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Influence of impact surface and temperature on the ripening response of kiwifruit

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Abstract

Kiwifruit (*Actinidia deliciosa*) at a typical harvesting stage were subjected to a drop height of 30 cm onto a steel plate (impact injury), and to abrasion injury by being drawn under pressure across a piece of packing-case wood. Reactions in terms of soluble solids content (SSC) and deformation measurements of flesh and core tissue, were assessed. Impact caused greater increases in SSC and deformation than abrasion, but both were greater than controls. More detailed impact tests involved comparisons of smooth steel plate with fine (280 mesh) and coarse (100 mesh) sandpaper surfaces, again measuring SSC, deformation and ethylene production. Fine sandpaper generally produced greater increases compared with steel than did coarse paper. Chilling to 4°C either on impact or during storage reduced increases in SSC and deformation responses. It is concluded that careless handling and rough surfaces in packing materials should be avoided, but prompt cooling will delay the onset of deterioration resulting from mechanical damage.

Keywords: Kiwifruit; Ethylene; Firmness; Mechanical injury

1. Introduction

Italy is the world's largest producer of kiwifruit (20,000 hectares and 320,000 tons), and about one-third of the production is exported to other European countries. Frequently, both wholesalers and retailers found that kiwifruit quickly soften; also consumer complaints of uneven softening and unpleasant taste are common. A close relationship between firmness and flavor has been reported (Stec et al., 1989). Accurate evaluation reveals that uneven softening is due to the presence of collapsed flesh tissue consequent upon mechanical injury. Such damage is the result of different factors: robust harvesting, handling operations (brushing, sizing, grading), packing and transport. Impact damage is more related to harvest and handling operations, while

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compression damage is more frequent in packing procedures. Abrasion injury is the result of the use of wooden boxes in which fruit are marketed.

Impact and compression injuries on kiwifruit are undetectable from an external quality evaluation unless the stress produces changes in the shape and surface appearance of fruit. Abrasion injury is easier to detect due to the removal of trichomes and the subsequent appearance of sunken areas through excessive water loss.

Mechanical injuries, as well as the stresses inducing lesions in green tissue cells, induce ethylene production (for detailed information, see Abeles et al., 1992). Brushing of kiwifruits has been seen to hasten the ripening process due to very small injuries on the epicarp inducing ethylene production (Massantini et al., 1995). Preliminary observations have shown that the most frequent injury to kiwifruit randomly packed in wooden boxes was impact, and then abrasion damage.

In this paper we report the results of the influence of mechanical injuries on the rate of ripening. Further details on the effect of the nature of the impact surface and fruit temperature at the time of mechanical injury on ripening are also given.

2. Materials and methods

Kiwifruits (*Actinidia deliciosa* (A. Chev.) C.F. Liang and A.R. Ferguson var *deliciosa* 'Hayward') were harvested carefully on a farm close to Rome at an advanced ripening stage. The soluble solids content (SSC) of the samples ranged between 10.5–11% and firmness within the limits of 42–45 N, monitored by an Effegi (EFFEGI, Gaiarine, RA Italy) penetrometer using an 8-mm tip after removing the fruit peel. The fruit were ready for sale and not for storage, uniformly sized (about 50 mm diameter) and selected for their regular shape, discarding those affected by injury. Kiwifruit were packed in paper pulp cell trays and reached the laboratory where they were underwent mechanical injury tests involving impact and abrasion within two hours from harvest.

Impact and abrasion tests

The impact test was carried out by using 3 different impact surfaces: a smooth solid steel surface, and two different grades of sandpaper, 100 (coarse) and 280 (fine) mesh. 100 mesh and 280 mesh sandpaper were used to cause the abrasion/puncture injuries because they simulated the surfaces of commercially-used wooden-boxes. Fruits were dropped from a height of 30 cm. Each kiwifruit was oriented with the longitudinal axis parallel to the impact surface, released by hand and caught after rebounding to avoid a second impact. To mark the impact area on the fruit, the surface was covered with a thin layer of white flour. The impact energy absorbed by the fruit, calculated from $E = m \times g \times d$ (Akkaravessapong et al., 1992) where m is the mass of the fruit, g is the gravitational constant and d is the difference between the drop height and the rebound height (around 3 cm), was about 0.26 Joule depending on fruit mass and the rebound height.

For the abrasion test, the fruit was placed on a piece (10 × 10 cm) of wood from a typical box and compressed at 2.5 N load with an 80-mm diameter flat compression anvil and held in an Instron Universal testing Machine, model 4301. The fruit were then pulled out taking care to keep the wood stationary. Impact and abrasion tests was conducted at 18 ± 1°C and R.H. 85 ± 5%. Control fruit were not injured. 50 fruit each

test were used initially, and at each sampling time 10 fruit were taken and cut widthwise through the impact area with a sharp knife to evaluate the internal injury. Then, a 1-cm thick slice including the injured area were excised and used for individual firmness measurements and SSC analysis.

Temperature tests

To evaluate the temperature effect on the appearance of impact symptoms, only 100 mesh sandpaper was used. The temperature regimes selected were:

(1) 18°C + 18°C: fruit kept at 18 ± 1°C for 24 h then dropped and stored at 18°C for 3 weeks;

(2) 18°C + 4°C: fruit kept at 18°C for 24 h then dropped and stored at 4 ± 0.5°C for 3 weeks;

(3) 4°C + 4°C: fruit kept at 4°C for 24 h then dropped and stored at 4°C for 3 weeks.

(4) Control: fruit not dropped and kept at 18°C in another storage room.

In this test 10 fruit were analyzed every week for internal tissue firmness and SSC. Fruit kept at 4°C were allowed to warm up before measuring the firmness.

Fruit evaluation

Flesh and core firmness was measured by the Instron Machine and expressed as mm of deformation: kiwifruit slices were placed over the steel plate and compressed with a flat probe (8 mm diameter) using different parts of the internal tissue: pericarp below the injured area (injured flesh = IF), adjacent, sound pericarp (sound flesh = SF) and core tissue. The load was fixed at 5 N and when tissue reached this resistance value the bar was quickly raised. Tissue firmness was expressed as 'deformation to 5 N' (Bourne, 1982). Bar and chart speeds were, respectively, fixed to 10 mm/min and 100 mm/min.

Soluble solids were measured by a Galileo Abbé refractometer (Galileo Spa, Florence, Italy) using tissue from the same fruit as were used for firmness measurements.

Staining tests

To detect starch, staining of pericarp injury was performed with a solution of potassium iodide (2 g in 100 ml water) in which 0.2 g of iodine was dissolved; to detect lignin, a saturated aqueous solution of phloroglucinol in 20% HCl (v/v) was used.

Ethylene production

Analysis of ethylene was conducted using 7-mm-thick discs (8 mm diameter) of 0.8–1.0 g weight excised from the pericarp below the impact area of dropped kiwifruit. Discs were placed in glass culture tubes and sealed with a rubber stopper for 30 min after 7, 14, and 21 h storage and 1 ml of head space sample was taken for ethylene analysis and injected into a Carlo Erba Fractovap 4200 gas chromatograph (Carlo Erba Spa, Milano, Italy) equipped with a flame ionization detector (FID) and 1-m-long alumina column (80–100 mesh) at 100°C.

Transpiration measurement

Transpiration measurements were conducted by using a Delta T Model AP3 (Delta T Devices Ltd, Cambridge, UK) adapting the sensor to the fruit surface profile; the

transpiration rate was expressed as the time lag (s) to reach a 10% increase in the basic relative humidity level.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) for factorial plots, and means were compared using least significant difference (LSD) at 5% probability level. The interactions of injury type × storage time and treatment temperature × storage time on SSC, deformation and ethylene values were examined. SSC percentages were transformed to arcsin % values for analysis.

Two experiments were conducted in the same harvest season and data reported refer to a single typical experiment.

3. Results and discussion

Impact bruises on kiwifruit did not appear externally and even after the removal of peel no symptoms of the injury were evident. On the 3rd or 4th day, when transverse sections were cut through the damaged area, the flesh showed a whitish V-shaped lesion. Staining with phloroglucinol did not show any purple color (no lignification); in contrast potassium iodide stained the whitish injury with a blue color (Fig. 1) to indicate the failure of injured cells to convert starch to sugar (Arpaia et al., 1994). When fruit softened, the whitish injury became less evident and a translucent, water-soaked truncated bruise resulted. A cone-shaped bruise has been observed in other fruits subjected to impact (Vergano et al., 1991) and Rodriguez-Sinobas et al. (1991) characterized the impact bruise response by pears in relation to ripening and softening. We were not able to characterize the injury on the flesh, but the whitish V-shape of the initial injury appeared to be the perimeter of a cone. The time course for the lesion appearance was 3–4 days and 6 days respectively for 42–45 N and 55–60 N firm fruits kept at 18°C.

As for most fruits, kiwifruit flesh can be considered a viscoelastic material. The two components of viscoelasticity affect tissue response: the viscous deformation component is permanent and not recoverable; the elastic deformation component is recoverable when stress is removed. This means that the predominance of one component over the other depends not only on the length of time during which a stress is applied but also on the softness of tissue, which increases with ripeness. Mohsenin (1972) considered the fruit in the first stage of ripening to have an elastic behavior. It is likely that in kiwifruit this elastic component is progressively lost and the viscous component becomes predominant, shown by the appearance of a V-shaped injury.

Abrasion mostly resulted in the removal of trichomes and lightly scratched the peel. After 1 day the injured area was depressed due to higher water loss as indicated by higher transpiration rate (data not reported).

Even one day after injury, fruit dropped onto a smooth surface showed a significantly (P = 0.05 probability level) higher SSC value than intact fruit, regardless of the type of injury (Table 1). With time the SSC values increased significantly for all samples but the influence of the injury (impact and abrasion) on the SSC increase was greater than for intact fruit (from day 1 through day 8: 2.5, 2.1 and 1.7% respectively for

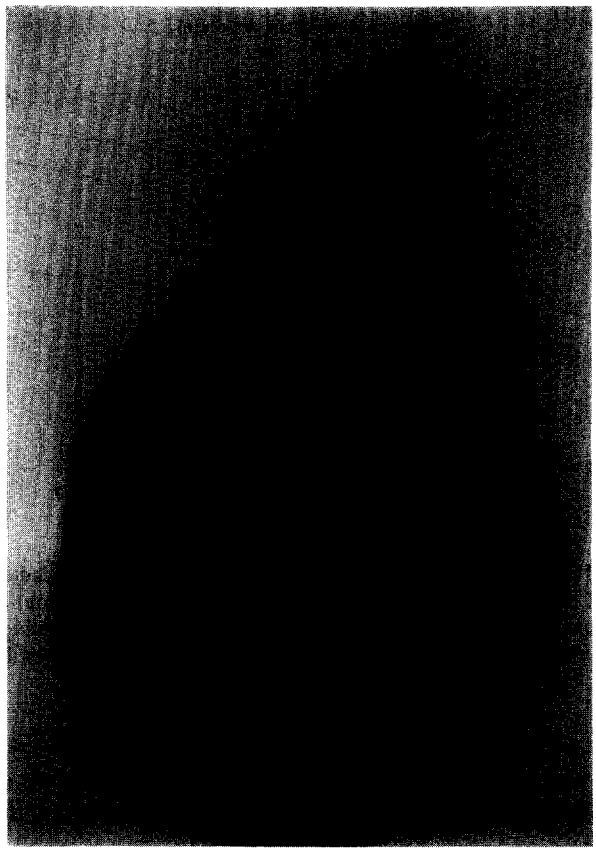

Fig. 1. V-shaped injury on pericarp of kiwifruit dropped from 30 cm stained with KI solution.

Table 1
Soluble solids content in kiwifruit dropped onto a smooth surface at a height of 30 cm (impact) or abraded over wood surface (abrasion) during maintenance at 18°C for 8 days. Control is represented by intact fruit. The initial reading (t = 0) for all points was 10.6%. Each value is the mean of 10 fruit readings. Means followed by the same letter were not significantly different at P = 0.05 probability level, using transformed data [a]

Time (days)	Injury			
	Impact	Abrasion	Control	Mean
1	11.4	11.1	10.5	11.0 c
3	12.3	12.0	10.8	11.7 bc
5	13.3	12.6	11.3	12.4 ab
8	13.9	13.2	12.2	13.1 a
Mean	12.7 a	12.2 a	11.2 b	

[a] The interaction between injury type and storage time was significant at P = 0.05 probability level (LSD = 0.97).

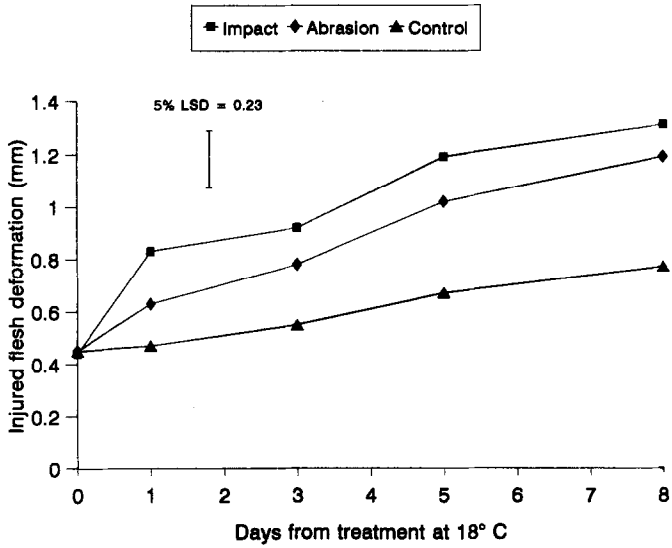

Fig. 2. Deformation of injured flesh (pericarp) just below the impact area of kiwifruit dropped onto a smooth surface from a height of 30 cm (impact) or abraded over a wood surface (abrasion) and kept for 8 days at 18°C. Control is represented by intact fruit. Measurements were taken by excising a 1-cm-thick slice widthwise and compressing the pericarp vertically in the excision direction. Values are the means of 10 fruit.

impact damaged, abraded and intact fruit). Starch hydrolysis and SSC increase are characteristics of ripening kiwifruit (Beever and Hopkirk, 1990). Thus, the observed increase of sugar is a consequence of an acceleration of ripening due to the mechanical injury.

Concerning the tissue deformation, since the first day the IF of impacted and abraded fruit showed significant higher values than control fruit (Fig. 2). The values in the injured area rose by 0.85, 0.7 and 0.3 mm, respectively, for impact, abrasion and control fruit following eight days storage. This enhanced deformation in injured fruit was confirmed by the significant interaction between type of injury and storage time. SF deformation was also affected to a lesser extent by the lesion, but the difference from the control was significant only on day 8 (Fig. 3). Furthermore, the deformation of core tissue also increased even though the damaged tissue was localized (abrasion) or confined to the pericarp (Fig. 4). Significant increase was observed in core tissue of injured fruit on day 5 and also in this case the interaction between type of injury and storage time was significant (LSD = 0.21).

If we look at the sequence of deformation increases in IF, SF and the core of impacted fruit, we note that, for the first, the increase reached 0.85 within 1 day (Fig. 2), for the SF it reached a similar value on the 3rd day (Fig. 3) and in the last case on the 5th day (Fig. 4).

Ethylene can diffuse easily through the intercellular space (Hyodo et al., 1989; Woltering, 1990), and it has been found in apples (Lougheed and Franklin, 1974) and in pears (Mencarelli and Botondi, 1992) that superficial injury leads to a rise of

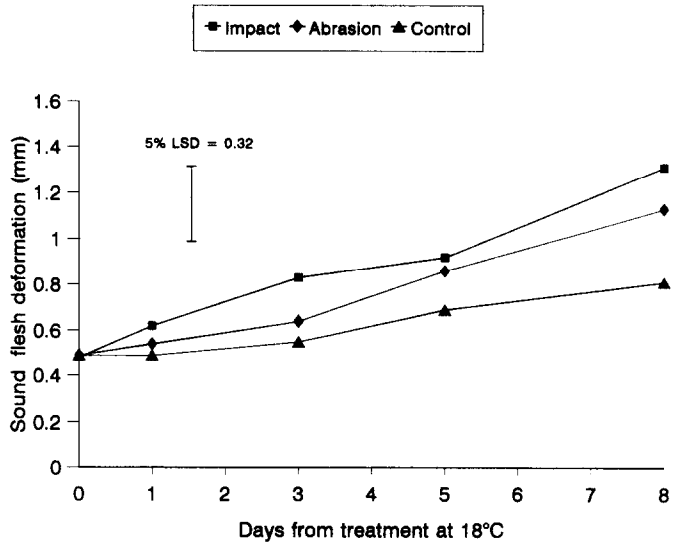

Fig. 3. Deformation of sound flesh (pericarp) adjacent to the injured area of kiwifruit dropped onto a smooth surface from a height of 30 cm (impact) or abraded over a wood surface (abrasion) and kept for 8 days at 18°C. Control is represented by intact fruit. Explanation of deformation test is indicated in the caption to Fig. 2. Values are the means of 10 fruit.

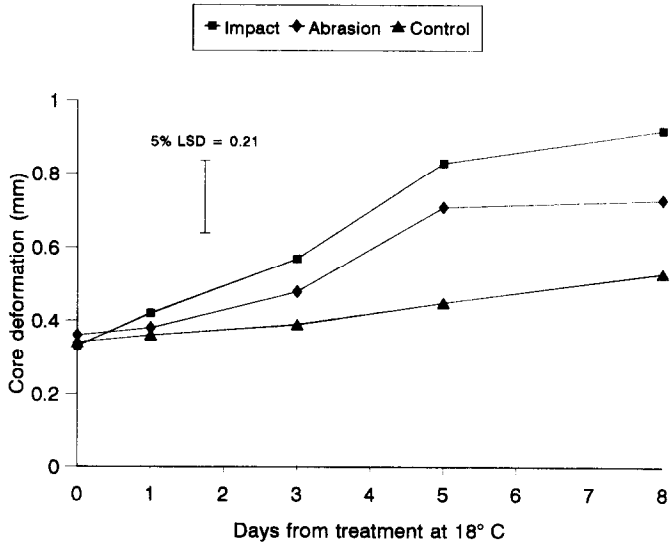

Fig. 4. Deformation of core of kiwifruit dropped onto a smooth surface at height of 30 cm (impact) or abraded over a wood surface (abrasion) and kept for 8 days at 18°C. Control is represented by intact fruit. Explanation of deformation test is indicated in the caption to Fig. 2. Values are the means of 10 fruit.

internal ethylene. Even ACC (1-aminocyclopropane-1-carboxylic acid) is translocated or diffuses through cells and accumulates in tissue away from the site of injury (Dunlap and Robacker, 1994; Hyodo et al., 1989). The reason of firmness loss of core tissue in dropped or abraded kiwifruit could be an effect of wound-ethylene diffusion and/or ACC diffusion. Analysis of ethylene evolution from dropped fruit revealed a production rate twice that in control fruit. After 8 hours from impact, discs excised from core tissue of dropped fruit and incubated only for 30 min to avoid the effect of wound-ethylene from cutting, produced 1.6 nl/g of ethylene versus 0.4 nl/g of discs excised from injured pericarp tissue. Discs from core and sound flesh of control fruit produced, respectively, 0.18 and 0.11 nl/g. Even though core tissue of kiwifruit produces more ethylene than pericarp, whether the fruit was injured or not, the rate of softening is lower than for pericarp tissue, probably due to difference in ethylene sensitivity (Redgwell et al., 1990) and tissue composition (Hallett et al., 1992; Redgwell et al., 1990).

In discs excised from IF but not from those of SF or core, ethane increased (data not reported) indicating the presence of dead cells (Elstner and Konze, 1976).

The increase of SSC in fruit dropped onto sandpaper was slightly higher than the one from fruits impacted onto smooth surface, but the difference was significant only on the 8th day for the 280 mesh sample (Table 2). The effect of surface identity on impact bruising was confirmed by firmness data (Fig. 5); injured flesh of fruit dropped onto the finer sandpaper (280 mesh) lost more firmness (increase of deformation) than the other samples, but the difference was significant only on day 8 when the injury resulted in the appearance of water-soaked tissue.

Ethylene analysis of discs excised from the impact bruised tissue using 280 sandpaper surface and incubated for 30 minutes, showed that by the 14th hour from impact the production increased greatly. Thus this surface induced a mean value for ethylene evolution that was significantly different from the other two samples, as was the mean of the production rates at 7, 14, and 21 h after impact (Table 3).

Transpiration rate from the injured area rose of 25–30% within 15 min in fruit dropped onto sandpaper, while for sound fruit the rate was constant; the highest value was for fruit

Table 2
Soluble solids content in kiwifruit dropped at a height of 30 cm over 100 and 280 mesh sandpaper or onto a smooth surface and kept 8 days at 18°C. Initial values mean was 10.7%. Each value is the mean of 10 fruit readings. Means followed by the same letter were not significantly different by $P = 0.05$ probability level using transformed data [a]

Time (days)	Surface			
	Sandpaper 100	Sandpaper 280	Smooth	Mean
1	12.2	12.5	11.9	12.2 c
3	13.0	13.1	12.5	12.9 b
5	13.1	13.3	12.7	13.0 b
8	13.8	14.7	13.4	14.0 a
Mean	13.0 ab	13.4 a	12.6 b	

[a] The interaction between surface and storage time was significant at $P = 0.05$ probability level (LSD = 0.97).

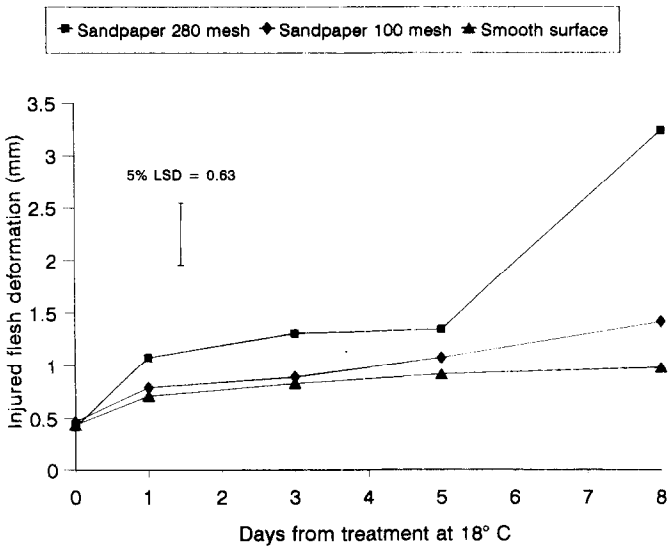

Fig. 5. Deformation of injured flesh (pericarp) just below the impact area of kiwifruit dropped from a height of 30 cm onto 100 and 280 mesh sandpaper or onto a smooth surface and kept for 8 days at 18°C. Values are the means of 10 fruit.

Table 3
Ethylene production (nl/g) of discs excised from kiwifruit dropped from a height of 30 cm onto a 100 and 280 sandpaper or a smooth surface and incubated for 30 min after 7, 14 and 21 h. Each value is the mean of discs excised from 10 fruits. Means followed by the same letter were not significantly different at $P = 0.05$ probability level [a]

Time (hours)	Surface			
	Sandpaper 100	Sandpaper 280	Smooth	Mean
7	0.2	0.4	0.2	0.3 c
14	0.8	3.2	0.6	1.5 b
21	1.4	6.3	1.0	2.9 a
Mean	0.8 b	3.3 a	0.6 b	

[a] The interaction between surface and storage time was significant at $P = 0.05$ probability level (LSD = 0.89).

dropped onto 280 sandpaper (data not shown). Thus, the dramatic ethylene burst could be the result of an increase of ethylene production but also a higher rate of diffusion. Initially this latter event is predominant, but the increase of SSC and the decrease of tissue firmness probably result from a rapid increase of ethylene production with time.

Concerning the effect of rough surface, our results confirmed the results of Quintana and Paull (1993) in papaya where fine sandpaper (280 mesh) would cause more skin damage per unit area compared with fruit dropped on coarse (100 mesh) sandpaper, hence the greater the response by the fruit.

Table 4
Soluble solids content of kiwifruit dropped from a height of 30 cm onto a smooth surface with the following temperature regimes: 18°C + 18°C = injured at 18°C and kept at 18°C; 18°C + 4°C = injured at 18°C and kept at 4°C; 4°C + 4°C = injured at 4°C and kept at 4°C; control: not injured and kept at 18°C. The initial solids content was 10.5%. Each value is the mean of 10 fruit readings. Means followed by the same letter were not significantly different by $P = 0.05$ probability level using transformed data [a]

Time (weeks)	Treatment temperature				
	18°C + 18°C	18°C + 4°C	4°C + 4°C	Control	Mean
1	12.0	11.0	11.2	11.1	11.3 b
2	12.3	11.1	11.4	11.2	11.5 b
3	13.2	11.7	12.2	11.9	12.3 a
Mean	12.5 a	11.3 b	11.6 b	11.4 b	

[a] The interaction was not significant at $P = 0.05$ probability level.

Fruit injured at low temperature or transferred soon after the impact injury to low temperature had the same content of soluble solids as control, uninjured fruit, during 3 weeks of storage (Table 4). In contrast, kiwifruit bruised at 18°C and uncooled, exhibited a significantly higher total soluble solids concentration than the other samples during all storage periods but the interaction of temperature and storage time was not significant. This response was paralleled by an increase of tissue deformation by IF which resulted in significantly greater values in uncooled fruit compared with those stored chilled (Fig. 6). Even though SF adjacent to the injured tissue of uncooled fruit was less firm

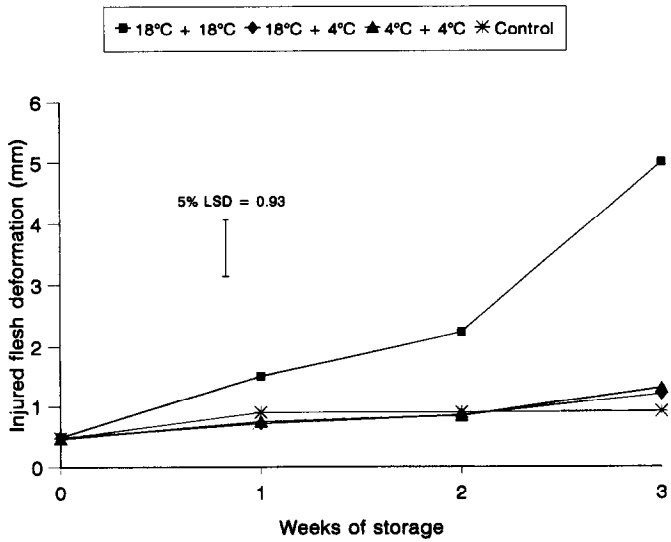

Fig. 6. Deformation of injured flesh (pericarp) just below the impact area of kiwifruit dropped at a height of 30 cm onto a smooth surface with the temperature regimes indicated in Table 4. Explanation of deformation test is given in the caption to Fig. 2. Values are the means of 10 fruit.

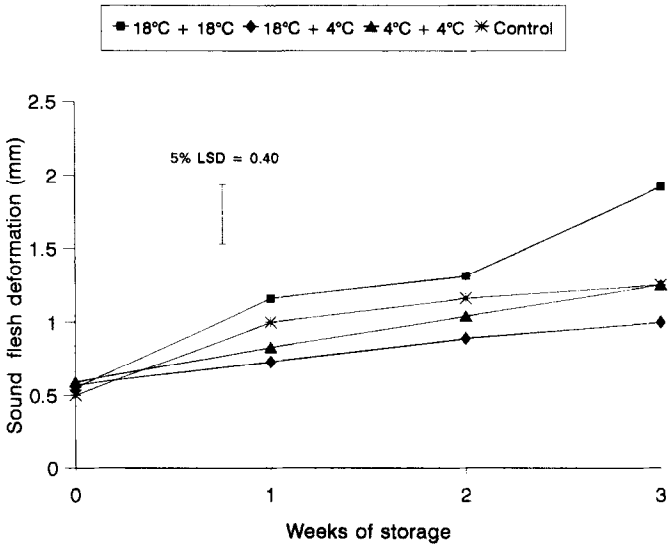

Fig. 7. Deformation of sound flesh (pericarp) adjacent to the injured area of kiwifruit dropped from a height of 30 cm onto a smooth surface with the temperature regimes indicated in Table 4. Explanation of deformation test is given in the caption to Fig. 2. Values are the means of 10 fruits.

than either cooled or uninjured fruit from the first week of storage, the differences only became significant by the third week of storage (Fig. 7). Chilled, injured fruit were just as firm as uninjured ones. The interaction between temperature and storage time was significant at $P = 0.05$ probability level (LSD = 0.40). Similar results were obtained by Saltveit (1984) who observed a reduction of bruise volume in apples kept at low temperature, resulting in reduced enzyme activity. As previously found and confirmed here, core deformation was affected by the superficial impact injury. The extent of subsequent cold treatment progressively and significantly reduced such deformation measurements and in the present case the interaction between temperature and storage time was significant at $P = 0.05$ (LSD = 0.26) (Fig. 8). Whitish V-shaped injury in cooled fruit was observed after 2 weeks.

Abrasion injury was less detrimental than impact on ripeness in terms of SSC and firmness. In this case the increase of ripening rate is probably due to the small superficial scratches and the consequent water loss. As we saw with brushed kiwifruit, any kind of superficial injury resulting in the breaking of the epicarp stimulates ethylene production (Massantini et al., 1995) which accelerates ripening and susceptibility to pathogenic attack.

4. Conclusions

Mechanically injury as a consequence of rough handling of kiwifruit induces faster ripening as indicated by the increase in ethylene production, SSC and decrease in tissue firmness. The use of rough surface containers such as wooden boxes could lead to abrasion damage which hastens transpiration and ripening.

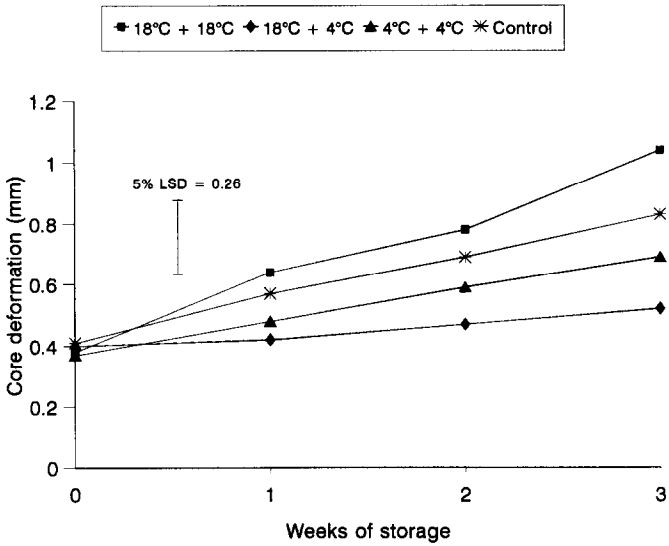

Fig. 8. Deformation of core of kiwifruit dropped at a height of 30 cm onto a smooth surface with the temperature regimes indicated in Table 4. Explanation of firmness test is reported in the caption to Fig. 2. Values are the means of 10 fruit.

The stage of harvest should receive more attention in order to have the fruit less sensitive to mechanical damage because of the predominance of elastic component, but keeping in mind the quality requirements for the market (SSC and firmness).

Temperature plays an important role in the control of ripeness induction due to mechanical injury. Cooling of kiwifruit soon after the harvest can limit the ripening response induced by tissue damage. Harvesting in the early morning might also make kiwifruit more resistant to mechanical damage.

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