Assessment of post harvest bruising of export apples with instrumented sphere technology

AP028

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Mr Danny Cotter

VIC Department of Agriculture
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SUMMARY

The instrumented sphere (model IS 100) is a sophisticated, electronic pseudo-fruit capable of recording impact data in the form of accelerations and velocity changes. Two spheres were purchased along with the necessary computer hardware/software to retrieve and interpret data.

Trials in ten apple packing sheds involved passing the IS through the normal handling chain (bin tip—palletization), and video-filming its progress. Timing mechanisms in the camera and IS were matched to pin-point locations where significant impacts capable of causing Granny Smith bruising occurred.

It was established that entry of the sphere/apple into a new section of the packing line (component) resulted in more damage than movement within a component. Impacts on entry/transfer to components were larger, and occurred more frequently than impacts along components.

Considerable variation was evident between sheds but some existing styles of equipment which are arranged in a straight line, produced relatively little damage to fruit.

Trials in the laboratory using a pendulum impact rig, and a hand-held penetrometer to create artificial bruising, have correlated drop heights onto various surfaces with impact accelerations, velocity changes, and bruise diameters on Granny Smith.

Additional research with Granny Smith has demonstrated that bruises do "fade" with time in storage, that bruises are worse on larger fruit, and that low (e.g. 1°C) fruit temperature during handling exacerbates the bruising problem.
INTRODUCTION

In 1988 the then Apple and Pear Research Foundation financed a small project which attempted to determine the severity of Granny Smith bruising by adopting a process of systems analysis involving fruit sampling.

Department of Agriculture officers, Bruce Cumming and Graeme Thomson, nominated sampling points in the handling chain within sheds in the Goulburn Valley and Gippsland. At each point 150 fruit were collected and stored for 6 weeks. At the end of that time bruise numbers and diameters were determined both with the skin intact, and removed.

The example presented in Figure 1 is a shed in the Goulburn Valley. In this case 150 fruit per sample point enabled meaningful interpretation of the results because the number in the sample covered the intrinsic variability of the apple population. In other sheds the data was inadequate because the sample size was too small. However, even at 150 fruit/sample the thousands of fruit required for analysis made the work almost unmanageable.

Nevertheless, the study showed that damage levels were high, that removal of the skin revealed far higher levels of bruising damage (Figure 1) and, most importantly, that bruise numbers increased dramatically through the process of handling within the shed.

In conjunction with this work a trial shipment of a few cartons was transported by sea to London. It was found that the processes of road and sea shipment from the Goulburn Valley via Melbourne, to London and site of assessment, only increased the number of bruises per peeled fruit by 0.97 (see page 36). Clearly the 20-30m of the packing line was the stage where quality was seriously lost.

To better understand and quantify the processes of bruising on packing lines, in a manner which was more time and labour efficient, an alternative was sought - the latest in electronic pseudo fruit, the IS100.
FIGURE 1: EFFECT OF DISTANCE ALONG PACKING CHAIN 'E' ON BRUISE NUMBERS (SOLID LINES) AND DIAMETERS (BROKEN LINES) WITH SKIN INTACT AND REMOVED
THE INSTRUMENTED SPHERE 100 (200G Model)

The IS100 was developed at Michigan State University in conjunction with the U.S. Department of Agriculture. It consists of a battery powered computer and a piezo-electric accelerometer enclosed in a spherical beeswax shell of 90mm diameter (Figure 2a). The accelerometer senses impacts along three axes (Figure 2b).

Impact signals registered by the accelerometer are sent to a processor chip where they are logged and timed, then sent to a memory chip. After the IS is operated the accumulated data are loaded into a computer for analysis (Figure 2c). IS based software controls sampling rates, checks and stores data, and sends the data to the computer. Computer based software provides data analysis and graphical display.

Appendix 1 contains a fuller description of the IS100, and a brief history of electronic pseudofruit.
FIGURE 2: INSTRUMENTED SPHERE 100 HARDWARE

A. IS100 Components

B. Accelerometer Orientation Within IS100

C. IS100 Configuration
PACKING LINE ASSESSMENT

IS data collected after assessment of 10 packing sheds is presented in Tables 1 and Figures 3-5. Sheds were located in either Gippsland, the outer Melbourne region, or Goulburn Valley. Tabulated data has been presented with a minimum threshold of 20G. 20G was chosen because other researchers believe that this is the minimum force likely to cause bruising damage to apples.

Assessment involved passing the IS together with fruit through the normal packing line, and video-filming its progress. Runs were typically started at the beginning of the PVC sorting rollers, and were terminated once the IS had entered a sized bin (or tray). Ten runs were performed in each shed. Runs were not started in water dumps because submersion of the IS might have caused damage to its electronic components.

By co-ordinating the intrinsic timing mechanism in the IS with the camera’s stop watch it was usually possible, on replay of the footage, to determine where on the line a particular impact had occurred. However, this was not always possible given that some components (e.g. dryers) were enclosed.

The length and number of directional changes of a line are two elements that influence the accumulation of bruises. Packing shed A (Table 1 and Appendix 2) housed a 25.3m line with 3 turns, and was particularly damaging to fruit. In contrast, shed B (Table 1, Appendix 2) was a short line which incorporated conventional components arranged without directional changes. The straight run experienced by fruit along this line resulted in relatively little damage.

The average impact in shed A was 35.2G as compared to only 24.6G in B. In the remaining sheds (Table 1), mean impact size ranged from approximately 30 to 45G.
The largest impact registered by the IS during each run was averaged over 10 runs, and presented in the last column of Table 1. Average maximum impact size was only 30.5G in shed B, 84.6G in A but a very large 121.2G in shed I.

Figure 3 compares sheds A and B showing the larger impacts experienced in A at entry to all components. Generally it was the sphere’s/apple’s entry or transfer into a component, rather than movement through the component, that was the predominant problem. In the ten sheds, more impacts occurred on entry to components (Fig. 4), and they were typically of greater magnitude (Fig. 5) than impacts along components. In shed A, over 10 runs, 151 impacts were recorded on the transfers, or entries, but only 22 within the course of components. No impacts were registered along components in shed G, however, entry impacts totalled 131 (Fig. 4).
### TABLE 1: PACKING SHED ASSESSMENT

Summary of impact data

<table>
<thead>
<tr>
<th>Packing Shed</th>
<th>Packing Line Length (m)</th>
<th>Mean number of impacts per run (&gt;20G threshold) n=10 runs</th>
<th>Mean impact size over 10 runs (G) (&gt;20G threshold)</th>
<th>Mean max. impact size (G) n=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25.3</td>
<td>17.3</td>
<td>35.2</td>
<td>84.6</td>
</tr>
<tr>
<td>B</td>
<td>14.9</td>
<td>4.0</td>
<td>24.6</td>
<td>30.5</td>
</tr>
<tr>
<td>C</td>
<td>15.3</td>
<td>7.3</td>
<td>30.6</td>
<td>48.7</td>
</tr>
<tr>
<td>D</td>
<td>22.3</td>
<td>6.8</td>
<td>30.3</td>
<td>46.6</td>
</tr>
<tr>
<td>E</td>
<td>23.9</td>
<td>8.6</td>
<td>36.6</td>
<td>91.0</td>
</tr>
<tr>
<td>F</td>
<td>24.2</td>
<td>5.0</td>
<td>31.7</td>
<td>47.1</td>
</tr>
<tr>
<td>G</td>
<td>23.4</td>
<td>13.1</td>
<td>43.5</td>
<td>94.4</td>
</tr>
<tr>
<td>H</td>
<td>26.4</td>
<td>10.2</td>
<td>44.9</td>
<td>110.7</td>
</tr>
<tr>
<td>I</td>
<td>21.1</td>
<td>10.2</td>
<td>44.2</td>
<td>121.2</td>
</tr>
<tr>
<td>J</td>
<td>22.0</td>
<td>7.9</td>
<td>37.1</td>
<td>65.8</td>
</tr>
</tbody>
</table>
FIGURE 3: MEAN PEAK ACCELERATION VALUES FOR IMPACTS OCCURRING ON ENTRY TO PACKING CHAIN COMPONENTS IN TWO SHEDS

MEAN PEAK ACCELERATION (G)

PROGRESSIVE CHAIN COMPONENTS

rollers dryer singulator sizer coll.belt bin

SHED A  SHED B
FIGURE 4: TOTAL IMPACTS a) ON ENTRY INTO COMPONENTS AND b) ALONG COMPONENTS, OVER TEN RUNS, ON PACKING LINES IN TEN SHEDS.
FIGURE 5: MEAN IMPACT SIZE a) ON ENTRY INTO COMPONENTS, AND b) ALONG COMPONENTS, ON PACKING LINES IN TEN SHEDS

MEAN IMPACT SIZE (G)

SHED

INTO COMPONENTS  ALONG COMPONENTS
**CORRELATION OF BRUISING WITH IS. OUTPUT**

Comparison of different experimental treatments necessitated artificially damaging fruit to create bruises resulting from forces/pressures of known magnitude. This was achieved with either a specially constructed pendulum impact rig, or a hand-held penetrometer.

Dropping fruit from a known height enables bruise characteristics (e.g. surface diameter, darkness) to be correlated to drop height. Along typical packing lines drop heights of 1 or 2 cm are of interest but in the laboratory it is difficult to control such small drops. To accurately quantify damage, fruit must not be allowed to bounce or have more than one impact.

The problem is solved by using a pendulum impact rig (Fig. 6) on which an apple moves through an arc to imitate a vertical drop.

The rig incorporates a flat impact surface of steel which can be covered with various types of sheet padding typically used in packing lines (e.g. vinyl, rubber, neoprene foam).

Using the IS on the rig enables correlation of drop height to impact acceleration (G) as registered by the IS. This data can be generated for various impact surfaces (Fig. 7, Table 2).

Once these impact correlations are established it is then possible, by using apples on the rig, to relate bruise characteristics (e.g. surface diameter) to drop height and/or impact size as registered by the IS.
FIGURE 6: Pendulum Impact Rig

600mm
FIGURE 7: SURFACE RESPONSE CURVES FOR IS DROP HEIGHT VS. IMPACT ACCELERATION
<table>
<thead>
<tr>
<th>SURFACE</th>
<th>REGRESSION FIT</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEEL</td>
<td>$Y = -2.2 + 0.05X + 0.001X^2$</td>
<td>100 %</td>
</tr>
<tr>
<td>RUBBER 1.5 mm</td>
<td>$Y = 3.0 - 0.04X + 0.002X^2$</td>
<td>99.8%</td>
</tr>
<tr>
<td>VINYL</td>
<td>$Y = -2.0 + 0.14X + 0.001X^2$</td>
<td>99.8%</td>
</tr>
<tr>
<td>NEOPRENE 3 mm</td>
<td>$Y = 17.6 + 0.38X + 0.0004X^2$</td>
<td>99.9%</td>
</tr>
<tr>
<td>NEOPRENE 6 mm</td>
<td>$Y = -29.5 + 2.34X - 0.005X^2$</td>
<td>99.5%</td>
</tr>
<tr>
<td>NEOPRENE 9 mm</td>
<td>$Y = -42.0 + 3.04X - 0.004X^2$</td>
<td>100 %</td>
</tr>
</tbody>
</table>

$Y$ - Drop Height (mm)

$X$ - Peak Impact Acceleration (G)
A correlation of IS impact acceleration, against flat steel, with bruise diameters on Granny Smith (Count 90, 1°C, firmness 6.1 kg/cm²), appears in Fig. 8. Fig. 9 presents similar data for count 110's struck against various surfaces; regression equations for curves of best fit appear in Table 3. For each treatment, 20 fruit (0-1°C, 7.1 kg/cm² firmness) were dropped from each height, and 2 bruises were inflicted upon opposite cheeks on every fruit. After 4 days at 0-1°C air storage, the apples were peeled and assessed for bruising.

Bruise diameters on count 90 Granny Smith were greater than those on 110's for equivalent impact accelerations onto flat steel (see Pg 28 for discussion of fruit size effect on damage). Diameters of bruises progressively increased with increasing impact acceleration. On count 110's an 80G impact corresponded to a bruise diameter of approximately 4.5 mm, and with impact acceleration of 200G and drop height of 60 mm, the diameter increased to 12.5 mm (Fig. 9).

Padding the steel surface with vinyl or 1.5 mm rubber sheeting had little effect and did not significantly reduce bruise diameters (Fig. 9). In contrast, neoprene foam of 3 mm thickness was very effective in reducing damage. A 200G impact onto 3 mm foam only caused an average bruise diameter of about 4 mm. Rubber does not absorb impact energy in the same way as foam, and most of the energy of an impact is taken up by the fruit. Impacts up to 160G onto 6 mm neoprene foam, and 120G on 9 mm foam with steel backing, did not bruise fruit.

The data presented in figures 7 and 9 allows growers to make predictive assumptions, in this case for count 110. Drop heights can be readily determined in individual packing lines, and these heights can be approximately correlated to impact size by using Fig. 7. For any given surface, this impact size is likely to cause a diameter approximating those indicated in Fig. 9. Of course factors such as fruit temperature and size affect diameter (see Pgs 28,32).
FIGURE 8: EFFECT OF IMPACT SIZE AGAINST FLAT STEEL ON GRANNY SMITH (COUNT 90)

BRUISE DIAMETER

\[ Y = -0.89 + 0.11X - 0.00005X^2 \]

\[ r^2 = 86\% \]
FIGURE 9: EFFECT OF IMPACT ACCELERATION AND IMPACT SURFACE ON BRUISE DIAMETERS OF GRANNY SMITH (COUNT 110) APPLES

STEEL

VINYL

RUBBER 1.5 mm

NEOPRENE FOAM 3 mm
Velocity change

As well as reducing peak impact acceleration, padding materials play an additional role in increasing the velocity change associated with an impact. The IS software generates impact curves by plotting acceleration against time and the area under the curve represents the velocity change of the impact.

When an apple rebounds from an impact onto a hard surface such as steel, it tends to exit with a velocity which is similar to the incoming velocity; the overall change in velocity is thus low. In contrast, during an impact against foam, energy is absorbed or dissipated and the apple rebounds with considerably lower velocity. This second type of impact with high velocity change is potentially much less damaging to fruit.

Figure 10 (Table 4 gives equations) shows data plots of impact acceleration vs. velocity change for IS registered impacts onto steel and padded steel surfaces. For equivalent impact accelerations the velocity changes onto vinyl and 1.5mm rubber are not significantly different from those associated with steel. In comparison, large velocity changes which increased progressively with thickness, were evident for neoprene foam.

Plotting peak acceleration vs. velocity change for every impact occurring in a shed during assessment (10 runs), allows a rapid visual estimation of the packing line's damage potential. Good lines will register few impacts and overall spread of impacts should indicate low peak acceleration and high velocity change. In contrast, the scatter plots for packing lines which bruise fruit badly will reveal many impacts with high impact acceleration and low velocity change.

Figures 11 and 12 show scatter plots of impact acceleration vs. velocity change for sheds A,B,F and G. All impacts with a peak acceleration greater than 20G have been plotted. Potential for damage would appear to increase in the order G,A,F,B; and the data in Table 1 is supportive of this sequence.
FIGURE 10: SURFACE RESPONSE CURVES FOR IS
Table 3: BRUISE DIAMETER VS IMPACT ACCELERATION

<table>
<thead>
<tr>
<th>SURFACE</th>
<th>REGRESSION FIT</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEEL</td>
<td>Y = -4.74 + 0.14X - 0.0002X²</td>
<td>78.9%</td>
</tr>
<tr>
<td>VINYL</td>
<td>Y = -3.92 + 0.1X - 0.00004X²</td>
<td>95.6%</td>
</tr>
<tr>
<td>RUBBER 1.5 mm</td>
<td>Y = -5.69 + 0.17X - 0.0003X²</td>
<td>91.6%</td>
</tr>
<tr>
<td>NEOPRENE 3mm</td>
<td>Y = 2.24 - 0.06X + 0.0004X²</td>
<td>36.6%</td>
</tr>
</tbody>
</table>

Y - Bruise Diameter (mm)
X - Peak Impact Acceleration (G)

Table 4: CHANGE IN VELOCITY VS IMPACT ACCELERATION

<table>
<thead>
<tr>
<th>SURFACE</th>
<th>REGRESSION FIT</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEEL</td>
<td>Y = 0.02 + 0.01X + 3E-6X²</td>
<td>99.9%</td>
</tr>
<tr>
<td>RUBBER 1.5 mm</td>
<td>Y = 0.03 + 0.01X - 8E-6X²</td>
<td>99.7%</td>
</tr>
<tr>
<td>VINYL</td>
<td>Y = 0.03 + 0.01X - 11E-6X²</td>
<td>99.7%</td>
</tr>
<tr>
<td>NEOPRENE 3 mm</td>
<td>Y = -1.29 + 1.56 LOG₁₀(X)</td>
<td>97.0%</td>
</tr>
<tr>
<td>NEOPRENE 6 mm</td>
<td>Y = -2.91 + 2.87 LOG₁₀(X)</td>
<td>99.7%</td>
</tr>
<tr>
<td>NEOPRENE 9 mm</td>
<td>Y = -3.84 + 3.64 LOG₁₀(X)</td>
<td>99.7%</td>
</tr>
</tbody>
</table>

Y - Change in Velocity (m/s)
X - Peak Impact Acceleration (G)
FIGURE 11: SCATTER PLOT OF I.S. RECORDED IMPACTS FROM 10 RUNS OVER PACKING LINES "G" AND "A" – HIGH DAMAGE POTENTIAL
FIGURE 12: SCATTER PLOT OF I.S. RECORDED IMPACTS FROM 10 RUNS OVER PACKING LINES "F" AND "B" - LOW DAMAGE POTENTIAL
ASSOCIATED RESEARCH AT I.P.S KNOXFIELD

An examination of apple bruising via IS technology cannot be undertaken in isolation from factors such as fruit mass and temperature which may influence manifestation of damage. To interpret data meaningfully and set up controlled experiments it is necessary to understand the importance of such parameters.

A. STORAGE EFFECT ON BRUISE FADING

*Graeme Thomson, Paul Daly*

**Introduction** - Many growers maintain that after prolonged time in storage bruises on apples "fade", or "blanch", to become less obvious. However, this process has not been demonstrated scientifically with Granny Smith apples.

**General procedure** - In this trial, fruit (Count 110 + core temperature 1°C) were artificially bruised with the skin intact using a "Fruit Tester" (FT 327) penetrometer. The penetrometer head was pushed against the intact fruit cheek for approximately 8 seconds until 8 kg/cm² was registered. Four bruises were inflicted on each fruit, and a total of 110 apples were damaged. All fruit were subsequently stored in air at 0-1°C. At various times during the ensuing month samples of 5 apples were assessed with a chromameter.

**Assessment of bruise darkness** - A ‘Minolta’ chromameter (CR-200) was used to determine the darkness of bruises resulting from different treatments. Bruise colour of peeled fruit was compared with the undamaged ground colour of the flesh. The L*a*b* measuring mode is one of the most popular colour notation systems. Any colour can be accurately and uniquely described by considering its hue (indicated by ‘a’), chroma (‘b’), and lightness or darkness (‘L’).
The difference in L values between bruised tissues and undamaged tissues was used to quantify darkness. The higher the 'L value difference' the darker the bruise.

Findings (Fig. 13) - "L" value differences, and therefore bruise darkness, increased progressively after initial bruising to peak at approximately 24 hours. Beyond this time a lightening of the damaged tissues was evident, and between one and four weeks after bruising "L" value differences decreased markedly. Bruise darkness was lower at 4 weeks than at any time tested in the first 24 hours after initial damage.

Conclusions - The physical damage (broken + crushed cells) and flattened area are still evident but the blanching of the brown compounds suggests that their chemical nature has changed, maybe as a result of wound repair mechanisms.
FIGURE 13: BRUISE DARKNESS DEVELOPMENT OVER TIME IN GRANNY SMITH APPLES

Log of time from bruising (hours)

Time from bruising

\[ Y = 7.34 + 2.24X + 1.53X^2 - 0.93X^3 \]

(\( X = \log \text{HOURS} \))

\( r^2 = 30\% \)
ASSOCIATED RESEARCH

B. FRUIT SIZE EFFECT ON DAMAGE

Graeme Thomson, Paul Daly

Introduction - There is some confusion as to whether small fruit bruise more readily than large fruit. Different counts of Granny Smith are associated with significant differences in weight, and firmness of individual fruit (Fig. 14).

General Procedure - Three counts (140, 110, 90) were artificially bruised on the pendulum impact rig using impact accelerations of 40, 120 and 200 G against flat steel. Two bruises were inflicted on each fruit, and 20 apples were used per treatment. All fruit were damaged with a core temperature of 1°C, and were stored subsequently in air at 0-1°C. Maximum bruise diameters and "L" value differences were measured after 4 days storage.

Findings - Bruise diameters were significantly larger on the count 90 fruit (Fig. 15). In general, bruise diameter progressively increased with both size of the fruit, and impact acceleration. At 120G, mean diameter was 10.9 mm on count 140s, and 15.1 mm on count 90. Significantly less darkening of the damaged area was evident on the smallest count (140), at impacts of 120 and 200G (Fig. 16). The chromometer aperture is too large to accurately assess small bruises resulting from a 40 G impact, hence the data does not appear in Fig. 16. Bruise darknesses on 110 and 90 count fruit were not significantly different.

Conclusions - Growers handling pre-sized fruit should be especially careful with the larger counts. Maybe the speed of the line needs to be reduced on a packing run of large fruit.
FIGURE 14: GRANNY SMITH FRUIT ATTRIBUTES

WEIGHT LSD (5%) = 4.83, 1-Way ANOVA

FIRMNESS LSD (5%) = 0.29, 1-Way ANOVA
FIGURE 15: EFFECT OF IMPACT AND APPLE SIZE ON BRUISE DIAMETER

LSD (5%) = 1.05, 2 Way ANOVA
FIGURE 16: BRUISE DARKENING RESPONSE OF THREE GRANNY SMITH SIZES TO DIFFERENT IMPACT LEVELS

LSD (5%) = 1.08, 2 Way ANOVA
ASSOCIATED RESEARCH

C. TEMPERATURE EFFECTS ON BRUISE COLOUR MANIFESTATION OF "GRANNY SMITH" APPLES

Graeme Thomson, Danny Cotter

Introduction - Appropriate temperatures for the storage and preservation of apples are well established. However, during postharvest handling the effect of temperature on bruise appearance is not fully understood.

In the present study, a chromameter was used to quantify bruise darkness of Granny Smith apples. The temperature of the fruit at time of bruising was considered along with the subsequent storage temperature.

General procedure - Fruit (Count 110) at 3 temperatures (0°, 10°, 20°C) were artificially bruised with the skin intact by using a 'Fruit Tester' penetrometer, and identical impact pressures (8 kg/cm², 8 sec). Two bruises were inflicted opposite one another on the cheek of every fruit, and 20 apples were used per treatment.

The artificially damaged fruit were then stored in darkness at either 0°, 10° or 20°C for 4 days. Bruise colouration of the peeled fruit was assessed after this period with a Minolta chromameter. Bruise colour was compared with the undamaged ground colour of the flesh by taking an L.a.b. reading on the cheek between bruises. The higher the "L value difference" the darker the bruise.

Findings (Fig. 17) - It is evident that fruit stored at 0°C for the 4 days subsequent to bruising showed greatest darkening of the damaged tissues, regardless of the initial temperature at bruising. In contrast, subsequent storage at 20°C was associated with least darkening of the bruise.
Temperature at time of bruising also played a role. A bruise inflicted on a fruit with core temperature of 0° was generally darker than a 10° fruit. The differences between 10° and 20° at time of bruising weren’t significant.

**Conclusion** - The effect of temperature at time of bruising might be partly explained by temperature effect on fruit firmness. Increasing temperatures lower firmness (Fig. 18) by increasing the plasticity of the fruit.

The results suggest that the usual sequence of events in packing sheds adds to damage levels. Packing of cold pre-sized apples is likely to increase levels of bruising. If the bulk of the handling processes could be accomplished while fruit is still warm from the orchard then less damage is likely to be incurred.

Fruit heating has been used successfully as a treatment prior to cool storage. Klein* (1989) found that if Granny Smiths were held for 4 days at 38°C before cool storage, then firmness was enhanced, shelf-life prolonged and the development of scald inhibited.

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FIGURE 17: TEMPERATURE EFFECT ON BRUISE DARKNESS OF GRANNY SMITH APPLES

LSD (5%) = 1.04, 2 Way ANOVA
FIGURE 18: TEMPERATURE EFFECT ON GRANNY SMITH (COUNT 110) FIRMNESS

LSD (5%) = 0.31, 1-Way ANOVA
ASSOCIATED RESEARCH

D. TRANSIT EFFECT ON BRUISING OF GRANNY SMITH APPLES

Graeme Thomson, Bruce Cumming

Granny Smith apples grown in the Goulburn Valley were size graded on trees using cardboard sizing-rings. Following picking they were packed straight into paper-fibre trays, and cardboard cartons. Two fruit sizes were used in equal proportions but packed into separate cartons; 73mm diameter (count 120) and 81mm diameter (count 90).

Packed cartons were road transported to a commercial export packaging shed where 50% of the crop was stowed aboard a shipping container, and the remainder was set up as a static trial in a CA coolroom (1°C). In both situations, 2 columns each of 7 cartons, were established.

The shipping container was transported by road to Melbourne Port, and was subsequently shipped over a period of 6 weeks to the Port of London. A motor vehicle trip brought the fruit to its final destination for assessment in metropolitan London. The static trial was road transported to Melbourne for assessment after 6 weeks.

Eight fruit were randomly selected from each tray in every carton. For each treatment (i.e. export and static) this gave a total of 448 fruit. Bruising damage was assessed by peeling the fruit and counting all observed bruises.

Results

For exported apples the bruise number per fruit was 0.97 while the static fruit averaged 0.18 bruise/fruit. The export mean of 0.97 bruise/fruit is significantly greater (LSD, 1% = 0.16; one way ANOVA).
APPENDIX 1
LITERATURE REVIEW

"Electronic pseudo-apples and their role in damage reduction during post-harvest handling"

Danny Cotter

1. INTRODUCTION

Victoria produces 90,000 tonnes of apples per year with a gross value of over $60 million. Only about 3% of this crop is currently exported but this figure can be expected to rise as Victoria increases its share of the market through improved product quality and marketing. Australian apples regularly arrive at export destinations in poorer condition than fruit from our competitors (Chile, New Zealand, South Africa), and it is estimated that our existing apple packaging and handling systems result in a 20% loss in crop value due to bruising.

Apples bruise when they strike hard surfaces or other apples. The external force causes rupture of apple tissue cells, exposing the cell contents to the intercellular air, resulting in enzymatic oxidation and discolouration (browning) of apple tissue (Holt and Schoorl, 1982). Studies have attempted with varying success to relate the bruising resistance of apples to variables such as variety, maturity, storage time, size of impact, duration of impact, firmness, approach energy (equivalent drop height) and absorbed energy. Schoorl & Holt (1977) and Brusewitz & Bartsch (1989) found that resistance to bruising decreased as storage time increased. Schoorl & Holt (1977) also reported that resistance to bruising varied for different varieties with temperature having no effect. In addition they found strong evidence that there is no correlation between apple firmness and bruise resistance (Schoorl & Holt, 1985).

It has been demonstrated that the main factors determining bruise size are: magnitude of impact force, the duration of force, and the failure strength of the apple tissue. These factors have been the subject of studies resulting in the development of 'pseudo-fruit' (Timm et al., 1989).

2. PSEUDO FRUIT

"Electronic fruit" measure impact forces with force transducers, and allow rapid, non-destructive collection of data. In early studies the sensed signal was transmitted via cable or telemetry to a recorder for analysis (Rider et al., 1973; O'Brien et al.; 1973, Aldred and Burch, 1977; Anderson and Parks, 1984; and Halderson, 1986). Rider et al. (1973) developed a pseudo fruit using cables to transmit data but the cables tended to prevent the pseudo fruit from simulating the free movement of real fruit. The device was designed to examine damage to peaches.
O'Brien et al. (1973) and Aldred & Burch (1977) working with peaches developed telemetry systems with limited degrees of accuracy, reliability and performance in actual field tests. The transmitters used in pseudo-fruit had too limited an output to be detected outside enclosed metallic structures (grading machines) even though they were successful in the laboratory.

In these early studies, triaxial piezoelectric accelerometers were used inside the pseudo-fruit to sense impacts. However, investigations did not continue to the point of providing instrument calibrations and correlations to bruise conditions.

Tennes et al. (1986) and Siyami et al. (1987) developed a compact instrumented sphere (IS), also using a triaxial piezoelectric accelerometer but with the sphere containing its own processing unit, memory and power supply. This did away with the need for external cables or a telemetry system. After the IS had been trialled, recorded data was down-loaded to a computer for analysis. The initial prototype IS was a 14 cm diameter sphere which weighed 1.44 kg (Siyami et al. 1987).

Klug et al. (1989) developed techniques to analyse the impact (acceleration) data recorded by the IS, and applied these techniques to data collected from an apple packing line. However, the size of the IS prevented it from being used in all sections of the packing line.

3. DESCRIPTION OF THE INSTRUMENTED SPHERE 100 MODEL

In recent years a team headed by Galen Brown and Roland Zapp at Michigan State University and USDA has been the forerunner in developing instrumented spheres. Their work has centred on examining apple damage, and consequently their IS has evolved to simulate this fruit. Early work (Tennes et al, 1986; Klug et al, 1987; Siyami et al, 1987) has culminated in the production of the IS 100 which is the most advanced IS available. The IS 100 is 8.9 cm in diameter and weighs only 0.32 kg. As well as having a smaller diameter than previous models the IS 100 consumes less power, and is more accurate (Zapp et al. 1987).

The main components of the IS 100 are the triaxial piezoelectric accelerometer (Colombia model 512 TX), an 8-bit CMOS Motorola microprocessor unit (MPU) (XC68HC11), 8 Kbyte ROM and an RS232 serial communication port. The MPU has an integral 8 channel analogue to digital (A/D) converter and the 8KbROM stores a BUFFALO (Bit User's Fast Friendly Aid to Logical Operation) monitor. A triaxial piezoelectric accelerometer is used instead of a piezoresistive one because it has lower power consumption, and higher sensitivity.

External communication with the MPU is through a miniature 5-pin connector which provides the bi-directional RS232 serial communication, battery recharging, system reset and system shutdown. The IS100 power supply consists of a rechargeable, 9V NiCad battery with a charge capacity of about 80 mA-hr. When the IS100 is in operation, the current drain is less than 14mA which corresponds to approximately 6 hr of battery life. At lower sampling rates life can be increased to approximately 13 hr.
The IS100 software consists of two parts, one part within the IS and the second part in a personal computer. The IS-based data acquisition program controls the sampling rate, checks and stores data, and sends data to the PC. The PC-based program provides data analysis including conversion of A/D values to acceleration (G) values, computation of velocity, and graphical display. The original software calculated relative energy and power as well but were omitted since some assumptions were required. To perform these computations, one of the following impact parameters had to be estimated: impact velocity, rebound velocity, velocity ratio, drop height, rebound height or height ratio.

Data acquisition is achieved by storing A/D values from each of the three accelerometer axes, if any one axis registers a value above a user specified threshold. There is also a pre- and post-threshold data length which can be user specified. The use of this threshold window eliminates the need for excess memory space filled with irrelevant data. A summary of the specifications of the IS100 impact recording device is given in Appendix I.

4. DATA ANALYSIS

The PC-based program is written in compiled BASIC and is used for unloading IS stored data and performing a number of processing tasks on the data. Analysis can be performed on all data or on one specific impact. The processing available includes filtering for noise suppression, averaging, peak detection, integration, differentiation and data calibration. The output includes the acceleration from each axis (x, y and z) and time of occurrence, as well as a vector sum of these accelerations. Peak acceleration, velocity from each axis (integration of acceleration curve) and the vector sum of these velocities is also tabulated and can be displayed graphically.

5. RESEARCH USING THE IS100

5.1 Calibration of IS100

Zapp et al. (1989) calibrated the IS100 measured impact voltages to true acceleration values by dropping the IS on an impact table, along with a calibrated reference. To develop bruise predictions for apples, the IS was dropped simultaneously with apples onto steel and padded surfaces from different heights. This resulted in a correlation between peak acceleration, velocity change and degree of bruising. Zapp et al. (1989) found that the lower the velocity change for a given peak acceleration, the larger the bruise diameter.

Siyami et al. (1988) developed bruise prediction equations for apple impacts by dropping apples (Ida Red) on an impact table along with an accelerometer. The apples were grouped in three sizes - 67 mm average diam, 72 mm average diam. and 77 mm average diam. Various models for predicting bruise diameter were investigated based on variables such as apple diameter, apple mass, Magness-Taylor force (apple firmness) and impact velocity (drop height). A multiple linear regression analysis (MLRA) model was the preferred choice for predicting bruise
size in terms of apple and impact properties, because the Hertz elastic contact theory and the plastic contact theory did not adequately predict the bruise diameter. Impacts of 35 to 300 G’s, and impact durations of 2 or 6ms were used. A simple correlation matrix was calculated for all data and this showed that maximum acceleration, total velocity change and equivalent drop height were the main significantly correlated variables for predicting bruise diameter.

The model which best predicted bruise size was as follows:

\[ ABD = B_0 + B_1(AAD) + B_2(MT) + B_3(MA) + B_4(MA)^2 + B_5(DV)^2 \]  

(1)

Where:

- \( ABD \) = average bruise diameter, mm
- \( AAD \) = average apple diameter, mm
- \( MT \) = Magness-Taylor firmness, kg
- \( MA \) = Maximum acceleration, m/s^2
- \( DV \) = Velocity change, m/s
- \( B_0 \) = regression coefficients

This model explained from 83.7% to 91.7% of the variation in ABD, depending on the size groups of apple and the impact duration. The correlation matrix showed apple mass to correlate better with bruise diameter over the range 11.00 mm to 32.55 mm than apple diameter. Therefore, if apple mass rather than diameter was used, a better MLRA model may be obtained. Apple diameter was selected as the apple size variable because "it is commonly referred to when dealing with apple handling procedures". This is not a valid reason for not using apple mass in the model.

5.2 Simulation of Packing Line Impacts

Sober, Zapp and Brown (1989) used an IS100 to record impacts along 12 operational apple packing lines. Velocity change (integration of the impact curve) along with peak acceleration was used to classify the impacts recorded by the IS. For a specific peak acceleration, the velocity change differs depending on the surface against which the IS or apple impacts. Preliminary tests showed that peak impacts below 20 G’s on a flat surface were insufficient to cause apple bruising. Impacts above 130 G’s were rare and were not included in analysis. Impact data from the IS used on the packing lines showed that 84% of impacts recorded were between 20 and 60 G’s, and velocity change ranged from 0.1 m/s to 3 m/s.

To emulate these types of impacts, a simple drop tester was used where the IS and an apple could free-fall to an impact surface. The drop height and impact surface could be altered to develop peak accelerations of 20 to 130 G’s and velocity changes of 0.20 to 2.76 m/s. An impact surface of steel was used to create small velocity changes, and foam surfaces of various thicknesses (1.6 mm - 6.4 mm) were used to achieve larger velocity changes. Each of the chosen surfaces was calibrated up to 130 G.

Sober et al. (1989) performed drop tests on freshly picked 'Paula Red' apples, and on 'Golden Delicious' that had been either freshly picked or held in CA storage for 6 months. Magness-Taylor firmness readings were taken, and the apple samples
divided by mass into small, medium and large sizes. These size groups were 116 ± 9G, 140 ± 7G and 175 ± 19G, respectively, for 'Paula Red' apples; 142 ± 6G, 166 ± 4G and 196 ± 9G for the fresh 'Golden Delicious', and 136 ± 7G, 165 ± 4G and 207 ± 11G for the CA stored 'Golden Delicious'. Individual apples were brought to room temperature and weighed before being dropped onto the impact surface.

The tested apples were allowed to stand for 24h to allow bruises to develop and were then visually inspected under natural and artificial light. Visible bruising, and bruising revealed after peeling, were studied and the bruise diameters measured.

Results showed no bruising to the CA stored apples, indicating that the apples were resilient enough to absorb the impact. The fresh apples showed no bruising for medium and large velocity changes due to the ability of the surfaces to cushion the impact and prevent bruising to fruit. However, for small velocity changes, bruising was evident. The amount of bruising and the impact acceleration threshold for bruising depended on variety, mass, and the number of days after harvest. An example of this post-harvest effect was provided by 'Paula Red' which had a threshold for visible bruising of 80 G's. At this peak G level, 20% of the small, 40% of the medium and 10% of the large apples bruised one day after harvest. Three days after harvest, 40% of the large apples bruised but no small or medium apples bruised at 80 G's. Of the apples that bruised at 80G, the largest average bruise diameter (ABD) was 14.0 mm for large apples assessed 1 day after harvest.

After peeling, 'Paula Red' apples had a threshold for observable bruising of 40 G's. At this level 40% of the large apples and 10% of the medium apples showed bruising 1 day after harvest. Small apples did not bruise. Three days after harvest only 10% of the large apples bruised at the 40 G threshold. The largest ABD was 5.6 mm, occurring 3 days after harvest on large apples.

Sober et al. (1989) further suggest that apple packing lines should be designed or modified to keep impacts below the peak threshold at which any bruising (visible before and after peeling) occurs. They found the lowest thresholds for bruising were 30G for 'Golden Delicious' and 40G for 'Paula Red' apples dropped onto flat surfaces. However, even lower levels may be necessary to avoid bruising on the smaller radius portions of the apple (calyx and stem ends) or when the apple strikes non-flat surfaces. MLRA was used to construct models predicting average bruise diameter and were of the form:

\[ \text{ABD} = B_a + B_1DV + B_2M + B_3G + B_4D + B_5F \]  

where:  

- \( \text{ABD} \) = average bruise diameter, mm  
- \( DV \) = velocity change, m/s  
- \( M \) = average apple mass, g  
- \( G \) = peak acceleration, G's  
- \( D \) = days after harvest  
- \( F \) = average Magness-Taylor flesh firmness, N  
- \( B_a \) = regression coefficients
This model explained 84.8% of the variation in ABD for 'Paula Red', and 57.2% of ABD variation for 'Golden Delicious'. A sensitivity test of each model showed that peak G's produced the greatest change in bruise diameter, followed by apple mass and velocity change (Sober et al. 1989). Magness-Taylor firmness was the poorest predictor of bruise diameter.

5.2.1 Discussion

The authors did not explain the use of the independent variables in the model except to say they were "available". All apple and impact variables should be considered and a correlation matrix calculated to determine which variables have the greatest effect on bruise size. Apple variety, mass, diameter, firmness, fruit temperature and number of days after harvest, as well as impact properties such as peak acceleration, velocity change, drop height and rebound height should be considered to determine which factors have the greatest influence on bruise diameter. The availability of time and resources usually limits such comprehensive studies to the major bruise affecting variables such as apple mass, firmness and variety, and the impact parameters peak acceleration and velocity change.

5.3 Comparison of IS and Apple Impact Characteristics

Timm et al. (1989) conducted tests with three apple varieties (McIntosh, Golden Delicious & Law Rome) to determine the affect of flesh firmness and impact surface characteristics on bruise size. At 7, 28, 42, 105 and 135 days after harvest, cool stored apples were dropped onto either a steel or padded surface from various heights. For each variety, all apples had similar mass and firmness (within ± 1 std. dev. of mean) at harvest. An accelerometer was attached to the top of each apple to measure the impact. The apples were stored to allow bruise colour to develop and then bruise diameter and weight were measured. An IS100 was dropped from the same heights onto the same surfaces to allow comparisons with the apple impact data to be made. Timm et al. (1989) found that after impacts onto a flat steel plate bruise diameter and mass increased with decrease in Magness-Taylor firmness, and increasing days after harvest. MLRA was again used to develop models for predicting bruise size:

\[
ABD = B_0 + B_1(\text{PA}) + B_2(\text{ID}) + B_3(\text{VC}) + B_4(\text{MT})
\]

and

\[
BM = B_0 + B_1(\text{PA}) + B_2(\text{ID}) + B_3(\text{VC}) + B_4(\text{MT})
\]

where

- \(ABD\) = average bruise diameter, mm
- \(BM\) = bruise mass, g
- \(PA\) = peak acceleration, G's
- \(ID\) = impact duration, ms
- \(VC\) = total velocity change, m/s
- \(MT\) = Magness-Taylor firmness, N
- \(B_0\) = regression coefficients

This model explained from 62.7% to 86% of the variation in ABD and 62.6% to 89.3% of the variation in BM depending on variety, and type of surface.
Comparison of the IS and apple/accelerometer impact data showed the ratio of peak G between the IS and the apple changed for the different surfaces. For a drop height of 40 mm onto steel, the ratio of peak acceleration recorded by the IS and the apple/accelerometer was nearly 1 to 1. As drop height increased, the ratio increased linearly and was approximately 2 to 1 for a 320 mm drop onto steel. For a padded surface, the ratio was nearly constant at 1.85 to 1 for all drop heights. These differences are due to the IS being a more rigid body compared to an apple and because the padded surface acts as a spring or damper. Therefore, peak acceleration alone cannot be used to determine the bruise potential of an impact. Velocity change and impact duration must also be considered when classifying impact characteristics and resulting bruise size.

5.4 Assessment of Orchard Handling and Transport Technique

Burton et al. (1989) used the IS to quantify and identify the areas where damage occurs to apples during orchard bin filling, subsequent handling and transport to the packinghouse. The IS was placed in pickers' buckets at different stages of filling and emptied into bins. In addition, the IS was situated at different levels and positions in bulk bins to record impact data during hauling. Apple bruising was analysed in terms of both bruise diameter, and number of bruises per fruit. They found that the IS did not perform as satisfactorily as expected. This was due to the field research procedures being based on the interpretation of data obtained from laboratory tests which didn’t include many of the conditions apples are subjected to in the field. Laboratory tests showed that a 30G impact or greater was needed to bruise an apple. However, in the field the IS repeatedly failed to record impacts above the selected 14G threshold even though bruising still occurred. Burton et al. (1989) suggest that further studies are required to fix a G level that relates to apple damage caused by field handling.

5.4.1 Discussion

The bruise threshold level of 30 G as cited above was for a perpendicular drop onto a flat steel surface. In reality, apples strike each other and other pliable, non-flat surfaces which may result in bruising at a lower peak acceleration level. The transport tests reveal a further limitation of the IS and its applications. The IS appears to be useful when used as a free moving device but its accuracy is limited when packaged and used as a sensor in a carton, surrounded by other fruit and subsequently influenced by a range of forces acting in different directions.

5.5 Assessment of Apple Grading Lines

Brown et al. (1989) used the IS100 to identify the causes and amount of bruise damage due to mechanical equipment, and operations used on apple packing lines. Over 20 commercial packing lines were evaluated to identify areas where damaging impacts occurred. Following assessment a few lines were changed to reduce impacts and were subsequently re-evaluated. Apple damage was analysed in terms of average number of bruises per fruit that were larger than 6.3 mm (1/4") diameter and the average accumulated bruise area (mm²) per apple.
The IS was used 8 to 12 times per packing line in order to obtain a representative sample of impacts. A manually recorded time-log enabled the impacts to be identified with specific components of the line; other researchers have used a video camera to achieve this (Bollen & Dela Rue, 1990b). Peak and average acceleration levels were recorded for the transfer points of the packing lines where apples are transferred from one process to another (e.g. sorting to washing). Typical impact levels revealed that bruising could occur at every transfer within a packing line since G levels at each transfer exceeded 30 G's.

When changes were made to a packing line (including padding, decelerating curtains or brushes, decreasing length and angle of transfer ramps), it was found that although apple damage was significantly reduced, impact levels as measured by the IS were either the same or increased (Brown et al. 1989). This result may be explained by the low number of replications (2 or 3 in some cases).

Examination of the complete acceleration record, not just the highest peak G at each transfer, showed that multiple damaging impacts occur at some transfers. The number of bruises per fruit and the bruise area per fruit were separately regressed on the summation of average G's, maximum G's and all peak G's above various threshold G levels. The summation of average or maximum G's showed no relationship with the number of bruises per fruit or bruise area per fruit but a strong relationship was found using the summation of all peak G's. The relationship between bruise area per fruit and the summation of peak G's greater than 20 explained 90.9% of the variation in bruise area per fruit. The relationship for 30 G's was not as strong which is probably due to bruises occurring at the calyx and stem ends of the apples, which are more sensitive to bruising due to their smaller radius.

Brown et al. (1989) recommended the following considerations to minimise apple damage when designing packing lines:
- minimise the number of transfers between equipment;
- minimise the impact level to near 20 G's at each transfer;
- minimise the number of impacts within a component of equipment and keep those impacts under 20 G's wherever possible.

It was further stated that the best ways to avoid high impacts are to:
- minimise height change, so drop energy is minimised;
- use deceleration devices (brushes, drapes, etc.) to dissipate energy and control the fruit;
- pad all hard surfaces to spread the impact force over a large area and simultaneously absorb energy in the padding to minimise rebound;
- convey apples in water to absorb energy, achieve uniform 'sheet flow' and avoid open areas on mechanical equipment where apples accelerate down ramps.

5.5.1 Discussion

The researchers, while recognising some of the effects the impact surface has on impact variables and resulting bruise development, arbitrarily choose an impact bruise threshold of 20G without scientific evidence. Clearly, more research is
needed to investigate the effects of impact surface shape and characteristics on impact variables, as measured by the IS, and bruise potential.

Marshall et al. (1989) and Guyer et al. (1990) used the IS to investigate the effectiveness of packing line modifications (cushioning, flaps, etc.) on bruise reduction. Marshall et al. (1989) reduced bruise damage by over 50% and peak accelerations by up to 75% on some lines with simple modifications. The transfers between components were investigated using the IS and damage free Golden Delicious. The reporting of results was inconsistent in that some transfers were shown to reduce peak acceleration values while others were presented as reducing the number of bruises per fruit or bruise area per fruit. Results showed, in some cases, while damage may be reduced by adding cushioning, the peak acceleration may increase. The researchers did not explain this inconsistency nor give any indication of the number of replications performed throughout their investigation.

5.6 Other Horticultural Products

Miller and Wagner (1990) assessed citrus packing sheds in Florida to determine the frequency and level of impacts and the effect of minor packing line modifications. Twenty-nine packing sheds were tested, with an average impact of 100.1 G and most impacts between 50 and 150 G. No indication of damage levels were given and data on the effect of line modifications was selectively edited. The lack of replications in some trials reduces the conclusiveness of some of their findings.

Bollen and Dela Rue (1990a) investigated bruise damage to kiwifruit, Asian pears (Nashi) and apples in New Zealand using IS technology. Packing houses were evaluated and a pendulum impact rig was used to attempt to correlate impact data with bruise data. The authors determined areas of each packing line which were damaging. The Asian pear packing process is currently a manual task and the IS failed to register an impact above 20 G which the authors suspect is the impact level required to cause significant damage. The laboratory tests were limited to flat surface impacts and curved surface (rollers, other fruit) impacts were not studied.

Schulte-Pason et al. (1990) used the IS to determine the impact conditions which initiate bruising for four varieties of apple and one variety of peach and pear. Drop tests were conducted onto a flat steel plate for all fruits and additionally onto padded surfaces for apples. Bruise threshold lines, which show the probability of bruising for given IS impact data, were developed for the most bruise sensitive variety of apple (McIntosh). These lines, however, are based on drops onto flat surfaces, curved surfaces were not investigated. Magness-Taylor firmness readings were taken but were not correlated with bruise or impact data, resulting in concern over the accuracy and usefulness of these bruise threshold lines which have been incorporated in the IS100 software. The drop tests performed on peaches and pears consisted of steel surface impacts only, limiting the usefulness of the bruise data.

Further work is necessary to develop bruise threshold lines and to study the effect of irregular impact surfaces.

Peterson and Colorio (1990) also investigated peach damage using IS technology. Four varieties of peaches were dropped onto foam surfaces, other peaches and an
IS to simulate impacts encountered during mechanical harvesting. Analysis showed peach mass and Magness-Taylor firmness played no significant role in predicting bruise size. The authors also found bruise diameter to be closely correlated with either velocity change or peak acceleration and that equations with 2 or more independent variables were not effective in accounting for bruise size. Proof of these findings is not given and the "$R^2$" values for the regression equations developed are low (0.44 to 0.63) and therefore don't explain the variation in bruise diameters to the same degree as earlier researchers (Sober et al. 1989 and Timm et al. 1989) who included other apple and impact variables in their regression equations.

Timm and Brown (1990) used the IS to record impacts along packing lines used for avocado, papaya and pineapple. Impact numbers and maximum and average peak acceleration recorded for transfer between components on each packing line were tabulated. Impacts were plotted in terms of velocity change and peak acceleration and compared with response lines for known surfaces. Many impacts were classified as "hard" and had high G levels which were likely to cause bruise damage. Further investigations are required to determine the impact characteristics needed to inflict bruise damage on these products. The study was performed to investigate the usefulness of the IS for damage reduction in other horticultural industries.

5.7 IS Impact Classification

The IS has proved to be a useful tool in measuring impacts recorded along packing lines. However, further investigations are required to correlate impact data to bruise data, especially for impacts onto non-flat surfaces. Most research has been concerned with impacts onto flat steel or cushioned surfaces, with a few researchers investigating fruit to fruit impacts and impacts on inclined surfaces.

Brown et al. (1990) studied flat surfaces and inclined surfaces, up to 20° from horizontal. No difference in impact data was found between impacts on a steel or padded surface that was angled 0°, 10° or 20° to the horizontal. The degree of damage to fruit was not investigated under these conditions nor were ramp angles greater than 20°.

Bollen and Dela Rue (1990b) investigated fruit to fruit impacts using damage free apples and the IS. Various impact scenarios were studied: IS impacting free fruit; IS impacting fixed fruit; fruit impacting IS, etc. Impacts against fixed fruit were similar to those against a fixed flat surface.

However, impacts on fruit that was free to move had peak accelerations similar in magnitude to flat surface impacts but velocity changes were smaller and subsequent damage was higher.

The IS impact data alone does not provide for prediction of bruising but must be complimented with knowledge of the impact surface characteristics.

Marshall and Burgess (1990) also investigated fruit-fruit impacts with an IS. A double pendulum impact rig was used to drop test the IS onto apples which were
free to swing away. Using Newton's principles of action/reaction and conservation of momentum, IS data was analysed and bruise estimation models were developed and evaluated. Bruise diameter was plotted against peak acceleration and energy absorbed during impact. Regression analysis using a same order polynomial was conducted to find which impact variable best predicted bruise size. Energy absorbed was found to predict bruise diameter more accurately than peak acceleration. Holt and Schoorl (1977) also found a strong correlation between bruise volume and energy absorbed.

5.8 Validity of Magness-Taylor firmness

The Magness-Taylor firmness has been used by many researchers, as a variable in their bruise prediction models. The Magness-Taylor method for measuring firmness has the disadvantage of poor reproducibility between operators. Bramlage and Blanpied (1977) claim differences of up to 20% between operators, therefore Magness-Taylor firmness may be too inconsistent to be used in accurate bruise prediction models. However, firmness has a much lesser affect on bruise size than peak acceleration, velocity change, impact duration and apple mass (Sober et al. 1989; Timm et al. 1989). Schoorl and Holt (1985) found strong evidence that there is no correlation between apple firmness and bruise resistance. The variability between operators in measuring Magness-Taylor firmness may explain some of the variation between the models proposed by previous researchers.

6. SUMMARY OF THE IS100

The IS100 in its current form is a relatively new device for measuring impacts on horticultural produce. Using the IS to predict levels of bruising requires preliminary investigations which relate apple characteristics to impact characteristics.

Apple variety, size, mass, firmness, the number of days after harvest, impact acceleration, duration, velocity change and impact surface material and shape all, to varying degrees, affect the amount of bruising an apple experiences.

The researchers involved with bruising investigations differ in their interpretation as to which of these variables have the greater influence on bruise size. Methods of correlating the data also differ with various regression methods being used with varying degrees of success. However, the IS impact data is useful in determining bruise levels and should improve with further investigations.
REFERENCES


ATTACHMENT I : SPECIFICATIONS FOR IS100 - IMPACT DETECTING DEVICE

Impact Detection Characteristics:

Sensing Unit: Triaxial Accelerometer
Impact Amplitude: +/- 200 G’s (3% Accuracy)
Frequency Response: 5 Hz-3 kHz
Digitation: 256 Counts

Operating Conditions

Temperature Range: -30°C to 60°C
Moisture: Immersible in Non-Corrosive Liquids

Physical Characteristics

Size: 89 mm Sphere
Weight: 320 Grams
Specific Gravity: Approx. 0.95

Power Requirements

Battery: 9 VDC Nickel-Cadmium
Time between charges: 6 to 13 hours, depending on Sampling Rate

Date Recording

Sample Rate: Selectable 31 Hz - 4 kHz
Trigger Threshold: Selectable 0-200 G's
Pre-Trigger Sample Number: Selectable 0-10 Samples
Post-Trigger Sample Number: Selectable 0-255 Samples
Samples Information: Impact Amplitude, Time, Three Dimensional Impact Orientation
Storage Capacity: Dependent on Impact Characteristics and Sampling Rate
Eg: 650 10ms impacts can be recorded at a 2 Hz sampling rate
# APPENDIX 2 - PACKING LINE DIAGRAMS

## LEGEND

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Bin</td>
</tr>
<tr>
<td>BF</td>
<td>Bin Filler</td>
</tr>
<tr>
<td>BWR</td>
<td>Brush Washer Rollers</td>
</tr>
<tr>
<td>CB</td>
<td>Collection Belt</td>
</tr>
<tr>
<td>CT</td>
<td>Convergence Transfer</td>
</tr>
<tr>
<td>CS</td>
<td>Cup Sizer</td>
</tr>
<tr>
<td>DBRS</td>
<td>Diverging Belt-Roller Sizer</td>
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<tr>
<td>DBS</td>
<td>Diverging Belt Sizer</td>
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<tr>
<td>DD</td>
<td>Dry Dump</td>
</tr>
<tr>
<td>DT</td>
<td>Drying Tunnel</td>
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<tr>
<td>FB</td>
<td>Feed Belt</td>
</tr>
<tr>
<td>RB</td>
<td>Ripple Belt</td>
</tr>
<tr>
<td>RD</td>
<td>Rubber Drapes</td>
</tr>
<tr>
<td>S</td>
<td>Singulator</td>
</tr>
<tr>
<td>ST</td>
<td>Sorting Table (PVC Rollers)</td>
</tr>
<tr>
<td>SR</td>
<td>Sponge Rollers</td>
</tr>
<tr>
<td>TBRR</td>
<td>Transfer Brush Roller and Ramp</td>
</tr>
<tr>
<td>TCB</td>
<td>Transfer Conveyor Belt</td>
</tr>
<tr>
<td>TDR</td>
<td>Transfer Down-Ramp</td>
</tr>
<tr>
<td>TW</td>
<td>Transfer Wheel</td>
</tr>
<tr>
<td>T</td>
<td>Tray</td>
</tr>
<tr>
<td>TF</td>
<td>Tray Fill</td>
</tr>
<tr>
<td>WFT</td>
<td>Water Floatation Tank</td>
</tr>
<tr>
<td>WBR</td>
<td>Waxer Brush Rollers</td>
</tr>
</tbody>
</table>
Packing Line A

Packing Line B
APPENDIX 3

RESEARCH EXTENSION

To promote awareness of the project to both grower and scientific communities, the following extension activities have been undertaken:

a) Seminar, IS project. Audience, members of the Post Harvest Section, Institute of Plant Sciences (Sept. 90).

b) Wandin Field Days, poster display and IS computer operations display (Oct 90).


d) Weekly Times article December 19, 1990. Title "Research into bruising may help apple exports". This article's preparation was shared with the contributing journalist.

e) Seminar, IS project and temperature effects on bruising. Audience, Gippsland Fruit Growers Association (Feb. 91).

f) Seminar, IS project. Audience, members of the Post Harvest Section, Institute of Plant Sciences (June 91).

g) Seminar, Apple bruising. Audience, Institute of Plant Sciences (Nov. 91).