24 to 34 cm high were produced with doses of 2 to 4 mg of paclobutrazol, 0.25 to 0.5 mg of uniconazole, or 0.5 mg of ancymidol. 'Golden Emblem' was the most-vigorous cultivar, with a height of 82.1 cm for the untreated control. Plants of acceptable height were produced with doses of 4 to 8 mg paclobutrazol, 0.5 to 1 mg of uniconazole, or 2 mg of ancymidol. Even though the plants were 3 to 4 times taller than the pot height of 15 cm, the recommended doses resulted in a minimal amount of leaf distortion, reduction in inflorescence diameter, and delay in the number of days until flowering.

All ancymidol doses significantly delayed flowering of the cultivars grown, while the optimal range of doses found in this study—2 to 8 mg of paclobutrazol and 0.25 to 1 mg of uniconazole—did not delay flowering. Only ancymidol and paclobutrazol are labeled for use on tuberous-rooted dahlias. The decision to use PGRs to control the growth of tuberous-rooted dahlias should be based on the response of the cultivar and the cost of the PGR (Table 2). The desired control of growth was obtained for the lowest cost by using paclobutrazol at the cost of \$0.084 to \$0.169 per pot for 'Golden Emblem' and \$0.042 to \$0.084 for 'Red Pigmy', which was 25% to 81% less expensive than ancymidol.

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Instrumented Sphere Used to Identify High-Impact Areas on Grapefruit Packing Lines in Texas

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ADDITIONAL INDEX WORDS. quality, decay, cushioning, bruising, citrus, packing shed, accelerometer, *Citrus paradisi*

SUMMARY. An instrumented sphere (IS) was used to identify high-impact areas on seven grapefruit (*Citrus paradisi* Macf.) packing lines in the Rio Grande Valley of Texas. The packing-line unit operations having the greatest percentage of high impacts were 1) the sizer, 2) when #2 fruit were separated by hand at the grading table, 3) when fruit were dumped from the harvest bin onto the packing line, and 4) when fruit dropped into a collection bin at the end of the packing line. The number of high impacts and the amount of cushioning in high-impact areas varied among the seven packing sheds. The amount of red dye visible on the surface of fruit collected from the end of each shed's packing line did not correspond with each shed's percentage of high impacts or with incidence of decay during fruit storage. The severity of impacts and degree of cushioning provided in these Texas packing sheds were comparable to that reported for 39 Florida packing houses. This study illustrates the usefulness of the IS for enhancing individual packing-line operations and for comparing individual shed performance to packing-line operations in other agricultural production regions.

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Quality control during harvest, handling, and marketing is essential for minimizing product loss in the fresh-produce industry. Damage to fresh produce during handling can provide an entry for postharvest pathogens and lower fruit market quality. Bruised tissue may not be immediately visible on the surface of the fruit and therefore difficult to identify and eliminate during grading. The number and magnitude of impacts a fruit receives during harvest and packing-shed operations may influence its postharvest shelf life.

The instrumented sphere (IS) is an 89-mm-diameter sphere containing a triaxial accelerometer, microprocessor, 32K of RAM memory, and a battery encased in beeswax (Zapp et al., 1990). This impact detection device was originally developed by Tennes et al. (1988) to quantify the magnitude of impacts produce was exposed to during harvesting and handling operations and to delineate produce impact tolerance thresholds. The IS has been used to delineate damage thresholds and quantify impacts on onion (Bajema and Hyde, 1995; Peterson, et al., 1991; Timm, et al., 1990), avocado, papaya, pineapple (Timm and Brown, 1991), tomato, bell pepper (Sargent et al., 1992), peach (Lin and Brusewitz, 1994; Schulte et al., 1994), potato (Hyde et al., 1992; Morrow and Ruscitti, 1990; Orr et al., 1994), and apple (Marshall and Burgess, 1991; Sarig et al., 1992; Schulte et al., 1992; Sober et al., 1990; Tennes, et al., 1990) packing lines. The IS has also been used to quantify impacts on citrus packing lines in Florida (Miller and Wagner, 1991a, 1991b), but attempts at delineating damage thresholds for citrus have not yet been realized (Miller and Burns, 1991; Miller and Wagner, 1991a).

In the Rio Grande Valley, grapefruit (*Citrus paradisi*) are usually harvested by hand into wooden field bins and transported to a packing shed for washing, sizing, waxing, grading, and packing. Fruit are often collected into wooden field bins after cleaning, waxing, and grading on the packing line and stored for short periods before they are once again run through a line for packing into shipping cartons. Grapefruit-to-grapefruit impacts and impacts on a hard or somewhat cushioned surface are frequent during these

handling operations. The objective of this project was to describe the number and magnitude of impacts grapefruit encounter during handling operations in Rio Grande Valley packing sheds, and to discern whether impacts encountered in normal packing shed operations were related to grapefruit damage or decay.

Materials and methods

INSTRUMENTED SPHERE. Transfer points were defined as locations on the packing line where grapefruit were transferred from one surface to another or underwent a change in direction or altitude. Transfer points on each of seven packing shed lines in the Rio Grande Valley of Texas were identified and assigned a unique number. An IS (500 g_n maximum recording capacity) was placed into a commercial field bin containing grapefruit and dumped with the grapefruit onto the packing line. The time at which the IS encountered each transfer point was recorded. The IS was run 10 times down each packing line operation. Each run down the packing line was considered a replication. Runs were replicated on repeated visits to each shed to ensure representative sampling of the packing line. Impact force was recorded by the IS in units of acceleration of gravity (g_n) where $1 g_n = 9.8 \text{ m}\cdot\text{s}^{-2}$. The amount of cushioning provided at impact (surface response) was recorded by the IS as a change in velocity ($\text{m}\cdot\text{s}^{-1}$). The minimum threshold for which the IS was set to record was $40 g_n$. Recorded data were transferred from the IS to a laptop computer, analyzed with the Instrumented Sphere Analysis Program, version 1.0, and entered into a spreadsheet. All recorded impacts were identified by their time of impact with their corresponding transfer point on the packing line. Results were presented as the number or percentage of all impacts recorded during replicated runs down each packing line.

Data were analyzed as suggested by Brown et al. (1990), similar to the method of Miller and Wagner (1991a, 1991b). The g_n impact force was related to the amount of cushioning provided upon impact to identify the potential of an impact to cause damage to the grapefruit. We inferred from grapefruit damage scores in controlled drop tests done by Miller and Wagner (1991) that impacts $>200 g_n$ were "very likely damaging," impacts >150 but

$\leq 200 g_n$ were "most likely damaging," impacts >100 but $\leq 150 g_n$ were "possibly damaging," and impacts $\leq 100 g_n$ were "most likely nondamaging." We categorized the amount of cushioning on impact as similar to that provided by steel or four different thicknesses of cellular urethane padding (Poron; Rogers Corp., Rogers, Conn.) and displayed the results graphically as five delineated regions. Regions 1–5 contained impacts encountering a surface similar to steel, 0.3 cm Poron, 0.6 cm Poron, 1.3 cm Poron, or thicker than 1.3 cm Poron, respectively. The surface response of impacts $>217 g_n$ could not be categorized because standards were unavailable. The percentage of recorded impacts within each damage category or surface response region was presented by unit operation as a percentage of total impacts during replicated runs down all seven packing lines and as a percentage of total impacts during replicated runs within each packing shed.

INCIDENCE OF DECAY AND DYE TEST.

Twenty grapefruit were collected during a single visit to each packing shed at three stages in the handling process: the grove, before packing, and after packing. The sampled grapefruit were transported in an enclosed, temperature-controlled vehicle to the ARS laboratory in Weslaco, Texas. Ten of the twenty fruit from each stage of the handling process were evaluated for surface injury with the triphenyl-tetra-

zolium chloride (TTC) dye test, and the remaining 10 fruit were stored to evaluate incidence of decay.

Surface injury was estimated by immersing 10 grapefruit in a solution of TTC as described by Eaks (1961). TTC is a water-soluble powder that precipitates and turns pink to bright red when it contacts injured plant tissue. The degree of dyed surface area was subjectively evaluated for the 10 fruit, 24 h after immersion in the TTC solution, using a visual score of 0 = none, 1 = slight, 2 = moderate, 3 = severe.

Ten grapefruit collected from each stage of the handling process were stored at 10°C for 3 weeks and 23°C for 7 days in a one-half standard grapefruit shipping box (21 boxes) and evaluated for incidence of decay. The number of grapefruit that developed decay during storage was counted at weekly intervals during storage. Decayed grapefruit were removed and discarded weekly to prevent one grapefruit from contaminating the other fruit stored in the same box. Incidence of decay for each handling stage was calculated by dividing the number of decayed grapefruit by the total num-

Fig. 1. Relationship between force and velocity change of 4708 impacts recorded during 10 runs in 7 Rio Grande Valley packing sheds to standard reference surfaces. Each circle represents a recorded impact.

Fig. 2. Cushioning provided for 3400 impacts recorded in 7 Rio Grande Valley packing sheds compared to impacts recorded over 3 seasons in 39 Florida packing sheds.

ber of grapefruit sampled (70) and multiplying by 100.

Surface injury or decay attributed to commercial harvesting was identified by comparing incidence of decay and surface injury ratings for grapefruit collected by hand from the citrus grove to that of grapefruit sampled from the harvest bin before packing. Surface injury or decay attributed to the packing line was identified by comparing incidence of decay and surface injury ratings for grapefruit sampled from the harvest bin before packing to that of grapefruit sampled from the end of the packing line.

Results and discussion

INSTRUMENTED SPHERE. Packing shed visits were initiated in January and completed at the end of April 1996. Between 20 to 40 transfer points (locations on the packing line where grapefruit were transferred from one surface to another or underwent a change in direction or altitude) were identified for each of the seven packing-line operations (Table 1). A total of 4808 impacts was recorded in the 7 sheds during 64 runs down the 7 packing lines. Each of the seven packing-shed operations had a similar percentage of impacts in the four impact categories (Table 1). Most (72.0%

$\pm 5.4\%$) impacts were classified as most likely not damaging and had a $g_n \leq 100$. About 16% of impacts were classified as possibly damaging, and 7% as most likely damaging. Impacts categorized as very likely damaging were least frequent ($4.5\% \pm 1.5\%$) but present in each of the packing lines. At least one impact with a force $> 400 g_n$ was recorded in each packing shed (Table 1). The percentage of impacts categorized as most likely damaging or very likely damaging (impacts $> 150 g_n$) ranged among packing lines from 2.6% to 8.1%. Eliminating these potentially damaging impacts could enhance the potential for avoid-

ing damage to grapefruit.

Most impacts recorded in the seven packing sheds had a force of 50 to $150 g_n$ (Fig. 1). The type of surface response for $> 80\%$ of all the impacts recorded in the seven packing sheds was similar to region 2, suggesting that the most common surface encountered upon impact provided cushioning similar to 0.3 cm Poron (Fig. 1). A few impacts had a $g_n > 150$ and encountered a surface similar to steel (region 1). While the number of impacts recorded in region 1 was minimal, eliminating impacts from region 1 could enhance the potential for avoiding damage to grapefruit.

The percentage of impacts recorded in Rio Grande Valley packing sheds within each surface response region was fairly similar to that reported for 39 Florida packing houses (Fig. 2). This data suggests that grapefruit packed in Texas are exposed to similar impacts during packing as grapefruit packed in Florida. Texas packing sheds had about 5% less (5.4) impacts in region 1 (the least cushioned surface) than Florida packing sheds (10.2%). However, Miller and Wagner (1991b) reported almost twice as many impacts in regions 3, 4, and 5 (7.4, 0.5, and 2.3, respectively) in the Florida pack-

Fig. 3. Percentage of total impacts recorded within each damage category at each of 14 unit operations common to 7 Rio Grande Valley packing sheds.

Fig. 4. Percentage of all very likely damaging impacts (>200 g) recorded in each packing shed at high impact unit operations; NE = not evaluated.

ing sheds than we recorded on Texas packing lines (3.6, 0.2, and 1.6, respectively).

The seven packing sheds had fourteen unit operations in common, with each unit operation being comprised of one or more transfer points. The common unit operations were the bin dump, small fruit eliminator, washer, water eliminator, waxer, dryer, grading table, hand separation of #1 and #2 fruit at the grading table, sizer, labeler, collection from packing line into a field bin, bin dump to a packing line, labeler, and the drop to a packing table where the fruit was boxed or bagged. Sixty-one percent of impacts classified as very likely damaging and 31% of impacts classified as most likely damaging were recorded at transfer points located within four unit operations (Fig. 3). The four unit operations where the highest impacts were recorded were 1) the sizer for #1 and #2 fruit, 2) separation by hand of #2 fruit at the grading table, 3) the initial dump from a field bin to the packing line, and 4) the collection of fruit into a field bin from the packing line (unit operations 1, 8, 11, and 12, Fig. 3). About 21% of the very likely damaging impacts (>200 g_n), 17% of the most likely damaging impacts (200 to 150 g_n), and 17.5% of the possibly damaging impacts (100 to

150 g_n) occurred at the sizer. Fifteen percent of the very likely damaging impacts happened when grapefruit were classified as #2 fruit and tossed by hand at the grading table to a different conveyer belt. Dumping fruit from the field bin to the packing line accounted for about 13% of the very likely damaging impacts, and 10% of the most likely damaging impacts. About 12% of the very likely damaging impacts occurred when fruit were collected into a field bin at the end of the packing line.

The number of very likely damag-

ing impacts (impacts >200 g_n) recorded at the four highest impact unit operations varied among the seven packing sheds (Fig. 4). For example, about 35% of all very likely damaging impacts recorded at a sizer happened in packing shed 4. Only about 2% of all very likely damaging impacts recorded at a sizer happened in packing shed 3. About 52% of all very damaging impacts during hand separation of #2 fruit at the grading table occurred in shed 5, whereas only about 2% occurred in shed 6. Sheds 2 and 7 accounted for 34% and 32% of all very likely damaging impacts at the bin dump. Shed 7 accounted for 74% of all the very likely damaging impacts during collection into a field bin from the packing line.

The cushioning provided at the four highest impact unit operations also varied among the seven packing sheds (Fig. 5). Packing shed 6 had about 38% of all impacts in region 1 recorded at the sizer, whereas packing shed 5 had only about 3% of all impacts in region 1 at a sizer. Almost 60% of all region 1 impacts in packing shed 5 were recorded when #2 fruit was tossed by hand to a separating conveyer belt at the grading table. Impacts in region

Fig. 5. Percentage of all impacts in reference surface region 1 (steel) recorded in each packing shed at high impact unit operations; NE = not evaluated.

Table 1. A description of the number of transfer points and the number and type of impacts recorded during replicated runs down each of seven grapefruit packing lines in the Rio Grande Valley of Texas in 1996.

Packing shed	Transfer points (no.)	Recorded impacts (no.)	Rating (%)				Maximum impact (g_n)
			Very likely damaging	Most likely damaging	Possibly damaging	Most likely not damaging	
1	24	786	4.7	3.6	13.1	78.6	638 ^x
2	20	452	6.0	7.0	15.5	71.5	510
3 ^y	25	305	2.6	8.1	14.3	74.9	514
4	30	769	4.6	6.8	16.5	72.2	443
5	25	574	3.1	6.8	12.5	73.5	468
6	40	823	4.0	6.7	17.0	72.4	449
7	39	1099	6.7	7.6	24.6	61.0	591
Average (SD)	29 (9)	687 (264)	4.5 (1.5)	6.7 (1.4)	16.2 (4.0)	72 (5.4)	516 (73)

^x $g_n > 200$ = very likely damaging, $g_n > 150$ yet ≤ 200 = most likely damaging, $g_n > 100$ yet ≤ 150 = possibly damaging, $g_n \leq 100$ = most likely not damaging.

^yData based on 4 instead of 10 replications.

^zIS damaged after impact and required repair.

1 during the initial bin dump were recorded only in packing sheds 2 (28%), 5 (28%), and 7 (44%). Impacts in region 1 at the collection bin were recorded only in packing sheds 1 (29%), 6 (14%), and 7 (58%). The variability among packing sheds in the number of likely damaging impacts and the amount of cushioning at high impact unit operations suggest that management practices at some sheds could be shared with others and that no one shed was inherently better than another.

INCIDENCE OF DECAY AND DYE TEST.

Fruit were collected during February 1996 from three handling sites in six out of seven packing shed operations. Incidence of decay was low, with only 6 out of 60 fruit developing any decay symptoms (Table 2). No decay was apparent on grapefruit collected from packing sheds 5, 6, or 7. Incidence of decay was highest in unwaxed fruit that was not treated with a fungicide, such as grapefruit collected from the harvest bin before packing (5%) and grapefruit harvested by hand from the grove (3.3%). Waxed fruit collected

from the end of the packing line had the lowest incidence of decay (1.7%). These data suggest that the fungicide incorporated into the wax on the packing line effectively reduced decay, and that impacts incurred on the packing line were not of sufficient magnitude to negate the shelf life extending attributes of fungicide and wax. Miller and Burns (1991) also reported that decay levels in grapefruit did not correspond well with prior impact exposure or impact surface.

Incidence of decay did not appear to be related to the amount of red dye visible on TTC-treated fruit. Grapefruit sampled from the end of the packing line had the greatest amount of surface area stained with red dye in three out of the six packing sheds (Table 2). Red dye was most commonly visible on the blossom end of the fruit, suggesting that the blossom end may be most sensitive to damage during handling. Miller and Burns (1991) found the TTC dye test to be a good indicator of abrasive injury but a poor indicator of drop height or number of drops. The large amount of

visible red dye observed in fruit collected from bins at the end of the packing line in sheds 1, 2, and 7 suggest that these fruit were exposed to an abrasive surface somewhere on the packing line, and that sheds 1, 2, and 7 could enhance fruit quality by eliminating abrasive contact points from their lines.

The IS is a technology available to packing shed managers for identifying high impact areas during handling of fresh produce and for measuring the success of modifications made to eliminate high impact areas. The IS provides quantitative data that can be used to assess the need for modifying handling operations by enabling a comparison of individual operations to impact levels in other packing sheds within and among agricultural production regions. The data presented in the present study can be used by packing-shed managers to modify high-impact areas in their packing-line unit operations and eliminate impacts having a high potential for causing damage to grapefruit market quality.

Table 2. Incidence of decay and surface injury scores for 10 fruit sampled from three handling stages in each packing shed.

Shed ^z	Incidence of decay (%)			Surface injury (10 fruit)		
	Grove ^y	Prepack ^x	Postpack ^w	Grove	Prepack	Postpack
1	0	3	0	1	1	3
2	0	0	1	1	1	2
4	2	0	0	1	1	1
5	0	0	0	1	1	0
6	0	0	0	1	1	0
7	0	0	0	0	1	3
Average	3.3	5	1.7	0.8	1	1.5

^zUnable to obtain fruit from packing shed 3.

^yGrapefruit harvested by hand from the citrus grove.

^xGrapefruit collected from the harvest bin in the shed before packing on the line.

^wGrapefruit collected from the end of the packing line.

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Using an On-line UV-C Apparatus to Treat Harvested Fruit for Controlling Postharvest Decay

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ADDITIONAL INDEX WORDS. radiation, ultraviolet light, induced disease resistance

SUMMARY. An apparatus was designed to deliver low-dose UV-C light to the surface of fruit on a processing line and tested for its control of postharvest decay. It consisted of a row of UV-C emitting lamps mounted on a frame above a conveyor belt that transported the fruit. The dosage of the UV-C light delivered to the fruit surface was regulated by varying the speed of the conveyor belt. Postharvest decay after 28 days storage of 'Empire' apples was reduced 52% relative to the untreated checks when the fruit were conveyed at 6.2 m·min⁻¹ (1.38 kJ·m⁻² dose) under the UV-C apparatus. Factors affecting the practical application of UV-C irradiation of fruit for controlling postharvest decay are discussed.

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