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Degreening, Softening and Chilling Sensitivity of Early Harvested 'Zesy002' Kiwifruit under Elevated Temperature Conditioning in a Controlled Atmosphere

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Abstract: Commercially produced volumes of *Actinidia chinensis* var. *chinensis* 'Zesy002' (Zespri® SunGold Kiwifruit, Tauranga, New Zealand) are increasing rapidly. One approach to managing the harvest logistics is to start the harvest season earlier by harvesting fruit before they have fully degreened on the vine. However, there are risks: the fruit are chilling-sensitive and they may soften excessively while degreening at elevated temperatures off the vine. Degreening and softening were investigated for 'Zesy002' kiwifruit harvested before fully degreened, and then allowed to degreen for 2 or 4 weeks at 10 °C in air or in a controlled atmosphere (CA; 2% oxygen/2% carbon dioxide). Fruit were then stored in air or CA at 1 °C up to 16 weeks from harvest, after which they were assessed for chilling injury. The main findings were that holding fruit in CA rather than air at 10 °C caused slower degreening, delayed the change to rapid softening, and also delayed the loss of chilling sensitivity. It is concluded that if 'Zesy002' fruit are to be degreened in CA, then either a longer conditioning period in CA, or more advanced fruit, should be used.

Keywords: *Actinidia*; fruit; flesh color; firmness; disorder; chilling injury

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1. Introduction

'Zesy002' (*Actinidia chinensis* var. *chinensis;* Zespri® SunGold Kiwifruit) is a yellow-fleshed kiwifruit that has replaced 'Hort16A' (*A. chinensis* var. *chinensis*; Zespri® Gold Kiwifruit) following the removal of 'Hort16A' because of its susceptibility to the bacterial disease *Pseudomonas syringae* pv. *actinidiae* [1]. The harvest, packing, and storage windows for 'Zesy002' need to be expanded to manage the rapidly increasing volume of fruit. One way to extend the harvest window for yellow-fleshed cultivars is to harvest fruit early, before they are fully degreened, and then to degreen the fruit under controlled conditions at the coolstore, as was done commercially with 'Hort16A' [2].

The fruit degreening is dependent on the breakdown of the green pigment chlorophyll [3]. Off-vine degreening can only be undertaken once fruit have started the process of degreening on the vine, and the time required for full degreening off the vine is dependent on the extent of degreening that has occurred before harvest. The overall pattern of flesh color change during degreening is sigmoidal, with the flesh color changing within fixed boundaries of approximately 115 °h when fully green and just below 100 °h when fully degreened [4,5]. Degreening of 'Hort16A', 'Zesy002', and other kiwifruit selections off the vine has been shown to occur best at temperatures above 5 °C [4,6], with temperatures of 7–10 °C selected to maximize degreening relative to softening or the occurrence of rots. The requirement for a degreening temperature of 7–10 °C also functions to condition the fruit to remove chilling sensitivity [2].

The softening of kiwifruit both on and off the vine follows a sigmoidal pattern [7–9]. An initial slow phase (Phase 1) is followed by a period of rapid softening (Phase 2), during which time most of the fruit firmness is lost, before a final third, slow softening phase (Phase 3). Controlled-atmosphere (CA) storage of kiwifruit is a well-established commercial procedure [10,11], with significant benefits to fruit firmness retention for a range of cultivars, including 'Hayward' [12,13], 'Hort16A' [14], and 'Hongyang' [15]. It is therefore of both scientific and commercial interest to know whether holding 'Zesy002' fruit in a CA environment at the higher temperatures needed for degreening can result in better firmness retention, so that the packing window for these fruit can be more flexible.

A final element to degreening kiwifruit off the vine is that, when the fruit are harvested early, they are chilling-sensitive [16]. Chilling injury (CI) is a risk reported for many kiwifruit cultivars, including 'Zesy002' [17], when fruit harvested at low maturity are stored at ~0 °C. It is perhaps fortunate that those temperatures needed for degreening also condition the fruit to reduce chilling sensitivity [18]. Storage of early-harvested 'Hort16A' fruit at 7 °C in CA resulted at the end of storage in fruit that were of a similar firmness to fruit that were stored under air at 1 °C, but without the high incidence of CI [19].

While the marketing of early-harvested, green-fleshed fruit following off-vine degreening is normally restricted to early sales, there is also the possibility of extending the storage of these fruit. However, prolonged storage at higher temperatures, even under CA, may result in the increased expression of rots. It is therefore essential to reduce the storage temperature at the end of degreening, both to maintain firmness and also to retard rot expression. The significant extension of storage may assist in widening the packing window for fruit stored in bulk—although the earlier the fruit are harvested, the longer the storage that is needed to take the fruit past the normal harvest and pack window.

In this project, the relative changes in degreening and softening have been investigated for fruit allowed to degreen for 2 or 4 weeks at 10 °C in air or CA, followed by storage in air or CA at 1 °C up to 16 weeks from harvest. The data have been analyzed for any effect of CA on the degreening rate and any subsequent effect of the degreening conditions on softening and chilling injury development.

2. Materials and Methods

2.1. Fruit

Commercially harvested and packed 'Zesy002' kiwifruit (early-season fruit, not fully degreened) were provided by Zespri Group Limited direct from a commercial packhouse after packing and before cooling. Fruit were received at the New Zealand Institute for Plant and Food Research Ltd. (PFR) Auckland from three orchards (designated O1, O2, and O3) on 28 March 2018. Fruit from O1 and O2 were count size 33 (weight range 105–114 g) and for O3 count size 36 (weight range 92–105 g). Fruit were provided in modular loose packs (ML; 5.5 kg fruit loose filled) with 96 packs per orchard. The packs were randomly allocated into eight treatments with 12 packs per treatment. Of these 12 packs, four were designated to firmness assessments, and eight to quality assessments after storage. For each orchard, a 30-fruit sample taken randomly from 30 packs was measured on receipt for flesh color, soluble solids content (SSC), and firmness.

2.2. Treatments and Assessments

A total of eight treatments were established in which fruit were stored in air or CA (2% oxygen/2% carbon dioxide) at 10 °C for 2 or 4 weeks for degreening, before being transferred to storage in air or CA (2% oxygen/2% carbon dioxide) at 1 °C up to 16 weeks after harvest (Table 1).

Table 1. Temperature and atmospheres applied in eight treatments (T1–T8) for the degreening at 10 °C and storage at 1 °C of *Actinidia chinensis* var. *chinensis* 'Zesy002' kiwifruit in air or a controlled atmosphere (CA; 2% oxygen/2% carbon dioxide).

Treatment	Code	Initial Period at 10 °C		Final Storage at 1 °C
		Atmosphere	Duration	Atmosphere
T1	Air2Air	Air	2 weeks	Air
T2	Air2CA	Air	2 weeks	CA
T3	Air4Air	Air	4 weeks	Air
T4	Air4CA	Air	4 weeks	CA
T5	CA2Air	CA	2 weeks	Air
T6	CA2CA	CA	2 weeks	CA
T7	CA4Air	CA	4 weeks	Air
T8	CA4CA	CA	4 weeks	CA

The CA treatments were applied in 12 m^3 CA coolstores with an activated carbon scrubber for carbon dioxide removal and a platinum catalyst scrubber for ethylene removal. An atmosphere of 2% oxygen and 2% carbon dioxide was established within 2–3 days of the fruit being placed into the stores.

Fruit were assessed for fruit flesh color and firmness after 2, 4, 8, 12, and 16 weeks of degreening and storage, plus one week in air at 20 °C (shelf assessment) at the end of storage. At the end of storage and shelf assessment, the incidences of chilling injury and rots were quantified.

2.3. Assessment Methods

Flesh color (°hue) was measured at the equator of each fruit using a Minolta CR-400 Chroma Meter (Konica Minolta Inc., Osaka, Japan) after removal of skin and flesh to a depth of 2 mm. Soluble solids content was determined on a combined sample of juice from both ends of each fruit, measured using a digital refractometer ("Pocket" PAL-1, 0–50 °Brix (%), Atago). Fruit firmness was measured using a Fruit Texture Analyser (Güss, model GS15, South Africa) fitted with a 7.9-mm-diameter Effegi™ penetrometer probe after removal of skin and flesh to a depth of approximately 1 mm. The probe was driven into the flesh at 5 mm/s to a displacement of 7.9 mm after triggering at 0.49 N (0.05 kgf). The maximum force was recorded as the fruit firmness value in kgf and data were converted to N, where 1 kgf = 9.81 N. Firmness was measured twice at the equator of each fruit, with the two measurements taken at 90° from each other.

Disorder assessments after storage and shelf assessment quantified the incidence of physiological disorders and rots. Fruit were examined whole at the end of storage and after one week of shelf assessment. Fruit examined whole were scored for skin discoloration associated with chilling injury and rots recorded by position of the rot lesion on the fruit: stem end, body, or stylar end. At the end of shelf assessment, fruit were cut transversely (three times spaced equally along the fruit) and the incidence of fruit with chilling-disordered tissues in the outer or inner pericarp recorded, as previously for 'Hayward' [20,21] and 'Hort16A' [22].

2.4. Data Analysis

Firmness and flesh color data have been described by the sample means and standard error of means (s.e.m.). Statistical analysis of treatment effects on the incidence of chilling injury and rots was by logistic regression (Wald) using Genstat 64-bit Release 18.2 (PC/Windows 8), Copyright 2016, VSN International Ltd. Graphs were created using Origin v8.5 (OriginLab Corporation, One Roundhouse Plaza, Northampton, MA01060, USA). Explanation of boxplot: the box includes 50% of the data, with the mean (□) and median (—) marked within the box. Whiskers represent 5%/95% of the data, with 1%/99% of data (X) marked.

3. Results

3.1. Fruit Characterization

At the start of the trial, fruit from O1–O3 had, on average: 107.3 °h flesh color, 6.0% SSC, and 66.1 N firmness, with individual orchard values of 105.4–108.5 °h flesh color, 5.8–6.2% SSC, and 64.8–67.7 N firmness (Table 2).

Table 2. Flesh color, soluble solids content (SSC), and firmness of *Actinidia chinensis* var. *chinensis* 'Zesy002' kiwifruit from three orchards (O1–O3) after packing and before establishment of treatments. Each value is the mean of 30 fruit (s.e.m.).

Orchard	Flesh Color (°hue)		SSC	Firmness
	Mean	Maximum	(%)	(N)
O1	108.0 (0.56)	113.2	5.8 (0.13)	65.7 (1.07)
O2	108.5 (0.45)	114.7	5.9 (0.10)	67.7 (1.28)
O3	105.4 (0.53)	111.8	6.2 (0.11)	64.8 (1.37)
Mean	107.3		6.0	66.1

3.2. Degreening

For fruit that were, on average, 107.3 °h at the start of the trial, degreening fruit in CA significantly retarded the degreening process, such that, after 2 weeks at 10 °C, fruit in air were, on average, 103.7 °h, whereas, in CA, the flesh color was 105.6 °h (Figure 1). This trend continued until after 4 weeks, when the fruit in air were 100.6 °h and in CA 104.6 °h.

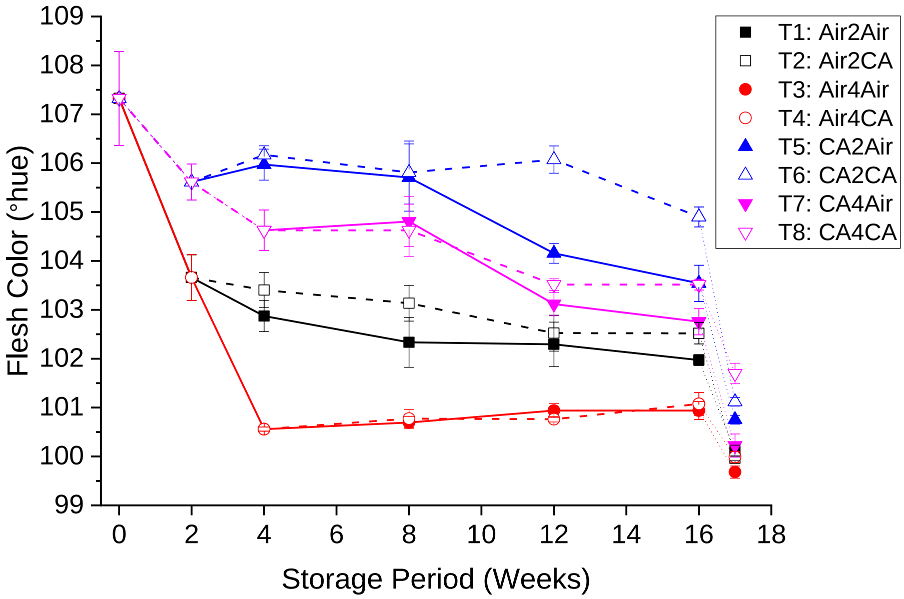

Figure 1. Flesh color of *Actinidia chinensis* var. *chinensis* 'Zesy002' kiwifruit held at 10 °C in air (T1–T4) or controlled atmosphere (CA; T5–T8) for 2 (T1, T2, T5, T6) or 4 (T3, T4, T7, T8) weeks, followed by storage at 1 °C in air (T1, T3, T5, T7) or CA (T2, T4, T6, T8). Both periods of CA were at 2% oxygen/2% carbon dioxide. Fruit were moved to air at 20 °C after 16 weeks. Solid lines in air, dashed lines in CA, dotted lines in air at 20 °C. Values are means of three orchards, 20 fruit (30 at harvest) per orchard (± s.e.m.).

The transfer of fruit from 10 to 1 °C reduced the rate of degreening, irrespective of the storage atmosphere. For fruit degreened in CA for 2 (T5, T6) or 4 (T7, T8) weeks, there was subsequently a period of 6 or 4 weeks in air or CA, for which there was little further degreening. Thereafter, there was a divergence between the treatments, with fruit in air (T5, T7) showing a greater decrease in flesh color than for fruit in CA (T6, T8). For fruit degreened in air for 2 weeks (T1, T2), transfer of the fruit to 1 °C slowed degreening markedly, and the very slow degreening rate at 1 °C was slightly slower in CA (T2) than in air (T1). However, after 4 weeks of degreening in air (T3, T4), transfer to 1 °C resulted in no further degreening, irrespective of whether in air (T3) or CA (T4). Transfer of fruit to 20 °C for 1 week after storage for shelf assessment resulted in a marked decrease in the measured fruit flesh color in fruit from all treatments.

After 16 weeks of degreening and storage, the impacts of temperature and atmosphere on the distribution of individual fruit flesh colors were as illustrated in Figure 2. The trends in individual fruit variability remained within the overall treatment effects described for Figure 1.

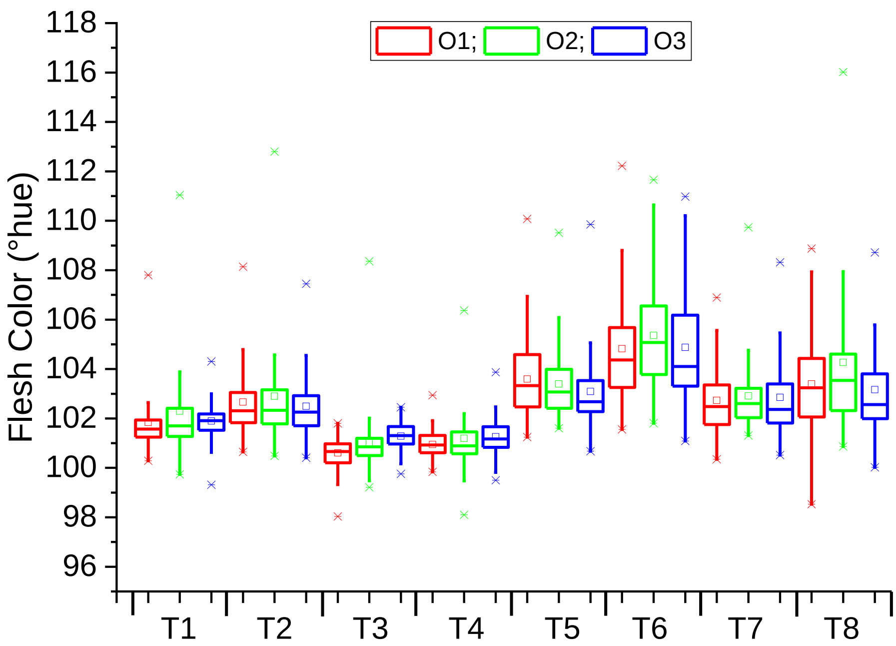

Figure 2. Boxplots of individual fruit flesh color of *Actinidia chinensis* var. *chinensis* 'Zesy002' kiwifruit from three orchards (O1–O3), 16 weeks after harvest. Fruit were held at 10 °C in air (T1–T4) or controlled atmosphere (CA; T5–T8) for 2 (T1, T2, T5, T6) or 4 (T3, T4, T7, T8) weeks, followed by storage at 1 °C in air (T1, T3, T5, T7) or CA (T2, T4, T6, T8). Both periods of CA were at 2% oxygen/2% carbon dioxide. Sample size 90 fruit.

Overall, the lowest mean flesh color values, and with the least variability, were seen in those fruit degreened in air for 4 weeks (T3, T4), irrespective of whether the fruit were subsequently stored in air (T3) or CA (T4). The highest mean flesh color values and greatest variability for fruit degreened in air were for fruit degreened only for 2 weeks and subsequently stored in CA (T2). In contrast, all samples of fruit degreened in CA, for 2 (T5, T6) or 4 (T7, T8) weeks, had higher mean flesh color values and also had greater variability in individual fruit flesh colors. The highest mean flesh color and greatest variability were in fruit degreened in CA for 2 weeks and then stored in CA (T6). The lowest mean and least variability were in fruit degreened in CA for 4 weeks and then stored in air (T7).

3.3. Softening

The fruit were, on average, 66.1 N at the start of the trial, and, irrespective of whether fruit were in air or CA, there was no softening after 2 weeks at 10 °C (Figure 3). At some point between 2 and 4 weeks at 10 °C, the fruit in air changed to rapid softening such that, after 4 weeks in air (T3, T4), fruit had softened to 32.4 N. In contrast, after 4 weeks in CA (T7, T8), fruit were still, on average, 64.8 N.

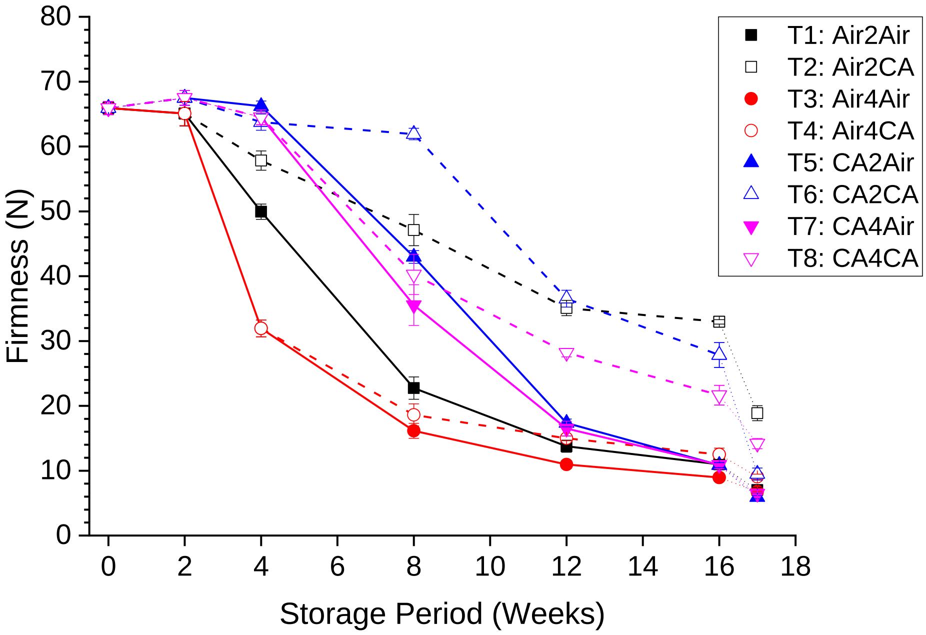

Figure 3. Firmness of *Actinidia chinensis* var. *chinensis* 'Zesy002' kiwifruit held at 10 °C in air (T1–T4) or controlled atmosphere (CA; T5–T8) for 2 (T1, T2, T5, T6) or 4 (T3, T4, T7, T8) weeks, followed by storage at 1 °C in air (T1, T3, T5, T7) or CA (T2, T4, T6, T8). Both periods of CA were at 2% oxygen/2% carbon dioxide. Fruit were moved to air at 20 °C after 16 weeks. Solid lines in air, dashed lines in CA, dotted lines in air at 20 °C. Values are means of three orchards, 20 fruit (30 at harvest) per orchard (± s.e.m.).

Whether fruit were held in air or CA for degreening at 10 °C affected the subsequent softening during storage at 1 °C. Holding fruit in CA at 10 °C resulted in delaying the time at which the fruit changed to rapid softening. Hence, for fruit from T5 (CA 2 Air), the change to rapid softening occurred after 4 weeks, whereas the fruit in T1 (Air 2 Air) started to soften rapidly between 2 and 4 weeks. The greatest delay in the change to rapid softening was in fruit from T6 (CA 2 CA), occurring at some time after 8 weeks. In the case of T6 fruit, this was a combination effect of CA at 10 °C for only 2 weeks before continuing in CA but at 1 °C. This contrasts with the effect of 4 weeks of CA at 10 °C (T8, CA 4 CA), for which the change to rapid softening occurred after 4 weeks. The time under CA at 10 °C retarded the changes in the fruit required for the fruit to progress into the rapid phase of softening; as a consequence, fruit moved to air at 1 °C after 2 weeks in CA at 10 °C (T5) still had a further 2 weeks before changing to rapid softening.

In addition to the changes that the treatments caused around the initial softening period, subsequent storage in CA, irrespective of whether the fruit were held in air or CA for 2 or 4 weeks, tended to result in firmer fruit at the end of storage. After 16 weeks, fruit stored in air were in a narrow firmness range of 8.8–10.8 N, whereas those stored in CA were in the range 12.8–33.4 N. Of these CA-stored fruit, all treatments were above 20 N, except T4 (Air 4 CA), which was 12.8 N, largely because of the softening that occurred during 4 weeks in air at 10 °C.

3.4. Chilling Injury

After 16 weeks, the incidence of CI in fruit from all treatments was low (≤0.6%; Table 3). There was a general increase in the expression of CI after 1 week at 20 °C, with incidences up to 8.3%. This increase in CI may in part have been due to the change in assessment methodology, from external observation to cutting the fruit with a check for internal symptoms. The statistical significance among treatments was largely driven by the high incidence of CI in fruit held under CA at 10 °C for 2 weeks (T5, T6).

Table 3. Incidence of chilling injury in *Actinidia chinensis* var. *chinensis* 'Zesy002' kiwifruit held at 10 °C in air (T1–T4) or controlled atmosphere (CA; T5–T8) for 2 (T1, T2, T5, T6) or 4 (T3, T4, T7, T8) weeks, followed by storage at 1 °C in air (T1, T3, T5, T7) or CA (T2, T4, T6, T8). Fruit were assessed after 16 weeks (Wk16) and a further week in air at 20 °C (Wk17). Both periods of CA were at 2% oxygen/2% carbon dioxide. Values are the mean of three orchards, eight packs each of 52–58 fruit per orchard.

Treatment: Code	Chilling Injury Incidence (%)	
	Wk16	Wk17
T1: Air2Air	0.0	1.5
T2: Air2CA	0.0	1.0
T3: Air4Air	0.5	0.9
T4: Air4CA	0.5	0.9
T5: CA2Air	0.6	8.3
T6: CA2CA	0.0	8.3
T7: CA4Air	0.0	0.1
T8: CA4CA	0.0	0.1
Statistical analysis: Wald *p* values	1.000	<0.001

After 1 week at 20 °C, there was a significant difference in the incidence of CI among the three orchards, with the incidence in fruit from O2 > O1 > O3. The observed trends in average incidence across orchards (Table 3) were consistent for the individual orchards (Table 4), with the treatment effects being most obvious in fruit from the most susceptible orchard (O2; Table 4).

Table 4. Incidence of chilling injury in *Actinidia chinensis* var. *chinensis* 'Zesy002' kiwifruit from 3 orchards (O1, O2 and O3) held at 10 °C in air (T1–T4) or controlled atmosphere (CA; T5–T8) for 2 (T1, T2, T5, T6) or 4 (T3, T4, T7, T8) weeks, followed by storage at 1 °C in air (T1, T3, T5, T7) or CA (T2, T4, T6, T8). Fruit were assessed after 16 weeks (Wk16) and a further week in air at 20 °C (Wk17). Both periods of CA were at 2% oxygen/2% carbon dioxide. Values are the mean of eight packs each of 52–58 fruit.

Treatment: Code	Chilling Injury Incidence (%)					
	Orchard 1		Orchard 2		Orchard 3	
	Wk 16	Wk 17	Wk 16	Wk 17	Wk 16	Wk 17
T1: Air2Air	0.0	0.5	0.0	3.4	0.0	0.6
T2: Air2CA	0.0	1.2	0.0	1.9	0.0	0.0
T3: Air4Air	1.0	1.0	0.5	1.7	0.0	0.0
T4: Air4CA	0.0	0.7	1.4	1.9	0.0	0.0
T5: CA2Air	0.0	8.7	1.7	15.1	0.0	1.1
T6: CA2CA	0.0	9.1	0.0	14.7	0.0	1.1
T7: CA4Air	0.0	0.0	0.0	0.2	0.0	0.0
T8: CA4CA	0.0	0.0	0.0	0.2	0.0	0.0
Wald *p* values	1.000	<0.001	0.095	<0.001		0.003

3.5. Rots

The total rot incidence at the end of storage was low, at ≤0.6% (Table 5), with no differences among treatments. The incidence of rots increased up to 7.5% during one week at 20 °C. There were treatment differences after 1 week at 20 °C, with the rot incidences in fruit from T5 (7.5%) and T7 (6.3%) being significantly higher than in the other treatments (1.0–2.3%). The majority of the rots were stem-end rots (up to 7.4% incidence, Table 5), with relatively few body rots (up to 1.3% incidence, Table 5).

Table 5. Incidence of total rots, stem end rots (SER), and body rots (BR) in *Actinidia chinensis* var. *chinensis* 'Zesy002' kiwifruit held at 10 °C in air (T1–T4) or controlled atmosphere (CA; T5–T8) for 2 (T1, T2, T5, T6) or 4 (T3, T4, T7, T8) weeks, followed by storage at 1 °C in air (T1, T3, T5, T7) or CA (T2, T4, T6, T8). Fruit were assessed after 16 weeks (Wk16) and a further week in air at 20 °C (Wk17). Both periods of CA were at 2% oxygen/2% carbon dioxide. Values are the mean of three orchards, eight packs each of 52–58 fruit per orchard.

Treatment: Code	Rot Incidence (%)					
	Total Rots		SER		BR	
	Wk16	Wk17	Wk16	Wk17	Wk16	Wk17
T1: Air2Air	0.5	1.6	0.2	1.0	0.3	0.5
T2: Air2CA	0.3	1.0	0.0	0.2	0.3	0.7
T3: Air4Air	0.2	1.5	0.2	1.5	0.0	0.0
T4: Air4CA	0.5	1.7	0.4	0.9	0.2	0.8
T5: CA2Air	0.3	7.5	0.2	7.4	0.1	0.2
T6: CA2CA	0.4	2.3	0.3	1.5	0.1	0.8
T7: CA4Air	0.6	6.3	0.5	5.2	0.1	1.1
T8: CA4CA	0.4	1.7	0.2	0.5	0.1	1.3
Wald *p* values	0.673	<0.001	0.760	<0.001	0.709	0.099

4. Discussion

Early-harvested 'Zesy002' fruit did degreen at 10 °C in CA, but at a slower rate than in air. As a consequence, the fruit in CA did not fully degreen within the 4-week period at 10 °C, whereas the fruit in air had fully degreened to an average close to 100 °h. CA maintained fruit firmness at 10 °C, such that either 2 or 4 weeks in CA resulted in little or no firmness loss by 4 weeks after harvest. The improved firmness retention in CA-held fruit after degreening was maintained through storage at 1 °C. Degreening at 10 °C largely eliminated CI following 2 or 4 weeks in air, or 4 weeks in CA. The presence of CI in fruit degreened for 2 weeks in CA was the combined result of CA and the shift in fruit temperature to 1 °C after only 2 weeks. Overall, it appears that the CI incidence was determined more by the initial holding period at 10 °C rather than the subsequent storage in air or CA.

The slowing of degreening in 'Zesy002' kiwifruit by CA is in agreement with observations on 'Hayward' fruit [23]. However, there is an element of interest in that degreening in 'Hayward' occurs very slowly over a long period, even at low temperatures, whereas 'Zesy002' fruit degreen fully and the rate of degreening is temperature-sensitive [6]. Whether it is simply a general suppression of metabolism by CA that limits chlorophyll loss, or specific roles for low O_2 and high CO_2, remains to be determined, along with the possibility of optimizing degreening relative to softening.

The flesh color data during storage suggest that a significant degree of degreening can occur at 1 °C or on transfer to 20 °C after storage. However, this was unexpected given previous observations on the temperature sensitivity of 'Zesy002' and other kiwifruit [6]. With the shift in color being associated with softening, it may be that, in this instance, the perception of the flesh color measured by the Minolta CR-400 Chroma Meter had been affected by the firmness of the fruit.

A consequence of the slowed degreening under CA is that either the fruit must be left longer in CA at the elevated temperature, or that more mature (advanced flesh color) fruit will have to be used. The usefulness of these two approaches depends largely on the physiological state of the fruit at harvest, and this state is dependent on the growing region. The difference in the physiology of fruit from different growing regions relates to the relative progress of flesh color change and softening, particularly the time at which the two processes change from a slow to a rapid rate of change. These two processes have been shown in 'Hort16A' not to be tightly linked [22], and this appears also to be true for 'Zesy002'.

In the New Zealand growing environment, harvesting fruit for off-vine degreening invariably means that the fruit are relatively immature [24]. As a consequence, the fruit have a period of 1–2 weeks of slow (Phase 1) softening after harvest, even when held at 10 °C. This retention of firmness early in storage has been suggested to be indicative of the chilling sensitivity of these fruit [25]. The association between the softening pattern and chilling risk has also been shown previously for 'Hort16A' [22] and 'Hayward' fruit [21]. Degreening off the vine is only successful when the fruit is degreened before becoming too soft. This is why 7–10 °C is used for degreening rather than 5 °C, with the degreening process being significantly slower at 5 °C, and with degreening at 7–10 °C being completed largely before the change to rapid softening [18]. This outcome is often discussed as temperature affecting the two processes differently, i.e., a larger effect on degreening than softening. However, this interpretation is inaccurate as the difference between the two processes relates to the pattern of change and the relative positions within those patterns. Whilst both degreening and softening have an overall sigmoidal pattern (three phases), at harvest, the degreening is (or should be) already in the rapid Phase 2, whereas softening is still in the slow Phase 1. This difference in the sigmoidal patterns is why the extension of the slow Phase 1 of softening by CA is of interest in degreening, by delaying the time before the change to rapid softening whilst degreening is continuing in the rapid Phase 2. It also explains why the amount of degreening required for full color change is so significant to the overall success of degreening. The more degreening required after harvest, the longer it takes to achieve the desired degreened color, and the greater the risk of fruit becoming soft or rotting. The extent of color change required at harvest may differ between orchards depending on the fruit to fruit variability in color—from the bulk of the fruit requiring degreening, to only odd outlier fruit, which are markedly greener than the majority.

It has long been recognized that temperature management after harvest can affect the expression of chilling damage in kiwifruit, with fast cooling being worse than slow cooling [20]. More recently, the degreening of fruit off the vine at temperatures of 7–10 °C has been shown to act as a period of conditioning to reduce the expression of CI, with better conditioning at 7–10 °C than at 5 °C [18]. The effect of conditioning the fruit can be seen in the relatively low CI incidence in the early-harvested fruit used in the current research. Among the eight treatments, the highest incidences of CI were found in the fruit held in CA for 2 weeks and then transferred to 1 °C, in air or CA. The contrast in the effectiveness of the conditioning in air and CA for 2 weeks suggests that CA had slowed the changes associated with conditioning, but that a further 2 weeks in CA effectively reduced subsequent chilling damage. The nature of the change in fruit affected by CA that influences the chilling sensitivity remains to be determined. An obvious factor may be the retarding effect on softening under CA, possibly associated with the relationship between firmness retention early in storage and chilling susceptibility [25]. However, the data suggest that this may not be the whole story, given the similar firmness values of fruit after both 2 and 4 weeks in CA, yet a marked difference in chilling injury. However, the chilling response may be associated with the induction of softening that occurs at temperatures in the 7–10 °C range [9], rather than the actual firmness of the fruit when stored.

In summary, in degreening 'Zesy002' fruit off the vine, it is necessary to consider the change in flesh color, softening, and the risk of CI. Overall, CA slowed degreening, softening, and the loss of chill sensitivity. If 'Zesy002' fruit are to be degreened in CA, then either a longer period, or more advanced fruit, should be used. For fruit destined for immediate sale/short storage, degreening in air and then storage in air appears to provide sufficient life. Alternatively, for longer-term storage, either degreening in air or a more prolonged degreening in CA, followed by storage in CA, may provide the best option.

5. Conclusions

It is concluded that holding fruit at 10 °C in 2% O_2/2% CO_2 CA rather than air:

- Slowed degreening;
- Slowed the transition from Phase 1 (slow) to Phase 2 (fast) softening;

- Slowed the loss of chilling sensitivity.

Thus, for the commercial application of degreening in CA, either a longer period of degreening, or the use of more advanced fruit with less chlorophyll, is required.

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