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Effect of mechanical and water-based postharvest treatments on storability of 'Hayward' kiwifruit (*Actinidia deliciosa*)

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Abstract A trial (15 orchards; *n* = 37500 fruit) was conducted to determine the impact of postharvest wetting and drying procedures on the subsequent storage characteristics at 0°C of 'Hayward' kiwifruit (*Actinidia deliciosa*). Treatments were a control (commercial practice before storage), wetting in water or $MgSO_4$ solution, and passive (drip-drying) or active (brush rollers and fan) drying before curing. Cumulative fruit loss in the Control after 20 weeks of storage was 2.2%. This increased by 71% with dry brushing, with wetting having negligible additional impact. Dipping fruit in $MgSO_4$ solution had no adverse consequence on total losses beyond use of water alone. There was no difference in overall fruit losses between passive and active drying processes, or between treatments containing wet and dry fruit where equivalent mechanical procedures were imposed. Physiological pitting (0.4%) was the only individual quality disorder where losses increased (to 1–1.2%) when fruit were wetted.

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INTRODUCTION

Relationships between density and quality attributes in agricultural and horticultural products have been observed for many crops including citrus, potato, and tomato (Fitzpatrick et al. 1969; Zaltzman et al. 1987; Miller et al. 1988). For kiwifruit (*Actinidia deliciosa* var. *deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson), flotation of harvested fruit in water or salt solutions would facilitate the segregation of poor-tasting, low dry matter fruit from their more mature, better-tasting counterparts (Jordan et al. 1994). Before density grading could ever be considered as an acceptable postharvest practice, however, it would need to be demonstrated that procedures like wetting fruit in water or brine solutions had no adverse effect on the subsequent quality of fruit in coolstorage.

The literature is surprisingly unclear concerning the consequences of storing kiwifruit following wetting at, or after harvest. Industry avoids packing wet fruit, but this is for practical reasons to prevent the matting of hair on wet fruit or the failure of labels to adhere to wet surfaces. Experimental hydrocooling of kiwifruit has been carried out in trial situations (Harris & MacDonald 1975; Gorini 1991; Lay-Yee & Whiting 1996; Lambrinos et al. 1997), but comprehensive investigations quantifying the impact of this procedure on fruit quality in commercial-sized trials have apparently gone unreported. Postharvest citric acid dips to remove superficial stains on kiwifruit were explored briefly in New Zealand during the 1980s (Poole & Holland 1988). However, this was never approved as acceptable commercial practice, and Pennycook (1986) demonstrated that its use could promote *Botrytis* storage rots.

To further evaluate the potential for flotation devices to non-destructively segregate kiwifruit with low and high dry matter attributes, a large-scale trial was conducted under commercial conditions to determine just what impact wetting and drying processes have on storage characteristics. Treatments included dipping fruit in both water and salt solution, and the use of passive and active drying processes. Quality losses were assessed according to commercial criteria after 12 and 20 weeks of storage at 0°C.

MATERIALS AND METHODS

Procedures at harvest

Collection of fruit covered the period 13–20 May 2002, corresponding to the latter half of commercial harvest. Processing harvested fruit and imposition of treatments began as soon as fruit arrived at the packhouse. This was usually the day that fruit had been picked, or within 24 h of harvest.

Just over 2500 medium-sized fruit (90–120 g covering industry count sizes 33–39) were acquired from each of 15 orchards. These were selected manually from 6–9 picking bins and placed in F47 plastic crates (stackable standard industry containers 60 × 42 × 23 cm with slotted sides and base that allow for excellent ventilation), each capable of holding some 250 fruit. Fruit in the 10 crates from each orchard were subsequently tipped onto a conveyor belt passing into a commercial grading system, and the crates refilled with counted numbers of kiwifruit as fruit exited from two drops along the grading line. This ensured all trial fruit received normal commercial handling while thoroughly mixing and randomising individual fruit populations.

Trial design

Two crates were arbitrarily assigned to each of the five following treatments. Control (C): fruit receiving normal commercial treatment before packing. Control plus a dry mechanical brush treatment (CM): fruit receiving normal commercial treatment as well as being passed over the brush unit used for brush- and air-drying wet fruit (but remaining dry throughout). Control plus a dry mechanical treatment followed by a water dip, a water spray wash, and the fruit left to drip-dry in their plastic crate (WD). Control plus a water dip, followed by a water spray wash and a mechanical treatment to brush- and air-dry the wet fruit (WB). Control plus a $MgSO_4$ dip (solution density c. 1025 kg m^{-3}), followed by a water spray wash and a mechanical treatment to brush- and air-dry the wet fruit (MB). Note, fruit in the WD treatment were brushed **before** being wetted, rather than after. This ensured all fruit in wetting treatments received a similar degree of mechanical "abuse", without, in the case of the WD treatment, removing any excess water which was allowed to dry by natural means.

For fruit receiving a water or salt dip, the plastic crate containing 200 fruit was submerged and agitated in a container holding 110 litres of solution for 30 s. Dipping solutions were replaced once during the trial after the first 12 orchards had been processed.

The spray wash consisted of a small 6-roller brush-unit, 6-fruit wide, with a water spray nozzle mounted above. Fruit were passed through this unit after dipping to eliminate or reduce carry-over affects (pathogens, salt residue) from one orchard to another. The transit time for a fruit in this unit was typically 20 s.

The brush- air-drying unit contained 12 brush rollers with 2 × 250 W fans mounted above directing air across the fruit. The transit time for a fruit in this unit was c. 36 s.

Following imposition of treatments, fruit were stacked in their crates in the shade under open conditions and ambient temperatures for curing. Crates of dry fruit, brushed wet fruit, and drip-drying fruit were stacked adjacent to each other, but in separate columns to avoid wetting dry fruit.

Three days after their arrival at the packhouse, fruit were transferred to modular bulk packs for storage. There were five bulk packs per treatment—most contained 100 fruit, others slightly less depending on handling losses during processing. Treatment packs were assigned randomly to one of five pallets (replicates), which were constructed progressively over a 7-day period as groups of orchards completed curing. The final pallets each contained 75 bulk packs—one pack of each treatment per orchard. During construction, part-pallets were held at 0°C over night and were withdrawn briefly to facilitate stacking of new layers—a process taking less than 20 min thereby avoiding undue warming of the fruit. On completion, trial pallets were located as a group in the same coolstore and were withdrawn after 12 (19–20 August) and 20 (7–9 October) weeks of storage for quality assessment.

Fruit measurements

Soluble solids content (SSC) (Atago refractometer, N20) was measured at harvest (on an additional 20-fruit subsample per orchard) and after 20 weeks of storage (two randomly selected fruit per treatment per orchard per pallet) by mixing two drops of fluid squeezed from the top and bottom end caps. Fruit firmness (hand-held Effegi penetrometer, 7.9 mm head) was determined after 20 weeks of storage as the average of two measurements recorded on opposing sides of the same fruit used for soluble solids assessment, following paring of skin and flesh to a depth of c. 1 mm.

Fruit losses were categorised as follows: rots (stem-end rots (SER), blossom-end rots (BER), side rots (SR), wound rots (WR)); soft fruit (soft patches, and overripe); pits (fungal and physiological); stains and others. In the few instances where two disorders were present on individual fruits, e.g., rots and softening, fruits were placed in the category believed to be the principal initiator of fruit failure. At 12 weeks, affected fruit were removed from packs, and were not replaced. Adjacent fruits affected by “nested” rots (“innocent bystanders”) were also removed: since they had not arisen as a consequence of any treatment process, they were not categorised or considered further as primary losses. Because of their longer development period and low incidence, physiological disorders were not assessed at this time. Data sheets placed beneath the lid of each box were used to record the numbers of fruit in particular loss categories at each time, as well as pallet, orchard, and treatment details, and the total number of fruit present at the time of packing.

Data analysis

For soluble solids and firmness results at 20 weeks, GENSTAT ANOVA was used to obtain means for the main effects, Orchard and Pallet, and their interactions. The means for Treatment effects and their standard errors were obtained from restricted maximum likelihood analysis (REML), where Treatments was treated as a fixed effect and the rest of the terms in the model as random. REML tests the effects of fixed factors with the Wald test (Dobson 1990).

For analysis of loss data at 12 and 20 weeks, variables were appropriately transformed to obtain normally distributed residuals. The “loss-proportions” (i.e., total or individual losses divided by the number of fruit per pack plus an increment of 0.01) were log transformed. The predicted mean proportions of the main effects (Orchard and Pallet) and interactions (with their respective standard errors) were obtained from ANOVA. Subsequently the predicted mean proportions were back-transformed. Similarly, the estimated mean proportions for Treatments and their standard errors were obtained from the REML analysis, and were back-transformed.

In the analysis that follows, only passing reference is made to Orchard effects, which were almost always significant. Examination of relative differences among orchards was not an issue in this trial, and only summary data are presented that facilitate such comparisons (Table 1). The reason for including fruit from multiple properties was to guard against the likelihood of selecting a single line susceptible to a particular storage disorder, and to ensure where Treatment effects were observed, that these acted consistently (Treatment × Orchard interactions) on fruit sourced from a range of locations.

RESULTS

Efficacy of drying procedures

In preliminary wetting experiments it was established that fruit in crates dipped in water retained c. 1.25 ml of superficial moisture per fruit. This moisture evaporated under open, shaded, conditions within 24 h, leaving only residual films at the point of contact between individual fruit. Fruit that had been wetted and then immediately brush-dried retained c. 0.3 ml per fruit and were completely dry one day later. This same pattern occurred in the full trial. Only in a few instances were fruit that had been left to drip-dry, found to have residual moisture films present after 3 days of curing. Such fruit were not dried, but were packed and placed in storage along with all the others.

Soluble solids and firmness

Average SSC of fruit at harvest was 8.2%. The lowest orchard mean was 7.3% indicating that all lines contained physiologically mature fruit and were above the 6.2% SSC threshold required for commercial harvesting (Table 1).

After 20 weeks, SSC averaged across the whole trial had increased to 14.3%. There were no Treatment effects, but not unexpectedly, differences between orchards were highly significant ($P < 0.001$) (data not presented).

Average fruit firmness at 20 weeks was 1.1 kgf. Again there were no Treatment effects, but variations between Pallets, Orchards, and a Pallet × Orchard interaction were each highly significant ($P < 0.001$). The pallet effect (Pallet 3 = 0.9 kgf, Pallet 4 = 1.2 kgf, standard error of a difference

(SED) = 0.02) suggests that the five pallets may have experienced slightly different conditions within the coolstore.

Fruit losses at 12 weeks

After 12 weeks of storage, fruit losses from all causes—a total of 404 fruit—amounted to 1.1%. Soft fruit (0.39%) and WR (0.36%) were the principal reasons for rejection, accounting for three-quarters of the total loss. Side rots (0.19%), SER (0.13%), and BER (0.02%) made up the remainder (Fig. 1).

There were significant Orchard and Treatment effects ($P < 0.001$) associated with total losses at 12 weeks, but only the Orchard effects were significant when individual loss categories were analysed separately (Table 1). Total losses were least for fruit receiving normal commercial practice (0.7%), and were increased, on average, to 1.0% after imposition of treatments (Table 2). That is, our treatments raised the overall level of disorder present, but not by elevating loss in any individual loss category in particular.

Although physiological disorders were not assessed formerly at this time, it was quite evident throughout the assessment process that the presence of fruit affected by pitting, or any other disorder, was uncommon.

Fruit losses at 20 weeks

In the final 8 weeks of storage, fruit losses amounting to an additional 2.5% (or 929 fruit) were sustained. Fruit affected by physiological pitting now dominated losses, followed by prematurely softened fruit (Fig. 1).

Cumulative total losses (1333 fruit) across the entire trial period amounted to 3.6% at 20 weeks—condition-checking losses determined at this time averaged 3% in these same 15 lines. Prematurely softened fruit (1.11%), physiological pitting (0.93%), and WR (0.67%) were the principal reasons for fruit loss, together accounting for over three-quarters of all fruit removed (Fig. 1). Residual losses consisted of SR (0.55%), SER (0.18%), over-ripe fruit (0.12%), and BER (0.03%).

There were both Orchard ($P < 0.001$) and Treatment ($P = 0.039$) effects associated with cumulative losses at 20 weeks. Orchard effects were significant for total losses and each individual loss

Table 1 Summary statistics of Orchard effects on loss and quality attributes. BER + SER + SR (blossom-end rots, stem-end rots, and side rots) represents a combined rot category resulting from "natural" causes (plant pathogens), as opposed to "artificial" potentially-avoidable wounding responses. Losses at 20 weeks are the cumulative losses in each category for the entire storage period. Orchard effects for each characteristic are significant at $P < 0.001$. (SSC, soluble solids content.)

Characteristic	Mean	Min.	Max.	SED
Fruit attributes				
SSC at harvest (%)	8.2	7.3	9.3	0.46
SSC after 20 weeks (%)	14.3	13.6	15.5	0.22
Firmness after 20 weeks (kgf)	1.06	0.88	1.21	0.04
Storage losses				
Week 12				
Soft + over-ripe (%)	0.36	0.11	0.93	0.14
Wound rots (%)	0.35	0.14	0.65	0.13
BER + SER + SR (%)	0.32	0.07	0.83	0.13
Total (%)	1.06*	0.49	1.96	0.27
Week 20				
Soft + over-ripe (%)	1.14	0.42	2.72	0.28
Wound rots (%)	0.66	0.26	1.10	0.20
BER + SER + SR (%)	0.70	0.26	1.66	0.22
Physiological pitting (%)	0.79	0.16	1.46	0.22
Total (%)	3.51*	0.92	5.96	0.62

*Totals are back-transformed means from logarithmic data used for the statistical analysis. Means of individual disorders determined by this same method do not necessarily sum to give the total presented.

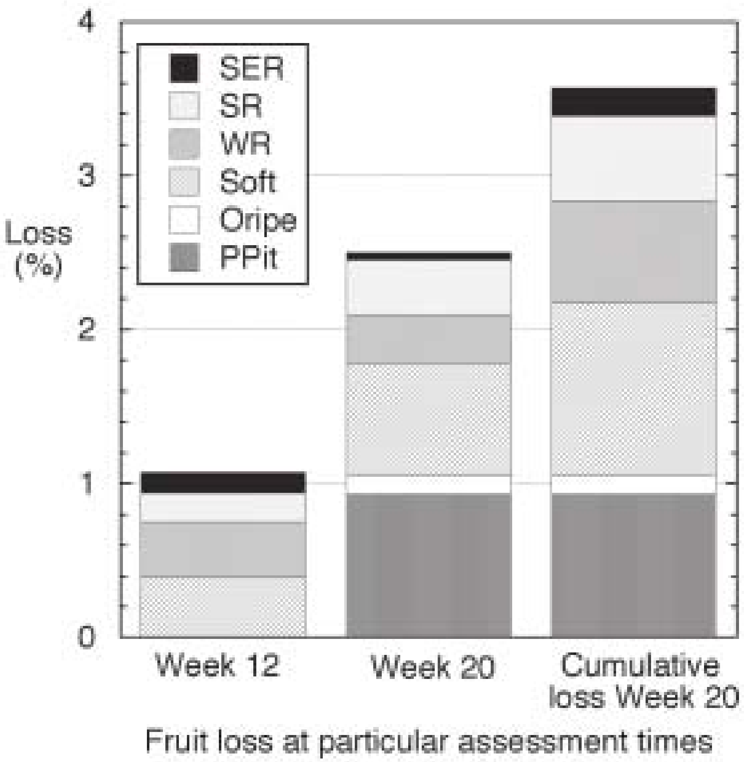

Fig. 1 Distribution of 'Hayward' kiwifruit (*Actinidia deliciosa*) losses in individual loss categories at 12 and 20 weeks after harvest, and cumulative losses for the whole trial (12 and 20 weeks combined) after 20 weeks of storage. (SER, stem-end rots; SR, side rots; WR, wound rots; Oripe, over-ripe fruit; and PPit, physiological pitting.) Category for blossom end rots (BER) was too small (0.01–0.02%) to distinguish and has been omitted.

Table 2 Effect of Treatment on fruit loss (%) after 12 and 20 weeks of storage. Losses at 20 weeks are the cumulative losses for the entire storage period. *P* is the significance of Treatment effects; values in a column followed by the same letter are not significantly different at the 5% level using Tukey's LSD. (C, Control: normal commercial handling. CM, Control plus a dry brushing treatment. MB, Control plus a $MgSO_4$ dip with brush-drying. WB, Control plus a water dip with brush-drying. WD, control plus a water dip and drip-drying.)

	Storage duration			
	12 weeks	20 weeks		
Treatment	Total loss	Soft + over-ripe	Physiological pitting	Cumulative loss
C	0.74a	0.94a	0.41a	2.20a
CM	1.18b	1.47b	0.64ab	3.66b
MB	0.88ab	0.97a	1.01bc	3.34b
WB	0.98ab	1.28ab	1.17c	4.10b
WD	1.18b	1.30ab	1.20c	3.96b
SED	0.15	0.17	0.16	0.36
P	0.039	0.032	<0.001	<0.001

category, with total losses on individual orchards ranging from 0.9 to 6% (Table 1).

Analysis of Treatment effects (Table 2) was by comparison of treatment means using four orthogonal contrasts, since this addressed directly the questions of specific interest. The results of this analysis appear below.

Contrast 1: comparison of Control versus the average of all other treatments

Means for total losses were least for fruit receiving normal commercial practice (2.2%), and increased to just over 3.7% following imposition of the various treatments ($P < 0.001$). In contrast to the

12-week assessment, Treatment effects at Week 20 were associated with increased losses in both physiological pitting and soft plus over-ripe fruit categories ($P < 0.001$, $P = 0.02$). Background pitting in commercially graded fruit (Control) was 0.4%. Our handling and treatment operations increased this 2.5-fold, the dominant influence being introduced in those treatments where fruit were wetted. For soft fruit, extra handling increased losses from 0.9 to 1.3%.

Contrast 2: comparison of non-wet treatment (CM) versus the average of wet treatments

Soft and over-ripe fruit losses were greatest (1.5%) when fruit were just dry brushed. Where brushing was incorporated with a wetting operation, its effect was ameliorated to a small extent (1.2%) ($P = 0.04$). In contrast, physiological pitting was exacerbated by treatments where fruit were wetted, increasing the incidence almost 2-fold from 0.6% to 1.1% ($P < 0.001$).

Contrast 3: comparison of magnesium sulphate treatment (MB) versus the average of water treatments

Soft and over-ripe fruit losses were lower where fruit were dipped in $MgSO_4$ solution (1%) rather than water (1.3%) ($P = 0.03$). A similar observation was also reflected in the total loss data (3.3% versus 4.0%, $P = 0.03$).

Contrast 4: comparison of brush-drying (WB) and drip-drying (WD)

No significant effects were observed between active and passive drying processes after fruit had been wetted in water.

DISCUSSION

Treatment effects at 12 and 20 weeks are quite clear—there is a penalty associated with the handling and mechanical processes required to wet and dry fruit that results in a further increase in total fruit loss of between 43% and 71% of that associated with normal practice. Furthermore, at 20 weeks, these additional losses can be ascribed to an increased incidence of prematurely softened fruit and development of physiological pitting. These increases relate to base loss levels in commercially graded fruit of 0.7% and 2.2% after 12 and 20 weeks of storage, respectively. Comparison of particular treatment means (Table 2) indicates much of this extra loss can be attributed to brushing fruit, and that further wetting operations have only a limited detrimental impact.

Analysis of Treatment effects leads to further conclusions. First, dipping fruit in $MgSO_4$ solution of medium density had no adverse consequence on total fruit losses beyond that which occurred when only water was used. Second, whether fruit were allowed to drip-dry over a 3-day curing period, or were immediately dried so that only a thin film of water remained on the surface, there was no differential effect on subsequent fruit losses during storage. And third, where equivalent mechanical procedures were imposed, **total** losses in harvested fruit that were fully wetted were no different from those that remained dry.

The absence of any Treatment × Orchard interactions is also important. It implies that fruit from **all** properties reacted similarly to our treatments, even though some had variable levels of susceptibility to particular disorders. Thus, where susceptibilities were expressed, the penalties associated with our treatments resulted in an incremental increase in total fruit losses, rather than synergistic or antagonistic effects across different lines.

Absence of Treatment effects associated with rots informs the debate concerning the consequences of wetting fruit around harvest. For example, does rainfall in close proximity to harvest disperse inoculum onto fruit thereby affecting the incidence of *Botrytis* in fruit subsequently stored? Manning & Pak (1995) indicated rainfall might actually be beneficial in reducing *Botrytis* storage rots. Trials involving hydrocooling of kiwifruit (Harris & MacDonald 1975; Gorini 1991; Lambrinos et al. 1997) did not include storage as an integral part of their investigations. However, where fruit were wetted to reduce fruit temperature following disinfestation procedures, no significant increase in rot incidence occurred (Lay-Yee & Whiting 1996). In contrast, where groups of fruit, some deliberately contaminated with *Botrytis*, and others not, were immersed successively in a single batch of citric acid solution without a subsequent wash step, the incidence of *Botrytis* rot in stored fruit increased with successive immersions (Pennycook 1986). The build-up of *Botrytis* inoculum in the dipping tank used in this trial was not monitored. With a background level of 0.13% and 0.05% SER at Weeks 12 and 20, respectively (the majority of it *Botrytis*), if transference of inoculum to the picking wound did occur, then the wash step incorporated apparently averted any potential problem. Incorporation of ozone-based sanitation procedures (Klingman & Christy 2000) might offer an additional level of security against dispersion of plant pathogens if on-line density systems were ever considered seriously.

Treatments were associated with increased physiological pitting after 20 weeks of storage; this was exacerbated where fruit were wetted. The background level was not high, but a 2.5- to 3-fold increase to 1.2% loss is commercially undesirable. Typical symptoms of physiological pitting in 'Hayward' are rash-like dark purple to black sunken spots on the fruit surface that appear c. 12 weeks after storage at 0°C. Tissue under the pit appears collapsed, dark or sunburned fruit appear to be more susceptible to pitting during storage than normal fruit, and no pathogenic association can be determined (Manning unpubl. data). Factors contributing to physiological pitting are poorly understood, primarily because of its spasmodic appearance and the inability of researchers to induce the disorder artificially (Manning & Beever 1992). Gorini (1991) reports pitting damage tended to be observed when hydrocooled fruit were stored immediately at 0°C while still damp, but was not observed if the storage temperature was initially set at 4–5°C. In this study, fruit were indeed stored at 0°C, but only after a curing period when almost all fruit were completely dry. Other factors associated with pitting include fruit maturity (immature fruit contain a higher incidence of pitting than mature fruit), curing period (pitting increases with longer curing delay), rate of precooling, mineral content (higher incidence in fruit with lower Ca concentrations), and mechanical damage (Manning & Beever 1992; Ferguson unpubl. data). Superficial abrasion or puncturing of the surface during brushing in our wash or drying steps would have allowed water to infiltrate beneath the skin surface. Whether brushing in the presence of water is a causal agent of pitting requires further investigation, but on the occasional instances where brushing effects on dry kiwifruit have been explored, brushing alone did not contribute to an increased incidence of physiological pitting (Burdon unpubl. data).

The motivation for this project was to investigate some of the factors that would need to be considered if flotation devices were utilised for density-grading kiwifruit. The data imply that use of $MgSO_4$ solutions does not impose any detrimental affects during subsequent fruit storage, and if anything, was associated with a reduction in the level of soft and over-ripe fruit present (Table 2). Obenland & Aung (1997) and Droby et al. (2003, and references therein) report similar beneficial affects from the presence of Na or Ca salts in treatment solutions following heat treatment of nectarine and postharvest control of pathogens in apples and peaches, respectively. We suspect that the penalty increase in soft and total losses attributable to the vigorous brushing treatment noted here (apart from when $MgSO_4$ was present), could be avoided by using in-line heating systems rather than brush/fan units (Billing & Dawson 1991). Brushing wetted fruit of other crops does not seem to cause similar problems (Fallik et al. 1999; 2002), but perhaps the skin of kiwifruit is more sensitive. The relationship between wetting and pitting however, is more problematic. If **abraded** wet surfaces promote physiological pitting during storage, then use of in-line heating (without brushes) may avert the disorder, at least whilst drying fruit. Brushing under water sprays was a key component of earlier prototype density systems as a wetting mechanism, and essential for correct density assessment (Jordan unpubl. data). Hence alternative wetting techniques for flotation systems would need to be explored if it was necessary to avoid brushing completely. At this point however, it is not clear whether it is the combination of wetting and abrasion that contributes to the problem, or wetting alone. Irrespective of whether or not density-grading of kiwifruit becomes a reality, this storage trial has, for the first time, quantified the losses associated with some fundamental postharvest procedures, and has highlighted new directions for investigating the problem of physiological pitting.

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