The pears were tested according to manufacturers' recommendations:

- Aweta (FI units): 3 taps per fruit, **average** calculated by program
- Sinclair (IQ units): 4 taps per fruit, **median** calculated by user
- Greefa (*i*FD units): 13 taps per fruit, **median** calculated by program
- FTA: 2 measurements per fruit, **average** calculated by user

PEARS: RESULTS

None of the three non-destructive firmness instruments tested on Anjou pears correlated well with the penetrometer at either +1 day or +5 days. However, the correlation between non-destructive firmness and penetrometer increased dramatically when the +1 day and +5 day data were considered together (Table 3). The Greefa had the best correlation with the penetrometer firmness ($r^2 = 0.5433$).

The range of firmness for each instrument is shown in Table 4. Scatter plots for each non-destructive instrument versus the penetrometer are shown in Figures 9 through 11.

Table 3. Correlation coefficients (r^2) for non-destructive and destructive firmness testing on Anjou pears tested 1 day out of storage and after 5 days ripening at room temperature.

Instrument	Greefa	Sinclair	Penetrometer
+ 1 day			
Aweta	0.5521	0.2927	**0.0049**
Greefa		0.3648	**0.0131**
Sinclair			**0.0591**
+ 5 days			
Aweta	0.5806	0.2766	**0.0001**
Greefa		0.5532	**0.0202**
Sinclair			**0.0048**
+1 day and +5 day combined			
Aweta	0.7286	0.5379	**0.3692**
Greefa		0.7024	**0.5433**
Sinclair			**0.4884**

Table 4. Overall firmness ranges for non-destructive and destructive firmness testing on Anjou pears including those tested 1 day out of storage and after 5 days ripening at room temperature.

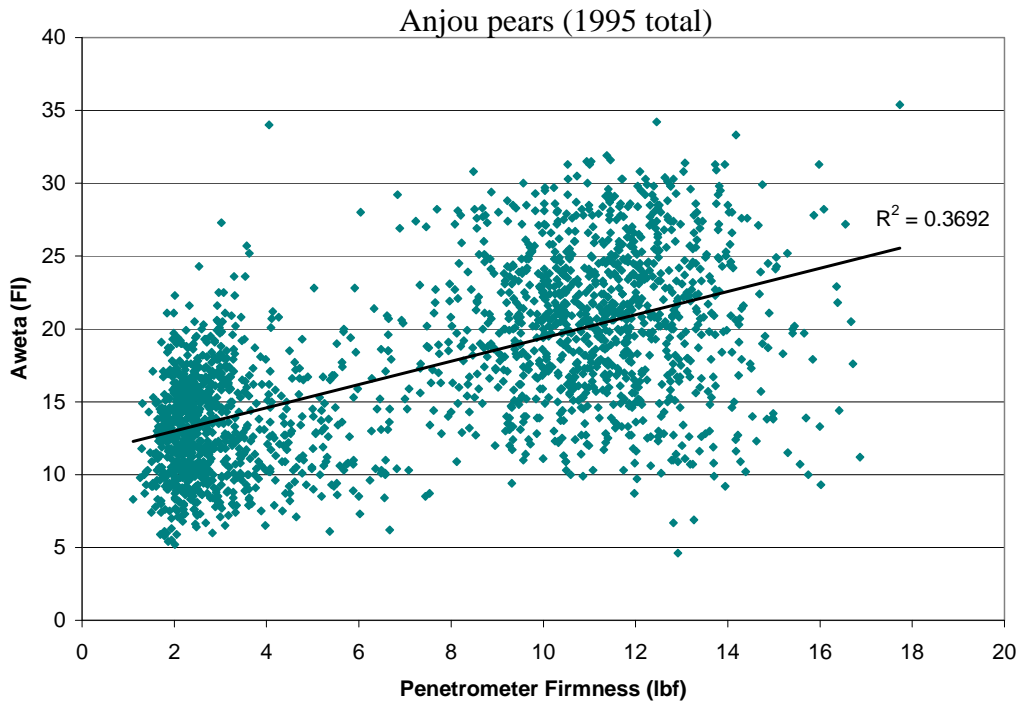| Instrument	Aweta	Greefa	Sinclair	Penetrometer
Minimum	4.6	16.0	11.0	1.1
Maximum	35.4	49.0	39.5	17.7
Average	17.3	31.4	25.6	7.0
No. of Fruit*	1995	1940	2022	2156
All fruit (2156 total) were intended to be tested using each non-destructive firmness instrument; however due to equipment malfunction, not all fruit were tested on every instrument.				

Figure 9. Firmness correlation between Aweta and penetrometer for Anjou pears.
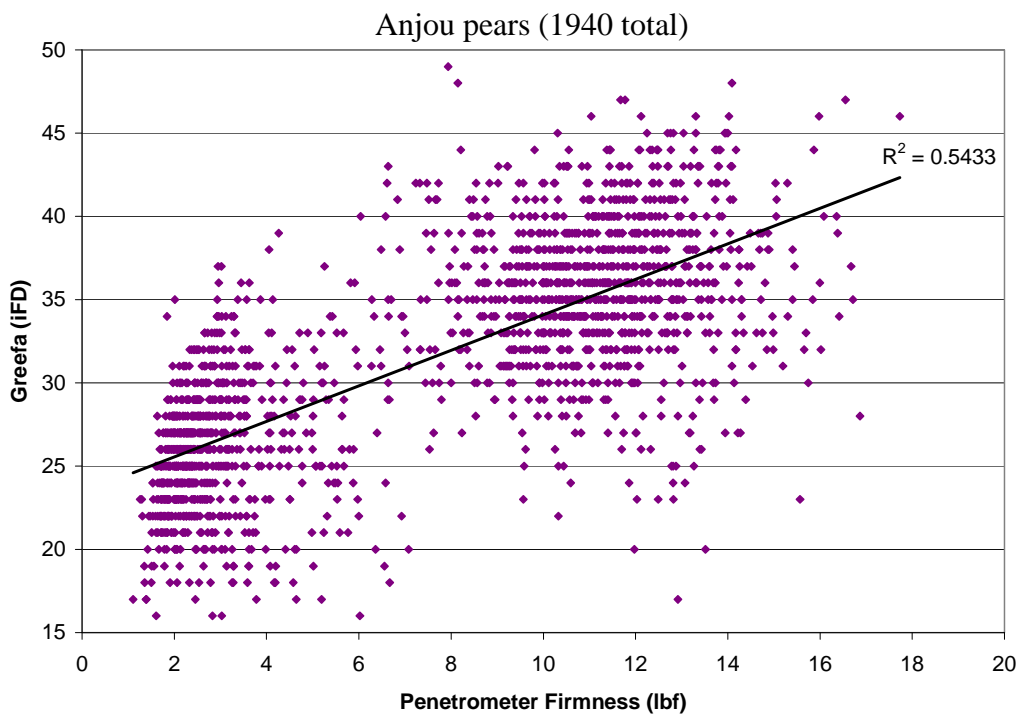
Figure 10. Firmness correlation between Greefa and penetrometer for Anjou pears.
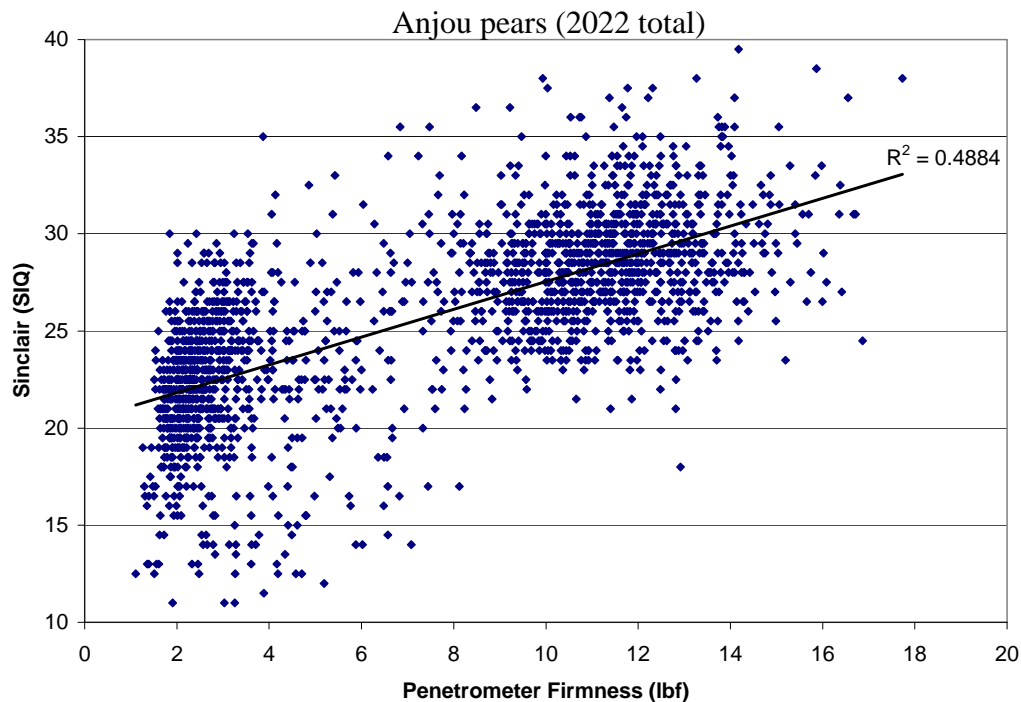
Figure 11. Firmness correlation between Sinclair and penetrometer for Anjou pears.

PEARS: CONCLUSIONS

On the positive side the correlation coefficients for the non-destructive firmness devices on pears (when all data were included) were superior to those developed in either of the apples tested. However, they were still very much below those required to develop confidence in the relationships.

The correlations were very poor when either the firm (+1 day) or soft (+5 days) fruit were considered by themselves.

It might be possible to use a non-destructive instrument to determine whether an Anjou pear is ripe or unripe. This might be useful as the pear industry moves to providing consumers with pears that are more ripe and ready to eat, since this pear often will not change color as it ripens.

APPENDIX A
Apple Purchase Intent Summary Tables

Gala Purchase Intent

Destructive Firmness (lbf)			
Firmness Range	Bin	Total fruit in bin	No. of Buy=Yes
< 9	9	12	8
9-10	10	15	7
10-11	11	43	22
11-12	12	56	35
12-13	13	72	48
13-14	14	58	38
14-15	15	67	55
15-16	16	55	45
16-17	17	57	42
17-18	18	22	19
18-19	19	15	11
> 19		15	14

Aweta Firmness (FI)			
Firmness Range	Bin	Total fruit in bin	No. of Buy=Yes
< 12	12	17	13
12-13	13	11	8
13-14	14	12	9
14-15	15	17	7
15-16	16	22	11
16-17	17	19	13
17-18	18	22	16
18-19	19	22	20
19-20	20	29	25
20-21	21	34	28
21-22	22	44	33
22-23	23	48	34
23-24	24	57	42
24-25	25	43	28
25-26	26	28	18
26-27	27	18	8
27-28	28	26	19
> 28		18	12

Sinclair Firmness (SIQ)			
Firmness Range	Bin	Total fruit in bin	No. of Buy=Yes
< 23	23	27	15
23-24	24	33	21
24-25	25	32	22
25-26	26	27	19
26-27	27	49	35
27-28	28	53	40
28-29	29	61	46
29-30	30	53	41
30-31	31	33	16
31-32	32	41	31
32-33	33	35	26
33-34	34	13	8
34-35	35	16	13
> 35		14	11

Greefa Firmness (iFD)			
Firmness Range	Bin	Total fruit in bin	No. of Buy=Yes
< 28	28	20	10
28-30	30	28	15
30-32	32	14	10
32-34	34	16	12
34-36	36	33	21
36-38	38	39	28
38-40	40	41	31
40-42	42	49	41
42-44	44	53	38
44-46	46	62	43
46-48	48	52	34
48-50	50	34	23
50-52	52	23	18
52-54	54	9	8
> 54		14	12

Note on Excel bin ranges: bin range of < 9 = firmness up to 9.00, bin range 9-10 = firmness of 9.01 to 10.00

Red Delicious Purchase Intent

Destructive Firmness (lbf)			
Firmness Range	Bin	Total fruit in bin	No. of Buy=Yes
< 9	9	18	11
9-10	10	25	9
10-11	11	37	15
11-12	12	13	8
12-13	13	6	1
13-14	14	7	4
14-15	15	51	44
15-16	16	61	52
16-17	17	43	34
17-18	18	19	15
> 18		10	8

Aweta Firmness (FI)			
Firmness Range	Bin	Total fruit in bin	No. of Buy=Yes
< 18	18	16	9
18-19	19	9	5
19-20	20	9	6
20-21	21	17	13
21-22	22	29	15
22-23	23	27	15
23-24	24	32	18
24-25	25	30	21
25-26	26	36	30
26-27	27	27	24
27-28	28	18	13
28-29	29	18	15
29-30	30	9	6
> 30		13	11

Sinclair Firmness (SIQ)			
Firmness Range	Bin	Total fruit in bin	No. of Buy=Yes
< 26	26	15	9
26-27	27	12	8
27-28	28	21	13
28-29	29	32	21
29-30	30	40	28
30-31	31	39	24
31-32	32	36	23
32-33	33	30	28
33-34	34	29	19
34-35	35	8	8
35-36	36	13	11
> 36		15	9

Greefa Firmness (iFD)			
Firmness Range	Bin	Total fruit in bin	No. of Buy=Yes
< 36	36	8	5
36-38	38	16	12
38-40	40	15	13
40-42	42	20	14
42-44	44	23	17
44-46	46	27	18
46-48	48	37	29
48-50	50	35	24
50-52	52	32	21
52-54	54	40	26
54-56	56	18	9
56-58	58	12	9
> 58		7	4

Note on Excel bin ranges: bin range of < 9 = firmness up to 9.00, bin range 9-10 = firmness of 9.01 to 10.00

APPENDIX B

Apple Data Analysis by Dr. Marvin Pitts

Scatter Plots of Braeburn, Golden Delicious, and Fuji apples tested by Gene Kupferman in 2003