Kiwifruit Softening: Comprehensive Research Approach in Chile and Relevant Results

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Abstract

Early softening is the main problem for the exports of Chilean kiwifruit. It has been related to orchard, harvest and postharvest factors. Therefore, a 4-year project is being carried out to study the problem comprehensively, to determine the main factors involved and the possibilities of predicting and controlling it. Experiments were carried out to determine the influence of growing conditions and the most important fruit characteristics on the softening rate of kiwifruit cultivated in different areas throughout Chile. Different postharvest handling techniques were evaluated to identify critical points along the entire production and postharvest chain. Fruit from all orchards were harvested at 6.2–6.5% soluble solids content (excepting fruit for maturity effects), and kept under the same storage condition (0°C, air). Samples were taken every fifteen days to determine softening propensity by measuring the number of days elapsing until fruit reached 18N firmness. Results so far indicate that softening behaviour of kiwifruit can be affected by light exposure, plant vigour and nutrition, fruit characteristics and position on the plant. Canopy management, water availability and Ca applications were also studied. Maintaining fruit firmness is assisted by vine management that ensures moderate vigour, adequate exposure of the plant and fruit to light, reduction of competition between fruit and vegetative growth and Ca applications to the fruit. Larger fruit size, time of harvest and position on the vine are also important characteristics. In addition, postharvest handling has been critically analysed and some limitations have been identified as a source of difficulties for Chilean kiwifruit that can be overcome through specific measures such as temperature management, controlled atmosphere and decay control, as well as control of ethylene. Using the results obtained a mathematical model to forecast early kiwifruit softening is being developed.

INTRODUCTION

Fruit softening during storage and transport is one of the main and, as yet, unresolved problems of fruit growing and handling (Johnston et al., 2001), resulting in shortening of the marketing period and causing consequent reductions in quality and price for exports to distant markets. This problem has seriously affected the Chilean kiwifruit industry so that a decision has been taken to study and develop technology to overcome these limitations.

The susceptibility of fruit to softening, which is determined by environmental conditions and cultural orchard management, is expressed according to harvest and postharvest management. A number of factors have been identified as the main ones affecting propensity of kiwifruit to soften, viz., foliar N, fruit Ca content, illumination, harvest maturity, among others (Antognozzi et al., 1995; Retamales and Campos, 1997), though they are not always influencing it in the same way or to the same extent. Therefore, a 4-year project is being carried out with the hypothesis that almost every production factor influences this process, and that softening depends much more on the equilibrium built up upon its integration, rather than on the individual effects of some of them. The main objectives of the project are to understand the process of premature softening, determining the main factors involved, especially in Chile, and to elaborate the technology (pre and postharvest) to prevent, minimize and forecast the problem. The project includes all relevant factors that promote fruit susceptibility to softening and that are responsible for the variability between and within orchards.

MATERIALS AND METHODS

The project has been carried out for 4 years and includes 4 areas: orchard management, harvest and postharvest handling, development of the prediction model and technology transfer. In the orchard, case studies and trials were carried out to determine the influence of growing conditions and the main characteristics of orchards, vines and fruit on the susceptibility to softening. A comprehensive analysis was also carried out to determine the critical points in Chilean orchard management. Fruit were harvested at 6.2–6.5% soluble solids (except for maturity trials), cured at room temperature for 48 hours (except in curing trials) and stored in air at 0°C and 90% RH (except in storage trials). A fruit sample was obtained from cold storage every 15 days and soluble solids and firmness were measured until reaching a firmness equivalent to 18N (commercial threshold). The softening process was expressed as softening index (SI, daily reduction in firmness during storage) and, preferably, as time in days from harvest for the fruit to reach 18N in cold storage (T-18N).

Different harvest and postharvest handling techniques were evaluated with the purpose of identifying critical points along the entire production and postharvest chain. Experimentally, the effects of harvest fruit maturity, curing procedures (time, temperature), AVG (aminoethoxyvinylglycine) and 1-MCP (1-methylcyclopropene) applications, and modified atmosphere, were determined. The development of the prediction model for fruit softening included the study and selection of relevant variables, cluster analysis, principal components analysis, stepwise regression, and logistic regression.

RESULTS AND DISCUSSION

Some of the main results of the project, including the first two seasons and part of the third are as follows.

Nutritional Aspects

No clear influence of foliar N content on fruit softening susceptibility could be determined (Fig. 1). Thus, in the first year the correlation between these parameters was not significant (R = 0.14, P = 0.53). When fruit were grouped according to the foliar N content as percentage of dry matter (high $\geq$ 2.4%; middle < 2.4 - $\geq$ 2.0; low < 2.0 %) there was considerable variation within the groups. Within each grouping the fruit from some orchards stored well for a long time whereas fruit from other orchards stored only for a short time: there were no important differences in storage time when the mean values for each group were used, with fruit from the middle nitrogen content group storing best. However, in the second season (2004/2005) a significant correlation (R = -0.46, P = 0.006) was determined, the fruit produced by plants with higher N levels storing for shorter periods. Furthermore, in a specific trial comparing fruit from plants without N fertilization with those from plants fertilised with the equivalent of 500 kg $N \cdot ha^{-1}$, the latter showed more rapid softening (Table 1).

Regarding calcium (data not shown), no relationship existed between fruit Ca content from different orchards with their softening susceptibility (R -0.15, P = 0.51 for the first year; and R = 0.18, P = 0.36 for the second year). Pre- and postharvest calcium applications, in some instances, increased fruit Ca content and delayed softening, such effects apparently depending on Ca-spray concentration and number of applications. (See: Effects of calcium content and calcium applications on softening of ‘Hayward’ kiwifruit. Cooper et al., Acta Hort. 753:297–304).

Shading and Vigour

A positive effect of light was determined, both in terms of general plant illumination and direct exposure of the fruit. Snelgar and Hopkirk (1988) found that stored fruit from vines grown under shade were slightly but consistently less firm than unshaded fruit. In our case, the fruit from exposed plants remained significantly longer (25%) in cold storage before reaching 18N than did the fruit from shaded vines (Fig. 2). Furthermore, within the vine, fruit directly exposed to the sun stored for longer. The final soluble solids (SS) content was not affected (Table 2).

Plants with higher vegetative vigour (larger leaves, thicker canes and higher number of water sprouts) produced fruit with reduced storage life (Fig. 3). Canopy management aimed at reducing vigour and shading within the plant and promoting greater exposure of the fruit to light seemed to be required in orchards with training problems or higher vigour resulting in excess shading. The reduction in vigour is also important per se in these cases, by reducing competition between fruit and vigorous shoots, hence improving the fruit nutritional balance.

Fruit Characteristics

Fruit position within the plant (Thorp et al., 2003), its size and maturity are important aspects as far as softening susceptibility is concerned, though a simple relationship between fruit position and firmness is not always present (Pyke et al., 1996). Referring to fruit position, those carried on basal shoots stored longer and had higher calcium contents and lower ratios of N+K/Ca (Table 3), though no statistical analysis was performed owing to composite samples being used use for mineral analysis. This is in agreement with Thorp et al. (2003), who found that fruit near the trunk or central leader had higher Ca concentrations than fruit at more distal positions. Distal fruit showed the opposite effect, with an 18% shorter storage period than the basal ones (Table 3).

Fruit size had a clear positive effect on duration in cold storage. In both orchards the biggest fruit were statistically different, increasing time to reach 18N by 35% at $0^{o}C$, having about 80% more seeds and, in a composite sample, around 10% more Ca than smaller fruit (Table 4).

The maturity stage at harvest was one of the most important factors in determining softening susceptibility. In all cases, less-mature fruit stored longer in storage, whilst the fruit harvested more mature (more than 9% SS) softened most quickly. There was not a single case in which the earliest-harvested fruit (5.5% SS) were more susceptible to softening (Table 5). Our results therefore differ from those obtained in other countries (Ravaglia et al., 1995; Ferrandino and Guidoni, 1999), but are consistent with the results of Retamales and Campos (1997) for Chile.

AVG Application

Application of AVG (500 ppm), an inhibitor of ethylene biosynthesis, either at 4 or 2 weeks before harvest, delayed fruit softening in cold storage. The difference between AVG-treated fruit and the control treatment increased during cold storage, with the biggest effects seen at the end of storage time (128 days) (Fig. 4). Time of AVG application had no effect.

CONCLUSIONS

Problems of early kiwifruit softening in cold storage are due to a lack of knowledge on how given factors in the orchard (determining susceptibility) and postharvest (determining expression) are influencing its occurrence. Furthermore, existing knowledge and available technology are not being applied in Chile.

No single factor alone is determining susceptibility to kiwifruit softening, but rather the integration of plant growth conditions and fruit characteristics and position.

The main orchard factors tending to reduce softening are moderate vigour and N content, high light exposure, larger fruit size, basal fruit position, and earlier harvest maturity. AVG applications showed also some promise and are worth investigating further.

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Tables

Table 1. Effect of N applications on kiwifruit harvest maturity and ripening.

Treatment kg N/ha/year	Harvest			Storage	
	ISS (°Brix) [1/]	DM (%) [2/]	Firmness (N)	FSS (°Brix) [3/]	T-18N (days) [4/]
50	6.6 a	16.9 a	78.4 a	13.3 a	91.2 a [5/]
500	6.3 a	16.2 a	76.2 a	13.0 a	71.6 b

[1/] ISS: initial soluble solids; [2/] DM: Dry matter; [3/] FSS: final soluble solids;
[4/] T-18N: time in days to reach 18N; [5/] Significant differences at 0.05%.

Table 2. Effect of kiwifruit exposure to light on softening during cold storage.

Treatment	Harvest			Storage	
	ISS (°Brix) [1/]	DM (%)[2/]	Firmness (N)	FSS (°Brix)[3/]	T-18N (days)[4/]
Exposed fruits	6.2 a	19.1 a	80.6 a	13.4 a	103 a [5/]
Shaded fruits	6.0 a	18.4 a	74.8 a	12.8 a	92 b

[1/] ISS: initial soluble solids; [2/] DM: Dry matter; [3/] FSS: final soluble solids;
[4/] T-18N: time in days to reach 18N; [5/] Significant differences at 0.05%.

Table 3. Effect of fruit position within kiwifruit vines on fruit mineral content and softening in cold storage.

Variables	Basal Fruits	Middle Fruits	Distal Fruits
T-18N (days*)	81.7 a [1/]	72.8 ab	67.4 b
Ca (% DM)	0.21	0.19	0.17
K (% DM)	1.51	1.58	1.6
N (% DM)	0.92	1.10	1.12
N/ Ca	4.3	5.7	6.5
N+K/ Ca	11.4	13.5	16.1

[1/] Significant differences at 0.05%.
* time in days for the fruit to reach 18N in cold storage

Table 4. Effect of kiwifruit size on rates of fruit softening during cold storage.

Orchard	Treatments	Fruit weight (g)	Fruit Ca (% DM)[1/]	Seed/ fruit	Harvest firmness (N)	Postharvest T-18N [2/] (days)
Quinta de Tilcoco VI Región	small fruits	80 b [3/]	0.13	692 b	62.4 b	49 b
	larger fruits	125 a	0.15	1059 a	64.1 b	73 a
Naicura VI Región	small fruits	90 b	0.16	678 b	64.1 b	46 b
	larger fruits	130 a	0.18	1103 a	74.4 a	71 a

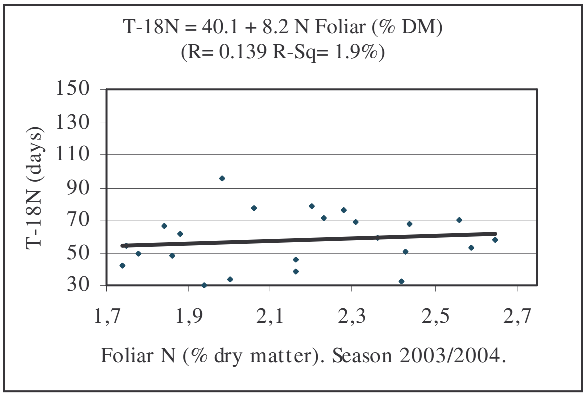
[1/] DM: Dry matter; [2/] T-18N: Time in days to reach 18N; [3/] Significant differences at 0.05%.

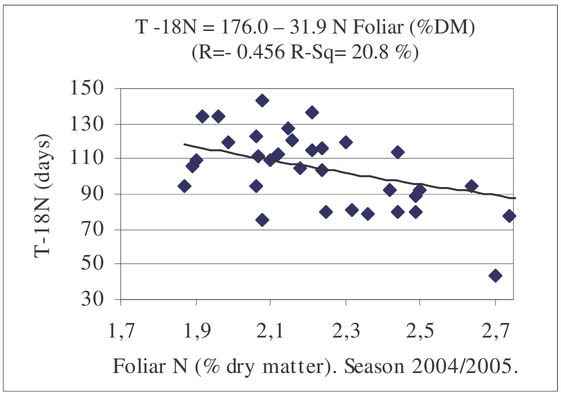
Table 5. Effect of kiwifruit harvest maturity on fruit softening during cold storage.

Orchard	T-18N [1/] (days)			
	T1 Early Harvest (5.5° Brix)	T2 Medium Harvest (6.2-6.5° Brix)	T3 M-L Harvest (> 7.5° Brix)	T4 Late Harvest (> 9° Brix)
Cardonal 1	74 a [2/]	68 a	40 b	23 b
Vergara	81 a	65 a	44 b	24 c
Frutal	76 a	68 a	49 b	33 c
El Alamo	102 a	96 a	66 b	38 b
Macarena	66 a	55 a	21 b	6 c
Alegría Puertas	82 a	61 b	51 c	31 d

[1/] T-18N: Time in days to reach 18N; [2/] Significant differences at 0.05%.

Figures

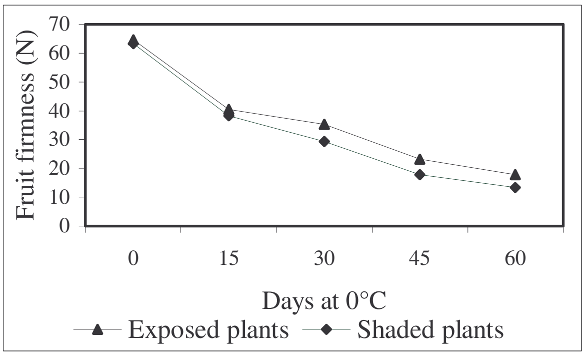




Fruit Nitrogen Groups	T-18N [1/] (days) + S.D. Season 2003/2004	T-18N (days) + S.D. Season 2004/2005
Group 1 (≥ 2.4 % DM) [2/]	55 ± 13.8 a	88 ± 18.4 b [3/]
Group 2 (< 2.4 – ≥ 2.0 % DM)	61 ± 17.2 a	109 ± 19.8 a
Group 3 (< 2.0 % DM)	56 ± 19.7 a	116 ± 15.8 a

[1/] T-18N: Time in days to reach 18N. [2/] DM: Dry matter
[3/] Significant differences at 0.05%.

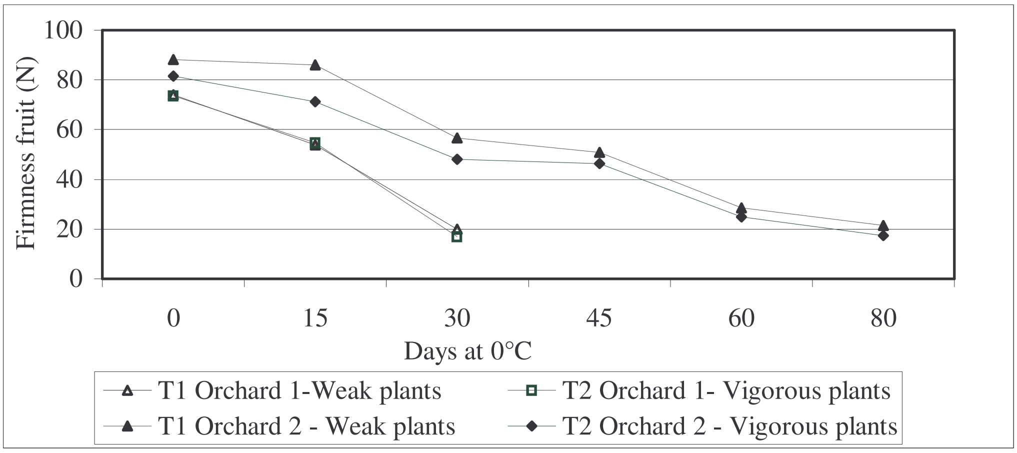
Fig 1. Relationship between foliar N concentrations and kiwifruit softening during cold storage.



Treatments	T-18N [1/] (days)
Exposed plants	63 b[2/]
Shaded plants	49 a

[1/] T-18N: Time in days to reach 18N
[2/] Significant differences at 0.05%.

Fig. 2. Effects of vine shading on kiwifruit softening during cold storage.



Treatment	Orchard 1		Orchard 2	
	T1	T2	T1	T2
T-18N[1/] (days)	40 a	35 b[2/]	86 a	82 b

[1/] T-18N: Time in days to reach 18N;
[2/] Significant differences at 0.05%.

Fig. 3. Relationship between vine vigour and kiwifruit softening during cold storage.

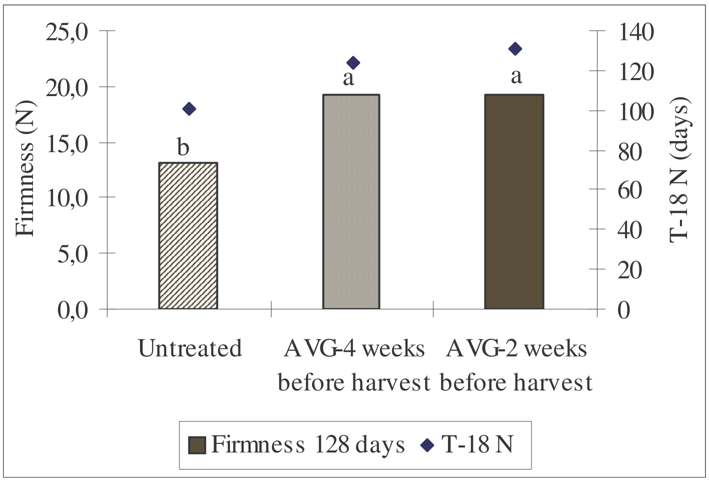


Fig. 4. Effects of AVG application on kiwifruit softening during cold storage.