Understanding the key preharvest factors determining 'Packham's Triumph' pear heterogeneity and impact in superficial scald development and control

Carolina A. Torres[1]*, Gloria Sepulveda[1], Nilo Mejía[2], Bruno G. Defilippi[2], Christian Larrigaudière[3]

[1]Department of Horticulture, Tree Fruit Research & Extension Center, Washington State University, Wenatchee, WA 98801, USA.

[2]Instituto de Investigaciones Agropecuarias (INIA -Chile), La Platina Research Centre, Av. Santa Rosa 11, 610, P.O. Box 439-3, Santiago, Chile

[3]XaRTA-Postharvest, Institute for Food and Agricultural Research and Technology (IRTA), Edifici Fruitcentre, Parc Científic i Tecnològic Agroalimentari de Lleida, 25003, Lleida, Spain

* To whom correspondence should be addressed. E-mail: ctorres@wsu.edu, Phone: +1 509 662 8808.

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E-mails:

Carolina Torres: ctorres@wsu.edu

Gloria Sepulveda: gloriasepulveda20@gmail.com

Nilo Mejía: nmejia@inia.cl

Bruno Defilippi: bdefilip@inia.cl

Christian Larrigaudière: christian.larrigaudiere@irta.cat

Abstract

Although superficial scald (SS) is well characterized on apples, there is still few information regarding the influence that initial fruit heterogeneity may have on the development of this disorder on pears. Pears (*Pyrus communis* L.) cv 'Packham's Triumph' were picked during three consecutive seasons at three harvest maturities (H1, H2, H3) from different commercial orchards. Different SS control treatments (DPA vs. 1-MCP; season # 2) and storage scenarios (RA, CA and RA + stepwise cooling; season # 3) were evaluated. Superficial scald incidence, maturity indices and biochemical analysis associated with SS were carried out at harvest and periodically postharvest in all treatments. In general, bioclimatic indexes (GDA and HL10) were poorly correlated with SS incidence. Only in season #1, harvest maturity was positively correlated with SS after 140 and 180 d into storage (r_s= 0.621* and 0.620*, respectively), the more mature fruit being more sensitive. The opposite was observed in season #3, and no pattern in season #2. There was a good and positive correlation between CTols dynamic (δCTols/δt) and SS development, with variation between seasons. DPA and 1-MCP effectively reduced SS up to 180 d regardless of years and orchard location. In contrast, the beneficial effect of CA storage was orchard dependent and SWC strategy did not control SS and affected fruit quality. Collectively our results suggest that initial fruit heterogeneity at harvest is an important factor that modulate SS development in 'Packham triumph pears. Climatic and fruit maturity indexes are not reliable for a multi-year prediction of SS development. In contrast to CA storage that reduced the disorder in an orchard dependent manner, 1-MCP and DPA treatments effectively controlled SS independently of initial fruit heterogeneity.

Keywords: Physiological disorder; pome fruit; storage; fruit quality; fruit biochemistry, chilling injury

1. Introduction

Chilean pear (*Pyrus communis* L.) production is around 213,260 tons/year from which 68%, in average, is sold in fresh markes around the world (ODEPA-Ciren, 2016a, 2016b, 2015). To reach those markets most fruit must be cold stored for up to 7-8 months before shipment. However, during storage several physiological disorders causing peel and flesh discolorations may develope as a result of chilling injury thus affecting fruit quality and marketability. Superficial scald (SS) is considered the most important peel disorder in winter pears (Chen et al., 1990; Whitaker et al., 2009). Symptoms are characterized by brown necrotic patches affecting skin hypodermal cell layers, beginning in the neck of the fruit and later spread non-uniformly to the surface. It generally appears in shelf-life once the fruit has been removed from cold storage (Lurie & Watkins, 2012; Whitaker et al., 2009).

As in apples, SS in pears is associated with (*E,E*)-α-farnesene oxidation, a volatile sesquiterpene present in the cuticle wax, resulting in accumulation of conjugated trienols (CTols) which occurs with fruit maturation once in cold storage (Anet, 1972; Huelin & Coggiola, 1970; Whitaker, 2007). Nevertheless, CTols accumulation does not always correlate well with SS development (Calvo et al., 2015; Whitaker et al., 2000). Another end product of the α-farnesene oxidation is 6-methyl-5-hepten-2-one (MHO); this ketone has been positively correlated with SS in pears (Hui et al., 2016). An important role has been given to the cell antioxidant system for SS suppression (Busatto et al., 2018; Rudell & Mattheis, 2009; Zhao et al., 2016), especially in pears (Larrigaudière et al., 2016). Synthetic antioxidants such as DPA and ethoxyquin applied right after harvest, effectively reduce SS development on both apples and pears (Lurie & Watkins, 2012).

Ethylene is also a key player in SS development by triggering α-farnesene synthesis (Gapper et al., 2006; Tsantili et al., 2007). Therefore, 1-methylcyclopropene (1-MCP), an ethylene perception inhibitor, prevents SS development by not only downregulating the expression of *α-farnesene* *synthase 1* gene (AFS1), but also enhancing other cold acclimation-related mechanisms (Busatto et al., 2018). In winter pears such as 'Packham's Triumph' and 'd'Anjou', which require 30-70 d at low temperatures (-0.5 and -1 °C) after harvest to reach eating quality (Villalobos-Acuña and Mitcham, 2008), 1-MCP applications may halt fruit ripening and softening (Candan and Calvo, 2011).

Among predisposing factors, genotype, preharvest climatic conditions and length of cold storage play a critical role (Ingle, 2001; Lurie & Watkins, 2012). Fruit maturity at harvest is also considered important. Conversely from apples, in which late harvested fruit exhibit less SS in long-term storage (Lurie & Watkins, 2012), European pears seem to have the opposite behavior. Despite this assumption, some contradictory results have been reported in different or even the same pear cultivars. In 'd'Anjou' and in 'Packham's Triumph' pears Calvo et al (2015 and 2017, respectively) found higher SS in late harvested fruit, while Zoffoli et al. (1998) found higher SS in early harvested 'Packham's Triumph'. Growing conditions have also been shown to modulate cultivar susceptibility on apples (Whitaker et al., 2009).

Warming treatments during cold storage have effectively shown to reduced SS on apples with varying degrees upon cultivar and growing region (Watkins et al., 2000), but there is scarse information on pears. Other storage regimes such as controlled atmosphere (and ultra-low oxygen,ULO, in some instances) can reduce this disorder but not completely prevent it from occurring (Larrigaudière et al., 2019; Truter et al., 1994), especially when fruit is removed from these storage regimes and then kept at low temperature for 2-3 months more prior reaching final consumers (Torres & Hernández, 2015).

'Packham's Triumph' pears in Chile develop SS much later into the storage season compared to 'Granny Smith' apples, and randomly between seasons and orchards, which makes the cold chain hard to manage. Therefore, in this study we aimed to understand the effect of growing season and site, harvest maturity, and their interaction with postharvest treatments on superficial scald development.

2. Material and methods

2.1 Plant material, fruit sampling and storage conditions

Pears (*Pyrus communis* L.) cv 'Packham's Triumph' were harvested from seven commercial orchards located in the main Chilean pear-growing region, characterized by a mediterranean climate. The study was conducted during three consecutive seasons: 2015/16 (#1), 2016/17 (#2), and 2017/18 (#3). The first one included four orchards, named "Genova" (33°64'38"S, 70°75'99"W), "El Carmen" (34°60'51"S, 70°97'84"W), "Lo Carrizo" (34°45'3"S, 71°7'1"W), and "Pirhuin 3" (35°2'27"S, 71°15'7"W). The second and the third season included three orchards, "Pirhuin 3", "Pirhuin 11" (35° 2'46"S, 71°14'43"W), "Agrofruta" (35°35'12"S, 71°28'56"W), and "Talcarehue" (34°38'16"S, 70°53'11"W). All orchards were managed conventionally with standard commercial practices.

Fruit was picked at three (Seasons #1 and #2) and two (Season #3) harvest maturity from each orchard, determined by maturity indices (flesh firmness, skin color, starch index) and days after full bloom (DAFB). They are referred as H1 (early-harvest, 120-132 DAFB, one week before commercial), H2 (commercial harvest, 127-138 DAFB) and H3 (late-harvest, 132-145 DAFB, one week after commercial harvest).

A total of 500 pieces of fruit per orchard and harvest maturity were stored in regular atmosphere (RA; -0.5 °C, >90 %RH) for up to 180 d, otherwise mentioned. Fruit maturity was determined at harvest and during cold storage after 1 and 14 d at 20 °C (shelf-life). Biochemical analyses on peel tissue were performed at harvest and after 30 and 60 d into cold storage.

2.2 Postharvest treatments during seasons #2 and #3

During season #2 fruit was picked from each orchard and harvest maturity, and treated with 1-MCP (SmartFresh®, AgroFresh, Spring House, USA; 0.3 µL L^{-1}) and DPA (DPA Shield, Pace International LLC, Wapato, USA; 1,200 µL L^{-1}) within 5 d of harvest. Treated (1-MCP and DPA) and non-treated (Control) fruit were stored in RA (-0.5°C, >90 %RH) for 180 d.

In season #3, three postharvest storage conditions were evaluated in fruit from three orchards and two harvest maturity. These storage conditions were regular atmosphere (RA at -0.5 °C and >90 %RH), controlled atmosphere (CA; O_2: 2.0 kPa, CO_2: 1.0 kPa, -0.5 °C, >90 %RH) and stepwise cooling (SWC, 1 week at 5 °C, 1 week at 3 °C, 1 week at 2 °C and 1 week at -0.5 °C, >90 %RH). Five replicates of 100 fruit each per sampling date were used to evaluate fruit maturity and SS incidence.

2.3. Bioclimatic indexes

Growing degree-days accumulated (GDA; 10 °C base; Stanley, 2000) from full bloom to harvest, and Chill Units (hours < 10 °C, HL10) 45 d prior harvest (Merrit *et al.,* 1968; Thomai *et al*., 1998) were calculated using air temperature obtained from weather stations located in each commercial site.

2.4 Maturity Indices

Maturity indices evaluated were: Peel color (Hue°), internal ethylene concentration (IEC), flesh firmness (N), starch index (SI, scale 1-6). Hue angle (H°=arcotan b*/a*; McGuire, 1992) was measured using a colorimeter (Minolta CR200b, Tokyo).

Internal ethylene concentration (IEC) was performed according to Torres et al. (2013). Briefly, one ml of gas was obtained from the core of the fruit and then injected into a gas chromatograph system (Series II HP 589 Hewlett Packard, CA, USA). Ethylene concentrations were calculated using a standard curve (1, 10, and 100 ppm of ethylene). Flesh firmness was obtained by inserting an 8 mm plunger into opposites sides of each fruit using a Texture Analyzer (GS14, GÜSS Manufacturing, Strand, South Africa), results were expressed in Newton (N). Twenty fruit were used to assess fruit maturity.

2.5. Superficial scald evaluation

Superficial scald incidence was evaluated visually after 140 and 180 d of cold storage plus 14 d at 20 °C (shelf-life). Scald incidence was expressed as percentage of fruit affected (#fruit with SS/total # fruit). One-hundred pieces of fruit per replicate were used for this evaluation.

2.6. Biochemical assays (α-farnasene and CTols)

Measurements of α-farnesene and CTols, compounds associated to scald development, were carried out according to Isidoro & Almeida (2006) and Calvo et al. (2015). Evaluations were done at harvest and during postharvest. For this, 10 peel discs of 1 cm^2 (and fleshless) were taken along the equatorial zone of five pears per replicate, with a total of 20 fruit obtained from four replicates. Ten discs were immersed in 5 ml of hexane (HPLC-grade; Merck, Germany) and extracted for 10 min at 25 °C under stirring (50 rpm) on an orbital shaker (model ES-20/60). Following extraction, solvent was filtered on Whatman cellulose paper and the final volume adjusted to 5 ml with hexane. Absorbance of 1 ml of extraction was recorded at 200, 232, 258, 269, 281 and 290 nm using a spectrophotometer (Biosan, Pharo 3000, Riga, Latvia) according to Giné Bordonaba et al. (2013). Concentration of α-farnesene was determined at 232 nm using molar extinction coefficient (27,700) according to methodology proposed by Huelin & Coggiola (1968) and expressed as μmol m^{-2} peel tissue. Whereas concentration of CTols, was calculated as the difference between each OD and 290 nm, and expressed as CT258, CT269, and CT281 using molar extinction coefficient of 25,000. Evolution of CTols accumulation dynamics was calculated as reported by Giné Bordonaba et al.

(2013). Total antioxidant activity (AO) was determined at 200 nm according to Meir & Bramlage (1988) and expressed as AO_{200} x 1000.

2.7. Statistical analysis

Correlation analysis between different variables and SS incidence was done using Spearman's rank correlation coefficients (r_s). Maturity indices were subjected to analyses of variance (ANOVA) to determine differences between treatments. Mean separation was carried out using Tukey´s multiple range test. All statistical analyses were performed using OriginPro version 2019 (OriginLab Coorporation, Northampton, MA, USA).

3. Results

3.1. Preharvest factors affecting SS development

Only in season #1 harvest maturity (H1, H2, and H3) was well correlated with SS incidence after 140 and 180 d into storage (r_s= 0.621* and 0.620*, respectively; **Table 1**). Nevertheless, this correlation was not observed in season #2 nor #3 or with all of them together (**Table 1**). HL10 was inversely correlated with SS, but only in season #1 with incidence after 180 d (r_s= -0.631, **Table 1**). Fruit from '"Pirhuin 3"' had the highest averaged SS incidence among all sites and seasons (Table 1). In this site, the average GDA increased with each season (843, 940, and 1,062 in seasons #1, #2, and #3, respectively) as it did the average SS incidence (51.7 %, 64.5 %, 93.9 % in seasons #1, #2, and #3, respectively).

The interaction Orchard x Harvest maturity was significant for flesh firmness in seasons #1 and #3 at harvest, and after 140 and 180 d into storage in all three seasons (**Table 2**). As expected, flesh firmness decreased as harvest date increased in all orchards, except 'Lo Carrizo' in season #1. This trend was maintained after 140 and 180 d into storage (**Table 2**). In general, SI increased as harvest maturity increased but not always consistently and significantly different within orchards in any of the seasons (**Table 2**). The effect of harvest date over skin color (Hue°) change from green to yellow was not consistent in any of the orchards, harvest date or seasons (**Table 2**).

In all cases SS incidence increased as time in storage did. In season #1, fruit harvested the latest (H3) had higher SS incidence, although not always statistically different (**Table 2**). The opposite was observed in season #3, and no pattern at all in season #2 (**Table 2**).

In general, fruit from "Talcarehue" in season #2 exhibited, on average, the lowest incidence of SS after 180+14 d (33 %), while that from "Pirhuin 3" the highest (64 %). The same trend was observed in season #3, but with much higher average incidences (70 % and 94 %, respectively). Conversely, in season #3 early-harvested fruit (H1) showed higher SS incidence than late-harvested one (H3, **Table 2**).

When all seasons were combined together, fruit firmness, skin color (Hue°) and SI at harvest were poorly correlated with SS after 140 or 180 d in storage (**Table 2**). Nonetheless, when seasons were separated, flesh firmness showed good correlations with SS after 140 (r_s= -0.678*) and 180 d (r_s= -0770*) but only for season #1 (**Table 2**). In the case of skin color, it was was poorly and negatively correlated with SS after 180 d when all seasons were included (r_s= -0.432*), but well correlated whe only season #2 was analyzed (**Table 2**). Overall, SI was not correlated with SS incidence postharvest (**Table 2**).

3.2. α-farnesene, CTols and antioxidant activity in fruit peel

The accumulation of compounds associated to SS was studied over three seasons. The evolution of α-farnesene and AO capacity during cold storage are shown in **Fig. 1**. In general, there was a peak on α-farnesene production around 60-75 d into storage in all three seasons, with the highest values for season #3 (**Fig. 1A, B, C**). Antioxidant activity progression during storage varied between seasons and growing sites with no clear overall pattern, except in season #3 were they followed the same pattern as α-farnesene accumulation (**Fig 1D, E, F**).

Conjugated trienols were explored using correlation analysis between the rate of production and SS incidence after 180 d (**Fig. 2**). Spearman correlation (r_s) were significant when all seasons were combined together (**Fig. 2A**) or for seasons #2, and #3, when separated (**Fig. 2C, D**). CTols rates were not correlated with SS 140 d (P=0.103). Overall, CTols accumulation dynamic were not statistically different between harvest maturity (P=0.084).

3.3. *Effect of 1-MCP and DPA treatments on superficial scald development*

Both 1-MCP and DPA were effective controlling SS development after 140 and 180 d in storage (**Table 3**). Alpha-farnesene rates were reduced, in average, by 45 % and 89 % in DPA and 1-MCP-treated fruit, respectively, compared to untreated Control (**Fig. 3**). Consequently, CTol rates were also reduced by 91 % and 95 % in DPA and 1-MCP-treated fruit, respectively, compared to the Control treatment (**Table 3**). In general, CTols accumulation rate (δCTols/δt) showed a good and positive (r_s > 0.6) correlation with SS (**Table 3**). Antioxidant activity varied between treatments and orchards with no clear pattern throuought storage (**Fig. 3**).

Internal ethylene concetration in 1-MCP-treated fruit was significantly lower that those of DPA-treated and Control from all sites, although not always significantly different (**Table 4**). In general, DPA or 1-MCP did not significantly changed fruit firmness or fruit green color (Hue°) after 140 d or 180 d in RA regardless of harvest date in any of the sites (**Table 4**).

3.4. Effect of CA storage and SWC treatment on superficial scald development

Controlled atmosphere storage significantly ($P \leq 0.05$) reduced SS incidence after 140 d and 180 d in all sites, except in "Pirhuin 3" (**Table 5**). The overall reduction in α-farnesene production was, on average, 41 % for CA-stored fruit compared to the untreated Control, except for that of "Pirhuin 3" site (**Fig. 4**). In general, fruit in SWC treatment produced as much α-farnesene, and earlier than that stored in air (RA) (**Fig. 4**). The same pattern as previously described for α-farnesene was observed in peel AO (**Fig. 4**).

The CTols accumulation dynamics were only reduced in CA-stored fruit by 66 % from that observed in the Control (**Table 5**), with the least reduction for "Pirhuin 3"'s fruit (**Table 5**). Overall, δCTols/δt was well and positively correlated with SS ($r_s > 0.6$, **Table 5**).

There was no consistent effect of CA or SWC on fruit firmness (**Table 6**). CA-stored fruit from "Agrofruta" and "Talcarehue" sites was less yellow than those from the other 2 sites, and had less IEC, mostly when they came from the early harvest (H1) (**Table 6**). In contrast, fruit from SWC treatment had generally higher IEC than other treatments (**Table 6**).

4. Discussion

4.1. Preharvest factors affecting SS development

Climate during the growing season has an important role in fruit susceptibility to physiological disorder's development postharvest. Although the biochemistry behind this observation is still under investigation in many of them, fruit acclimation to chilling in cold storage appears to be of great importance (Lurie and Watkins, 2012). Superficial scald is a manifestation of chilling injury during cold storage in pome fruit, modulated by multiple pre-and postharvest factors including environmental conditions during the growing season (Emongor et al., 1994; Smock, 1953). Scald susceptibility has been shown to vary between seasons, growing conditions, and harvest maturity (Wilkinson and Fidler, 1973). On apples, low preharvest temperatures (<10°C) 2-3 weeks before harvest decrease fruit susceptibility to the disorder (Barden and Bramlage, 1994; Blanpied et al., 1991; Merritt et al., 1961), whilst hot and dry climate in this period, as well as warm nights, increases fruit susceptibility (Fidler, 1957; Little and Taylor, 1981). Low temperature preharvest would induce fruit acclimation to later chilling temperatures in storage by increasing antioxidants and total lipids, especially unsaturated fatty acids, to cope with this stress (Diamantidis et al., 2002; Thomai et al., 1998).

In our work, none of the growing sites had more than 37 h of HL10 accumulated within 45 d prior harvest, which is around a third of that required for scald-free fruit (Barden and Bramlage, 1994; Thomai et al., 1998). This would indicate that our experimental sites had an overall warmer climate, conducive to SS development regardless of the seasonal climatic variation. Nevetheless, this was only true when fruit was stored for more than 140 d (**Table 1**). Overall, HL10 was only fairly correlated with SS incidence, except in season #1 where this index was well and negatively correlated with SS after 180 d in storage (r_s = -0.631) (**Table 1**). This suggest that this bioclimatic index would not be suitable to predict SS sensitivity on Packham's Triumph pears grown in warm growing areas in Chile, as it had been found for other winter pears cultivars such as 'd'Anjou' pears grown in cooler climates. For example, HL10 has been well correlated with scald susceptibility on 'd'Anjou' pears grown in OR, USA, where HL10 is around 175 h, in average, prior fruit harvest (Ma et al., 2001).

Although we found no correlation between GDA and SS when all seasons and orchard sites were combined (r_s = 0.386; **Table 1**), we did see a good linear correlation (R^2 = 0.974) of this bioclimatic index with SS incidence after 180 d in "Pirhuin 3" site, which was the one sampled in all three seasons.

Superficial scald on apples has also shown to decrease with harvest maturity (Dilley, 1969; Huelin & Murray, 1966). This relationship would be, in part, attributed to antioxidants/α-farnesene and CTols ratios (Huelin & Murray, 1966). In pears, the influence of harvest maturity on SS susceptibility is much less clear and consistent. Later-harvested winter pears ('Beurre d'Anjou', 'Packham's

Triumph') have shown to be more susceptible to SS than earlier and less mature ones (Calvo et al., 2017, 2015; Wang & Arzany, 2019). Nevertheless, Boonykiat et al. (1987) and Zoffoli et al. (1998) found the opposite in 'd'Anjou', Isidoro & Almeida (2006) in 'Rocha', and Zoffoli et al. (1998) also in Bartlett and 'Packham's Triumph'. In our study, harvest maturity (H1, H2, and H3) was positively correlated with SS incidence after 140 and 180 d into storage (r_s = 0.621* and 0.620*, respectively; **Table 1**) only in season #1. This was not observed in seasons #2 or #3 or all of them together (**Table 1**). This suggests that the effect of harvest maturity over SS development would depend on other growing conditions modulating fruit biochemistry (including maturation), which may explain contrasting results from different studies using smaller number of sites and seasons. Furthermore, in our study, flesh firmness used as a maturity index was not correlated with SS incidence when all seasons and locations were combined together, but it was significantly and negatively correlated in season #1, where early-harvested fruit (H1) showed higher incidences of SS (**Table 2**). Wang & Arzany (2019) also reported a good and negative correlation between flesh firmness at harvest and SS development on 'd'Anjou' pears.

4.2. Superficial scald incidence and the relationship with α-farnesene, CTols and antioxidant activity

The current mechanism involved in SS development initiates with the accumulation of (*E,E*)-α-farnesene, a key sesquiterpene compound part of the lipidic and waxy layer of pome fruit skin, that oxidizes into CTols, responsible for SS symptoms (Ingle and D'Souza, 1989). Nevertheless, in both, apples and pears (*E,E*)-α-farnesene and CTols accumulation does not always correlate well with SS development (Calvo et al., 2015; Gapper et al., 2006; Lindo-García et al., 2020; Whitaker et al., 2000). In addition to these group of compounds, antioxidants have been found to play also an important role counteracting oxidative stress and SS development apples (Busatto et al., 2018; Rudell and Mattheis, 2009; Zhao et al., 2016), as well as on pears (Larrigaudière et al., 2016).

The dynamics of accumulation of all these compounds in the fruit peel vary between cultivars, environmental conditions, harvest maturity, storage regimes and postharvest treatments, modulating its susceptibility to SS (Emongor et al., 1994; Lurie and Watkins, 2012; van der Merwe et al., 2003).

Conjugated trienols (CTols) include hydro-and endoperoxides with peaks in the UV spectra at 258, 269, and 281 nm. In pears, CT258, CT269, and CT281 have shown to increase during cold storage specially during the first 2-3 months before SS symptoms appear (Calvo et al., 2015; Larrigaudière et al., 2016; Zoffoli et al., 1998). In agreement with these authors, we found that CTols increased during cold storage, and their accumulation dynamic (δCTols/δt) was positively correlated with SS incidence when seasons, orchards and harvest maturity were combined together (r_s = 0.739; **Fig. 2A**). When seasons were separated, season #1 in contrast to seasons #2 and #3, showed a poor correlation (**Fig. 2B**). The CTols accumulation rates we found were significantly lower (>10-times) than those reported in apples (Giné Bordonaba et al., 2013), and close to zero when 1-MCP or DPA was applied at harvest (**Table 3**).

The accumulation rates of α-farnesene found in fruit from all seasons and treatments followed the same pattern previously reported on pears (Isidoro and Almeida, 2006) and apples (Whitaker, 2007). They steadily increased until 60-75 d and then declined (**Fig. 1 and 3**). The higher α-farnesene levels observed in season #3 (**Fig. 1**) coincided with the highest SS average incidence (63 and 78% after 140 and 180 d, respectively) among seasons, but with comparable CTols rate as season #2 (**Fig. 2**).

An important role has been given to the cell antioxidant system for SS suppression on apples and pears. Nonetheless, Calvo et al. (2015) found that later-harvested (more mature) fruit peel had higher antioxidant potential at harvest, but more or as much SS than less mature fruit. These authors also found that a decrease on antioxidant capacity prior SS appearance (120 d into storage) would play a more important role than the overall antioxidant capacity. In our study we found no relationship between AO and SS development on fruit from different growing sites, harvest maturity or seasons (data not shown), but different methodologies were used in these studies. In fact, AO remained overall relatively stable thoughout storage in seasons #1 and #2 following a normal distribution, and increased until 100 d into storage, on season #3 (**Fig. 1**).

4.3. Effect of 1-MCP and DPA treatments on superficial scald development

The use of synthetic antioxidants, such as DPA and ethoxyquin has been the primary method to control SS on pears in different pear-producing countries. In agreement with previous reports (Drake et al., 2006; Isidoro and Almeida, 2006), DPA-treated fruit had shown a significant reduction in SS incidence. In this work, we found 99% reduction (in average) in SS development after 6 m of storage (**Table 3**). CTols accumulation rate was 30 % of that obtained in Control fruit (**Table 3**), evidencing the antioxidant action of DPA (Huelin & Coggiola, 1968). Similar results have been reported by Isidoro & Almeida (2006) in 'Rocha' pears, and 'Granny Smith' apples (Lurie et al., 1989; Moggia et al., 2010). In general, the overall correlation found in this work between δCTols/δt and SS incidence after 140 and 180 d in storage was moderate and positive (r_s= 0.659* and r_s= 0.758*, respectively) (**Table 3**).

Ethylene is a key player in SS development by triggering α-farnesene synthesis (Gapper et al., 2006; Tsantili et al., 2007). Therefore, 1-MCP, an ethylene perception blocker, prevents SS development by not only downregulating the expression of *α-farnesene synthase 1* gene (AFS1), but also enhancing other cold acclimation-related mechanisms (Busatto et al., 2018). In our study 1-MCP applications effectively reduced SS incidence to neary 0 % in most cases (**Table 3**), along with α-farnesene levels (**Fig. 3**) and subsequent CTols accumulation rate (**Table 3**). The latest were zero for 1-MCP treated fruit from H1 and H2 in all sites except "Pirhuin 11" (**Table 3**). These results are in agreement with those reported for 'Gem' (Dong et al., 2018), 'Rocha' (Isidoro & Almeida, 2006), ‘d’Anjou’ (Gapper et al., 2006; Lu et al., 2011; Zhi and Dong, 2018), and ‘Packham’s Triumph’ (Calvo, 2003) pears.

Although the literature indicates that 1-MCP-treated pears have shown higher antioxidant capacity and content than untreated ones (Zhi & Dong, 2018), in our study we did not find any consistent differences in peel AO between treatments (**Fig. 3**),

In agreement with previous results, 1-MCP treated fruit produced significantly lower amounts of ethylene in most cases, compared to the untreated control and DPA-treated fruit after 140 and 180 d in cold storage (**Table 4**)**.** Similar results have been reported on ‘d’Anjou’ (Chen and Spotts, 2005; Gapper et al., 2006; Zhi and Dong, 2018), ‘Bartlett’ (Wang & Sugar, 2015), Gem (Dong et al., 2018), and ‘Packham’s Triumph’ (Calvo & Candan, 2015) pears. Nevertheless, ethylene inhibition did not translate in firmer fruit (**Table 4**), as previously reported in pears (Calvo, 2003; Gapper et al., 2006; Spotts et al., 2007; Zhi & Dong, 2018). These results are consistent to those obtained in ´Bartlett´ pears (Wang & Sugar, 2015). The effect of this treatment on color retention was not observed in any of the orchards or harvest maturity after 140 or 180 d in storage (**Table 4**). Similar results have been previously reported in ‘d’Anjou’ pears (Xie et al., 2014), although generally, 1-MCP applications at harvest have shown to maintain pears greener during storage and most dramatically during shelf-life (Argenta et al., 2003; Calvo, 2003; Mitcham et al., 2001; Zhi & Dong, 2018). In fact, although 1-MCP treatment may halt normal ripening (Calvo & Candan, 2015; Chen & Spotts, 2005; Ekman et al., 2004), treated fruit in this work were able to ripen normally after 7 d at 20 °C (shelf-life) reaching, in average, 32 N of flesh firmness and yellow-green skin color (data not shown).

4.4. Effect of CA storage and SWC on superficial scald development

The use of CA storage with or without the use of DPA or 1-MCP has shown to reduce SS incidence on apples and pears (Isidoro and Almeida, 2006; Smock, 1979). Overall, we found a significant reduction (77 % and 70 % in average) in SS development compared to fruit stored in air or conditioned using SWC (**Table 5**), with variations between orchards. “Pirhuin 3” site showed the least benefit from CA storage (**Table 5**), most probably due to environmental growing conditions in the orchard and different metabolic make-up at harvest. In fact, this site also showed the highest α-farnesene accumulation (**Fig. 4**) and later CTols accumulation rates (**Table 5**) in CA-stored fruit compared to the other sites. Fruit from “Agrofruta” and “Talcarehue” sites showed significantly lower levels of α-farnesene when stored in CA compared to that stored in air or conditioned after harvest (SWC) (**Fig. 4**). Similar results have been reported on apples with variations between cultivars and growing conditions (Whitaker et al., 1997). In pears, CA (and ULO in some instances) can reduce SS development but not completely prevent it from occurring (Larrigaudière et al., 2019; Truter et al., 1994).

Although warming treatments have shown good effect in reducing α-farnesene, CT281 accumulation and SS on apples (Moggia et al., 2009; Watkins et al., 2000), an increase in storage temperature on pears have been shown to be detrimental for overall fruit quality and SS incidence (Bower et al., 2003). In agreement with these results, in our study SWC not only did not reduce SS (**Table 5**), but also accelerated fruit maturity by reducing fruit firmness and green skin color, mainly in fruit from H3 (**Table 6**). Fruit with SWC treatment produced as much α-farnesene (and an earlier peak in “Talcarehue” and “Agrofruta” sites) as it did the one from RA storage (**Fig. 4**), and both treatments led to similar CTols accumulation dynamics (**Table 5**).

5. Conclusions

Superficial scald is an important physiological disorder in pears around the world. Unlike apples, fruit susceptibility is much less understood and unpredictable due to its nature. We found that fruit maturity effect on SS susceptibility vary between seasons. Only in one season (#1) the higher SS sensitivity was related to higher harvest maturity. In this case, flesh firmness used as the main maturity index in this cv., showed a good correlation with the disorder's incidence. Nevertheless, and although CTols dynamics were well correlated with SS development when all seasons were combined, this parameter was not correlated with SS incidence in season #1. Warm-growing climates, such as those prevalent in Chile, athough predisposing to SS development, may influence fruit biochemistry in different ways not yet elucidated or predictable using the bioclimatic indexes GDH or HL, modulating then fruit susceptibility. Nevertheless, DPA and 1-MCP treatments significantly reduced SS development; CA storage also, but with variations between orchards. Further research is needed to understand the influence of preharvest climate on fruit biochemistry and its consequence in SS development on pears.

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Table 1. Bioclimatic indexes and SS average incidence after 140 (SS 140) and 180 d (SS 180) in Regular Atmosphere storage (RA, -0.5 °C and >90 %RH, plus 14 d shelf life, 20 °C), and Spearman correlation coefficients (r_s) of harvest maturity (H1, H2, H3), GDA, HL10, and DAFB with SS 140 and SS 180. Spearman Rank Correlation (r_s; *: significant at 0.05 level).

Season	**Orchard**	**Harvest maturity**	**GDA**	**HL10**	**DAFB**	**SS 140 (%)**	**SS 180 (%)**
# 1	"Genova"	H1	838	22	126	2.3	19.4
		H2	910	17	133	12.6	26.6
		H3	977	1	140	14.7	42.6
	"Lo Carrizo"	H1	974	10	125	2.6	37.4
		H2	1053	10	132	9.7	36.9
		H3	1125	6	139	29.1	39.4
	"El Carmen"	H1	939	13	126	3.4	41.3
		H2	1008	10	133	16.6	32.5
		H3	1088	0	140	10.2	77.9
	"Pirhuin 3"	H1	774	30	121	15.1	30.4
		H2	844	23	128	12.9	57.3
		H3	910	0	135	51.5	67.3
# 2	"Agrofruta"	H1	891	37	121	2.0	63.1
		H2	973	31	130	0.0	37.7
		H3	1069	26	135	2.8	71.5
	"Pirhuin 3"	H1	845	31	119	2,7	60.7
		H2	939	27	126	2.3	50.1
		H3	1037	27	133	2.1	82.6
	"Pirhuin 11"	H1	845	31	119	2.0	58.8
		H2	939	27	126	2.8	62.9
		H3	1037	27	133	3.7	63.7
	"Talcarehue"	H1	861	1	131	0.0	31.1
		H2	980	1	137	0.0	15.6
		H3	1047	1	144	1.0	53.2
# 3	"Agrofruta"	H1	929	20	126	57.6	79.4
		H3	1073	20	133	55.2	61.1
	"Pirhuin 3"	H1	989	18	120	91.5	100
		H3	1135	31	135	84.3	87.8
	"Talcarehue"	H1	1095	0	128	60.5	74.7
		H3	1257	0	137	27.0	65.0

All seasons	r_s (SS 140)	0.153	0.336	-0.231	-0.097
Season #1	r_s (SS 140)	0.621*	0.133	-0.314	0.467
Season #2	r_s (SS 140)	0.164	0.019	0.301	-0.321
Season #3	r_s (SS 140)	-0.488	-0.314	0.264	-0.600
All seasons	r_s (SS 180)	0.279	0.406*	0.096	-0.044
Season #1	r_s (SS 180)	0.620*	0.354	-0.631*	0.527
Season #2	r_s (SS 180)	0.414	0.320	0.303	-0.046
Season #3	r_s (SS 180)	-0.488	-0.314	0.265	-0.543

Table 2. Effect of harvest maturity and orchard on fruit maturity (flesh firmness, Hue) and SS incidence (%) after 140 and 180 d in RA storage (-0.5 °C and >90 %RH, plus 14 d shelf-life at 20°C) in Packham´s Triumph pears over three growing seasons (#1, #2, #3). Spearman Rank Correlations between maturity indexes at harvest and SS after 140 and 180 d in all seasons or each season separately are indicated at the end of the table.

Season	Orchard	Harvest	Maturity index at harvest			Maturity index at 140 d		Maturity index at 180 d		SS (%)	
			Firmness (N)	Color (Hue°)	Starch index	Firmness (N)	Color (Hue°)	Firmness (N)	Color (Hue°)	140 +14 d	180 +14 d
# 1	"Genova"	H1	86.3 e[z]	116.4	2.1 ab	73.1 f	112.3 d	68.9 d	108.9 bc	2.3 a	19.4 a
		H2	77.0 c	113.6	2.4 b	69.4 e	109.8 b	60.5 cd	108.1 bc	12.6 a	26.6 a
		H3	72.5 b	115.4	2.7 b	59.3 b	107.8 a	55.6 c	105.1 ab	14.7 a	42.6 abc
	"El Carmen"	H1	73.8 c	115.7	1.8 a	67.4 de	110.6 bc	60.9 cd	109.5 bc	3.4 a	41.3 abc
		H2	69.4 ab	115.6	2.2 ab	63.8 c	110.0 bc	39.6 a	107.4 b	16.6 a	32.5 ab
		H3	67.6 a	113.8	2.0 ab	53.7 a	107.3 a	46.7 b	113.3 d	10.2 a	77.9 c
	"Lo Carrizo"	H1	76.5 c	115.5	2.5 b	72.7 f	110.5 bc	68.5 d	108.4 bc	2.6 a	37.4 ab
		H2	78.3 d	115.1	2.7 b	66.1 cde	110.2 bc	64.5 d	105.0 ab	9.7 a	36.9 ab
		H3	71.6 b	114.5	2.3 b	64.2 cd	110.3 bc	55.2 c	104.5 a	29.1 ab	39.4 abc
	"Pirhuin 3"	H1	74.7 c	116.6	1.9 ab	68.9 e	111.5 cd	64.5 d	108.1 bc	15.1 a	30.4 ab
		H2	71.2 b	116.4	2.1 ab	63.1 c	111.6 bcd	52.0 bc	106.1 ab	12.9 a	57.3 abc
		H3	66.3 a	114.5	2.3 b	55.6 a	107.9 a	47.2 b	104.5 a	51.5 b	67.3 bc
	P value		0.0013	0.2467	0.0370	0.0149	0.0033	0.0003	0.0000	0.0172	0.0232
# 2	"Agrofruta"	H1	77.8	115.2	1.6 ab	71.6 f	111.3 bcd	52.9 a	106.4	2.0	63.1 c
		H2	72.9	115.1	2.5 c	65.9 cd	111.2 bcd	58.7 a	106.4	0.0	37.7 ab
		H3	69.8	114.6	1.4 a	61.5 b	109.7 bc	64.9 b	106.7	2.8	71.5 bc
	"Talcarehue"	H1	73.4	116.8	1.4 a	41.0 a	104.7 a	61.4 b	108.1	0.0	31.1 ab
		H2	68.0	116.3	1.6 ab	70.3 def	111.5 cd	56.0 a	108.2	0.0	15.6 a

		H3	66.7	115.6	1.5 ab	69.3 def	111.3 bcd	60.5 ab	108.4	1.0	53.0 b
	"Pirhuin 3"	H1	76.5	114.8	1.9 b	66.1 cd	113.0 de	72.5 c	108.7	2.7	60.7 bc
		H2	75.1	114.9	1.4 a	64.5 bc	114.3 d	60.1 ab	108.5	2.3	50.1 bc
		H3	68.4	114.2	1.4 a	67.0 cde	112.5 de	63.6 b	112.9	2.1	82.6 cd
	"Pirhuin 11"	H1	78.2	115.5	1.5 ab	71.3 ef	111.0 bcd	61.4 b	108.7	2.0	58.8 bc
		H2	75.6	115.2	1.3 a	68.9 cdef	111.2 bcd	61.8 b	108.6	2.8	62.9 bc
		H3	68.0	114.5	2.6 c	66.4 cd	109.1 b	61.4 b	108.1	3.7	63.7 bc
	P value		0.1852	0.8038	0.0000	0.0000	0.0000	0,0000	0.2209	0.1443	0.0407
# 3	"Agrofruta"	H1	69.8 c	114.8 b	1.5 a	68.3 c	104.5 a	62.5 d	105.1 ab	57.6	79.4 d
		H3	64.5 b	113.6 a	4.0 c	48.8 a	101.7 a	55.0 cb	104.5 a	55.2	61.1 a
	"Talcarehue"	H1	72.5 c	115.8 b	1.6 ab	58.1 b	106.0 b	58.2 cd	108.4 b	60.5	74.7 c
		H3	57.4 a	113.4 a	1.9 ab	48.9 a	105.0 a	50.4 b	104.2 a	27.0	65.0 b
	"Pirhuin 3"	H1	78.7 d	115.5 b	2.3 b	68.3 c	110.6 c	41.7 a	105.6 ab	91.5	100.0 f
		H3	72.9 c	115.3 b	2.8 c	61.4 b	112.6 c	54.6 c	108.5 b	84.3	87.8 e
	P value		0.0003	0.0110	0.0000	0.0003	0.0038	0.0000	0.0018	0.1918	0.000
	All seasons	r_s (SS140)	-0.199	-0.235	0.446*						
	Season #1	r_s (SS140)	-0.678*	-0.207	0.067						
	Season #2	r_s (SS140)	0.100	-0.715*	-0.135						
	Season #3	r_s (SS140)	0.933*	0.829*	0.086						
	All seasons	r_s (SS180)	-0.291	-0.432*	-0.118						
	Season #1	r_s (SS180)	-0.770*	-0.291	-0.067						
	Season #2	r_s (SS180)	0.039	-0.767*	0.129						
	Season #3	r_s (SS180)	0.886*	0.600	-0.143						

Note: [Z]Average in the same column per season followed by the same letter indicate no statistical differences (Tukey, $P \leq 0.05$). Spearman Rank Correlation (r_s; *: significant at 0.05 level).

Table 3. Correlations between δCTol/δt and SS average incidence after 140 (SS 140) and 180 d (SS 180) in untreated Control, 1-MCP (0.3 mL L^{-1}) and DPA-treated fruit (1,200 mL L^{-1}) stored in RA (-0.5 °C and >90 %RH, plus 14 d shelf life, 20 °C). 'Packham's Triumph' pears. Season #2.

Season	Orchard (B)	Harvest	Treat (A)	δCTol/δt	SS 140+14 d (%)	SS 180+14 d (%)
#2	"Agrofruta"	1	Control	0.138	2.0	63.1
		2		0.124	0.0	37.7
		3		0.096	2.8	71.5
	"Pirhuin 3"	1		0.061	2.7	60.7
		2		0.050	2.3	50.1
		3		0.117	2.1	82.6
	"Pirhuin 11"	1		0.062	2.0	58.8
		2		0.055	2.8	62.9
		3		0.118	3.7	63.7
	"Talcarehue"	1		0.075	0.0	31.1
		2		0.071	0.0	15.6
		3		0.227	1.0	53.0
	"Agrofruta"	1	DPA	0.000	0.0	0.0
		2		0.000	0.0	0.0
		3		0.012	0.0	8.3
	"Pirhuin 3"	1		0.000	0.0	1.5
		2		0.010	0.4	0.0
		3		0.110	0.4	1.5
	"Pirhuin 11"	1		0.071	6.2	19.0
		2		0.038	0.4	0.0
		3		0.110	1.2	0.0
	"Talcarehue"	1		0.000	0.0	0.0
		2		0.000	0.0	0.0
		3		0.040	0.0	8.2
	"Agrofruta"	1	1-MCP	0.000	0.0	0.0
		2		0.000	0.0	0.0
		3		0.025	0.0	0.0
	"Pirhuin 3"	1		0.000	0.0	0.0
		2		0.000	0.0	0.0
		3		0.013	0.0	0.0
	"Pirhuin 11"	1		0.013	0.0	0.0
		2		0.023	0.0	0.0
		3		0.036	0.0	0.0
	"Talcarehue"	1		0.000	0.0	0.0
		2		0.000	0.0	0.0
		3		0.021	0.0	0.0
Spearman r_s with SS 140 d				0.659*		
Spearman r_s with SS 180 d				0.758*		

Note: δCTol/δt calculated between 0 and 60 d into storage. Spearman Rank Correlation (r_s; *: significant at 0.05 level).

Table 4. Effect of 1-MCP (0.3 μL L^{-1}) and DPA (1,200 μL L^{-1}) and harvest maturity (H1, H2, H3) on fruit maturity (flesh firmness, Hue°, and IEC) after 140 and 180 d in RA storage (RA, -0.5 °C and >90 %RH). 'Packham´s Triumph' pears, season #2.

Factor		Firmness (N)				Hue (°)				IEC (mL L^{-1})			
		"Agrofruta"	"Pirhuin 3"	"Pirhuin 11"	"Talcarehue"	"Agrofruta"	"Pirhuin 3"	"Pirhuin 11"	"Talcarehue"	"Agrofruta"	Pirhuin 3	"Pirhuin 11"	"Talcarehue"
140 d													
Harvest: A	H1	62.9	68.9	70.7	60.4	110.4	113.5	112.1 b	109.4	57.3	95.3	74.9	91.0
	H2	64.1	72.0	68.0	67.2	112.1	113.2	111.0 ab	111.9	27.9	63.0	59.9	10.1
	H3	63.0	67.3	65.4	65.1	110.7	112.1	110.3 a	111.0	34.0	78.5	39.6	40.2
	P value	0.0000	0.0000	0.1526	0.0000	0.0038	0.0552	0.0378	0.0053	0.5076	0.0002	0.0000	0.0000
Treatment: B	Control	66.3	65.9	68.9 b	60.2	110.7	113.2	110.5	109.2	74.7 b	149.2	120.5	74.5
	DPA	56.1	72.2	70.1 b	65.9	111.6	112.7	111.1	111.0	41.3 b	86.9	53.7	66.2
	1-MCP	67.6	70.3	65.1 a	66.7	110.8	112.8	111.9	112.3	3.2 a	0.7	0.3	0.5
	P value	0.000	0.0000	0.0000	0.0738	0.1382	0.5816	0.0963	0.0008	0.0000	0.0000	0.0000	0.0000
A x B	H1-Control	71.6 a[Z]	66.1 bc	71.3	41.0 d	111.2 ab	112.9	111.0	104.7 a	101.2	169.3 d	151.5 c	154.2 d
	H1-DPA	48.1 b	72.1 a	72.1	67.2 bc	109.1 a	113.5	111.5	111.5 bc	68.8	115.9 cd	73.2 b	118.1 d
	H1-1-MCP	69.2 abc	68.6 bc	68.6	73.0 a	110.7 ab	113.8	113.6	112.1 bc	1.9	0.73 a	0.12 a	0.6 a
	H2-Control	65.9 cd	64.5 c	68.9	70.3 ab	111.2 ab	114.3	111.2	111.5 bc	69.0	98.3 c	131.9 c	0.0 a
	H2-DPA	57.7 cd	75.1 a	69.1	68.2 ab	113.2 bc	112.7	110.5	111.2 b	11.6	90.1 bc	47.7 b	29.7 b
	H2-1-MCP	68.9 ab	76.6 a	65.9	63.1 cd	111.8 b	112.4	111.4	113.2 bc	3.3	0.71 a	0.33 a	0.5 a
	H3-Control	61.5 d	67.0 bc	66.4	69.3 ab	109.7 ab	112.5	109.1	111.3 bc	54.0	180.1 d	78.2 bc	69.4 c
	H3-DPA	62.5 c	69.4 ab	69.1	62.1 cd	112.5 bc	111.8	111.2	110.4 b	43.5	54.9 b	40.3 b	50.8 bc
	H3-1-MCP	64.9 cd	65.6 bc	60.8	63.9 cd	110.1 ab	112.1	110.6	111.5 bc	4.5	0.60 a	0.29 a	0.51 a
	P value	0.0000	0.0000	0.1536	0.0009	0.0012	0.3079	0.2363	0.0004	0.0970	0.0317	0.0000	0.0003
180 d													
Harvest: A	H1	44.4	51.7	66.6	71.2	106.5 b	107.2	110.9 b	112.7 b	124.4	241.4 b	177.7	139.3
	H2	51.2	58.2	64.3	65.7	105.0 a	108.2	108.5 a	110.2 a	158.9	142.4 a	312.5	286.2
	H3	60.5	60.5	64.3	64.0	107.2 b	107.9	109.4 a	112.2 b	140.9	156.3 a	173.9	202.4
	P value	0.0000	0.0000	0.1505	0.0000	0.0019	0.5399	0.0000	0.0000	0.5953	0.0007	0.0000	0.0000
Treatment: B	Control	58.8	59.2	61.5 a	65.4	106.4 b	108.2 ab	108.5 a	112.5 b	297.0 c	282.5 b	343.4	347.2
	DPA	52.3	64.6	65.4 b	67	108.8 c	108.6 b	109.5 a	110.6 a	123.9 b	251.3 b	320.2	276.8
	1-MCP	44.8	46.9	68.3 b	68.5	103.5 a	106.5 a	110.9 b	112.0 b	3.2 a	6.4 a	0.6	3.9
	P value	0.0000	0.0000	0.0000	0.0207	0.0000	0.0395	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A x B	H1-Control	52.8 c	61.2 cd	61.2	72.5 bc	106.4 bc	108	108.7 ab	114.3 d	262.6	382.8	299.1 bc	246.5 bc
	H1-DPA	44.1 b	66.9 de	69.5	71.6 bc	109.1 cd	109.4	110.7 b	111.2 bc	108.8	338.1	233.6 b	168.8 b
	H1-1-MCP	36.2 a	46.8 a	69.1	69.3 b	104.2 b	104.3	113.4 c	112.6 c	1.9	3.48	0.6 a	2.5 a
	H2-Control	58.8 cd	55.9 bc	61.8	60.3 a	106.3 bc	108.2	108.5 ab	110.3 b	383.5	238.8	466.7 d	466.2 d
	H2-DPA	56.9 cd	63.7 d	62.5	64.7 ab	109.4 cd	108.7	108.6 ab	108.3 a	89.7	179.4	470.2 d	389.4 cd

H2-1-MCP	37.7 ab	55.3 b	68.4	72.4 bc	99.3 a	107.7	108.6 ab	112.1 bc	3.3	9.1	0.7 a	3.1 a
H3-Control	64.8 de	60.5 c	61.6	63.6 ab	106.6 bc	108.3	108.0 a	112.9 c	244.9	225.8	264.6 bc	328.8 c
H3-DPA	56.0 cd	63.0 d	64.2	64.7 ab	107.8 c	107.8	109.3 ab	112.2 c	173.3	236.3	256.7 bc	272.2 bc
H3-1-MCP	60.5 d	58.4 bc	67.3	63.8 ab	107.0 c	107.5	110.8 bc	111.4 bc	4.5	6.6	0.5 a	6.1 a
P value	0.0000	0.0000	0.1559	0.0000	0.0000	0.1877	0.0085	0.0000	0.1049	0.0559	0.0000	0.0003

Note: ^{z}Averages in the same column followed by the same letter do not statistical differences (Tukey, $P \leq 0.05$).

Table 5. Correlations between δCTol/δt and SS average incidence after 140 (SS 140) and 180 d (SS 180) in fruit from different orchards and harvest maturity, stored in RA (-0.5 °C and >90 %RH, plus 14 d shelf life, 20 °C), CA (O_2: 2.0 kPa, CO_2: 1.0 kPa, -0.5 °C and >90 %RH), and conditioned (SWC; 1 week at 5 °C, 1 week at 3 °C, 1 week at 2 °C and the rest at -0.5 °C and >90 %RH). 'Packham's Triumph' pears. Season #3.

Season	Orchard	Harvest	Treat.	dCTol/dt	SS 140+14 d (%)	SS 180+14 d (%)
#3	"Agrofruta"	1	RA	0.062	58.0	79.0
		3		0.076	55.0	61.0
	"Pirhuin 3"	1		0.056	92.0	100.0
		3		0.091	84.0	87.0
	"Talcarehue"	1		0.097	61.0	75.0
		3		0.079	27.0	65.0
	"Agrofruta"	1	CA	0.014	0.0	2.0
		3		0.050	0.0	5.0
	"Pirhuin 3"	1		0.035	74.0	85.0
		3		0.024	20.0	3.0
	"Talcarehue"	1		0.006	0.0	4.0
		3		0.027	1.0	10.0
	"Agrofruta"	1	SWC	0.135	52.0	46.0
		3		0.110	29.0	56.0
	"Pirhuin 3"	1		0.081	90.0	100.0
		3		0.106	89.0	94.0
	"Talcarehue"	1		0.067	42.0	30.0
		3		0.019	13.0	36.0
	Spearman r_s with SS140 d			0.644*		
	Spearman r_s with SS180 d			0.622*		

Note: δCTol/δt calculated between 0 and 60 d into storage. Spearman Rank Correlation (r_s; *: significant at 0.05 level)

Table 6. Effect of RA (-0.5 °C and >90 %RH), CA (O_2: 2.0 kPa, CO_2: 1.0 kPa, -0.5 °C and >90 %RH), and SWC (1 week at 5 °C, 1 week at 3 °C, 1 week at 2 °C and the rest at -0.5 °C and >90 %RH) and harvest maturity (H1, H3) on fruit maturity (flesh firmness, Hue°, and IEC) after 140 and 180 d. 'Packham´s Triumph' pears, season #3.

Factor		**Firmness (N)**			**Hue (°)**			**IEC ($\mu L\ L^{-1}$)**		
		"Agrofruta"	"Talcarehue"	"Pirhuin 3"	"Agrofruta"	"Talcarehue"	"Pirhuin 3"	"Agrofruta"	"Talcarehue"	"Pirhuin 3"
					140 d					
Harvest: A	H1	65.4	60.0	66.7 b	109.6 b	110.3 b	112.1	45.6	122.3	89.4
	H3	47.6	48.9	58.0 a	104.9 a	107.9 a	110.1	47.4	157.3	94.8
	P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6389	0.0012	0.2922
Treatment: B	RA	58.7	53.4	64.8 b	104.7 a	107.9 a	109.8	59.0	136.4	87.5
	CA	56.9	56.9	57.9 a	112.3 b	113.0 b	113.6	31.8	68.0	77.0
	SWC	55.2	52.9	64.2 b	104.9 a	107.4 a	109.9	48.9	215.9	111.7
	P value	0.0070	0.0017	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A x B	H1-RA	59.9 d [Z]	66.4 c	68.1	106.7	107.8	111.6 c	67.1 c	141.8 b	92.9 ab
	H1-CA	68.3 e	58.1 b	62.7	114.3	114.4	114.8 d	24.7 a	62.6 a	75.5 a
	H1-SWC	67.9 e	55.5 b	68.9	107.9	108.7	109.8 b	44.9 b	162.6 b	99.7 b
	H3-RA	52.8 c	48.9 ab	61.4	102.7	106.1	108.0 a	50.9 bc	130.9 b	82.2 ab
	H3-CA	48.8 b	47.7 a	53.3	110.2	111.5	112.4 cd	38.9 ab	73.4 a	78.5 ab
	H3-SWC	42.8 a	50.3 b	59.2	101.8	106.1	109.9 b	52.4 bc	269.3 c	123.7 c
	P value	0.0000	0.0000	0.5968	0.2219	0.5877	0.0029	0.0044	0.0000	0.0243
					180 d					
Harvest: A	H1	65.4	60.0	66.7 b	107.5 b	110.3 b	112.1	45.3	79.8	74.2
	H3	48.1	48.9	58.0 a	103.8 a	107.9 a	110.1	38.0	95.6	76.3
	P value	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.1221	0.0188	0.6440
Treatment: B	RA	58.6	53.5	64.8 b	103.1 a	107.0 a	109.8	50.5	88.6	63.5 a
	CA	56.4	57.0	57.9 a	108.0 b	113.0 b	113.6	27.5	52.5	62.8 a
	SWC	55.4	52.8	64.2 b	105.9 a	107.4 a	109.9	47.0	122.0	99.4 b
	P value	0.0067	0.0181	0.0000	0.0000	0.0000	0.0000	0.0011	0.0000	0.0000
A x B	H1-RA	68.3 e	58.1 bc	68.3	104.5	106.0	110.6 b	64.3 c	90.8 bc	67.9
	H1-CA	59.9 d	66.4 c	62.7	112.6	109.3	114.0 c	27.5 a	48.7 a	62.1
	H1-SWC	67.9 e	55.5 b	69.1	104.7	109.9	105.4 ab	43.9 ab	100.0 bc	92.6
	H3-RA	48.8 b	48.9 ab	61.4	101.7	105.0	112.6 a	36.6 ab	86.4 b	59.1
	H3-CA	52.8 c	47.6 a	53.2	103.4	105.2	110.4 bc	27.5 a	56.5 ab	63.5
	H3-SWC	42.8 a	50.3 ab	59.4	107.2	104.9	98.8 ab	50.0 ab	144.1 c	106.3
	P value	0.0000	0.0004	0.4263	0.2237	0.6034	0.0106	0.0144	0.0123	0.1487

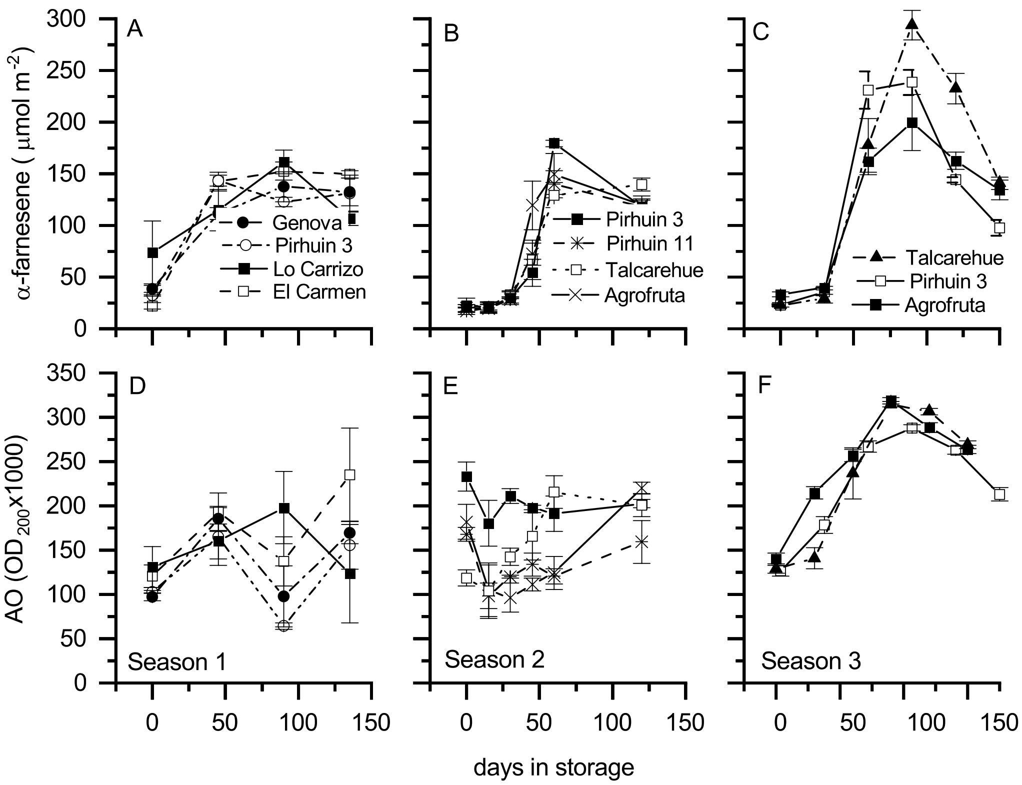
Note: [Z]Averages in the same column followed by the same letter do not statistical differences (Tukey, $P \leq 0.05$).

Figure 1. Alpha-farnesene (A, B, C) content and antioxidant activity (AO; D, E, F) in peel tissue from 'Packham's Triumph' pears from different growing sites ("Genova", "Pirhuin 3", "Lo Carrizo", "El Carmen", "Pirhuin 11", "Talcarehue", "Agrofruta") in seasons #1 (A, D), #2 (B, E), and #3 (C, F) during RA storage (-0.5 °C, >90 %RH). Each data point is the mean of nine replicates ± standard error.

Figure 2. Correlation analysis (r_s) between CTols rate of accumulation (0-60 d in storage) and SS after 180 d (plus shelf-life) in pears cv. 'Packham's Triumph', and polynomial regression adjusted (red lines) to data from all seasons (A), seasons #1 (B), #2 (C), and #3 (D). Spearman Rank Correlation (r_s; *: significant at 0.05 level).

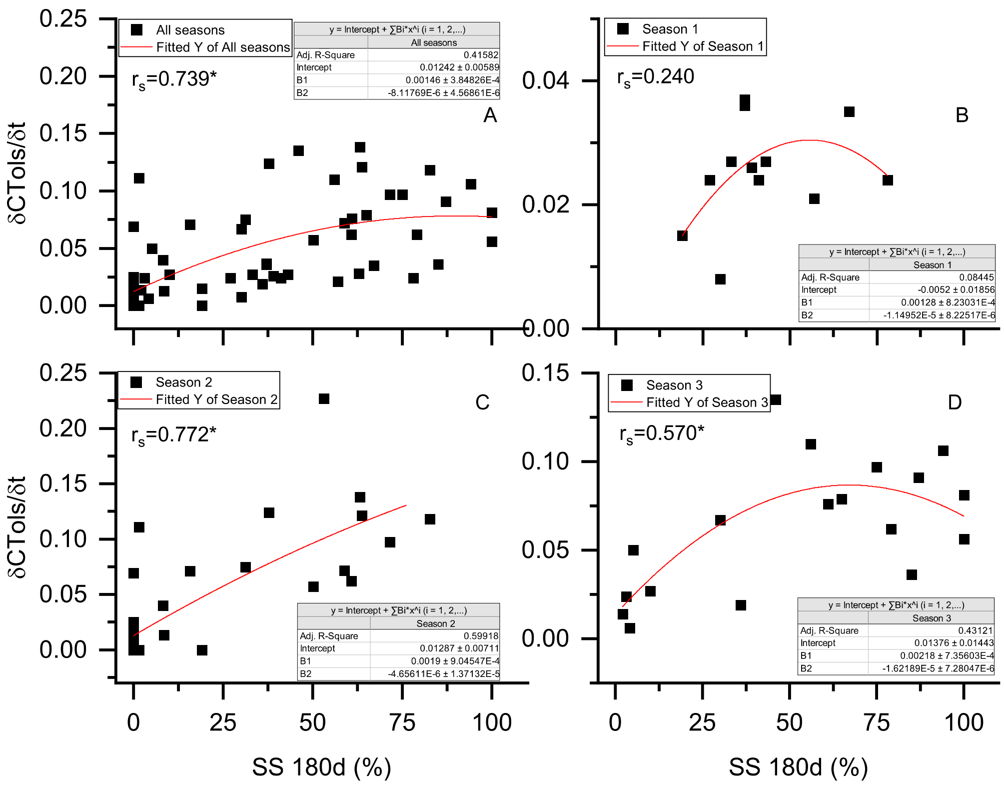
Figura 3. Alpha-farnesene (A, B, C, D) content and antioxidant activity (AO; E, F, G, H) in peel tissue of untreated Control (-■-), DPA-treated (1,200 µL L^{-1}; ··◇··), and 1-MCP-treated (0.3 µL L^{-}1; -◆-) 'Packham's Triumph' pears from "Talcarehue" (A, E), "Pirhuin 11" (B, F), "Pirhuin 3" (C, G), and "Agrofruta" (C, F) sites during cold storage (RA, 0.5°C, >90 % RH). Each data point is the mean of nine replicates ± standard error.

Figura 4. Alpha-farnesene (A, B, C) content and antioxidant activity (AO; D, E, F) in peel tissue of 'Packham's Triumph' pears stored in refrigerated air (RA, -0.5°C and >90 %RH; -■-), stepwise cooling (SWC; 1 week at 5 °C, 1 week at 3 °C, 1 week at 2 °C and the rest at -0.5 °C, >90 %RH; -▲-), and controlled atmosphere (CA, O_2: 2.0 kPa, CO_2: 1.0 kPa; ··◇··) from "Talcarehue" (A, D), "Pirhuin 3" (B, E), and "Agrofruta" (C, F) sites. Each data point is the mean of nine replicates ± standard error.



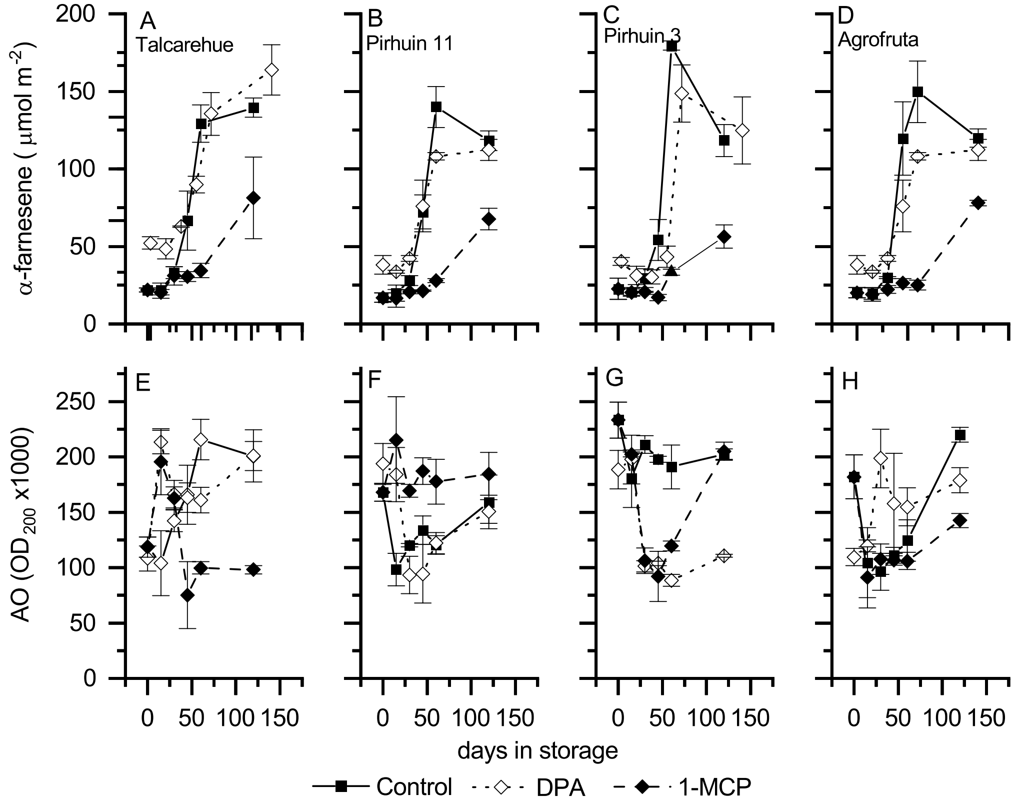
α-farnesene (µmol m-2)
AO (OD200x1000)
A
B
C
D
E
F
Genova
Pirhuin 3
Lo Carrizo
El Carmen
Pirhuin 3
Pirhuin 11
Talcarehue
Agrofruta
Talcarehue
Pirhuin 3
Agrofruta
Season 1
Season 2
Season 3
days in storage

Fig. 1.



All seasons
Fitted Y of All seasons
rs=0.739*
y = Intercept + ∑Bi*x^i (i = 1, 2,...)
All seasons
Adj. R-Square 0.41582
Intercept 0.01242 ± 0.00589
B1 0.00146 ± 3.84826E-4
B2 -8.11769E-6 ± 4.56861E-6
A
Season 1
Fitted Y of Season 1
rs=0.240
B
y = Intercept + ∑Bi*x^i (i = 1, 2,...)
Season 1
Adj. R-Square 0.08445
Intercept -0.0052 ± 0.01856
B1 0.00128 ± 8.23031E-4
B2 -1.14952E-5 ± 8.22517E-6
Season 2
Fitted Y of Season 2
rs=0.772*
C
y = Intercept + ∑Bi*x^i (i = 1, 2,...)
Season 2
Adj. R-Square 0.59918
Intercept 0.01287 ± 0.00711
B1 0.0019 ± 9.04547E-4
B2 -4.65611E-6 ± 1.37132E-5
Season 3
Fitted Y of Season 3
rs=0.570*
D
y = Intercept + ∑Bi*x^i (i = 1, 2,...)
Season 3
Adj. R-Square 0.43121
Intercept 0.01376 ± 0.01443
B1 0.00218 ± 7.35603E-4
B2 -1.62189E-5 ± 7.28047E-6
δCTols/δt
SS 180d (%)

Fig. 2.



744

745

746 **Fig. 3**.

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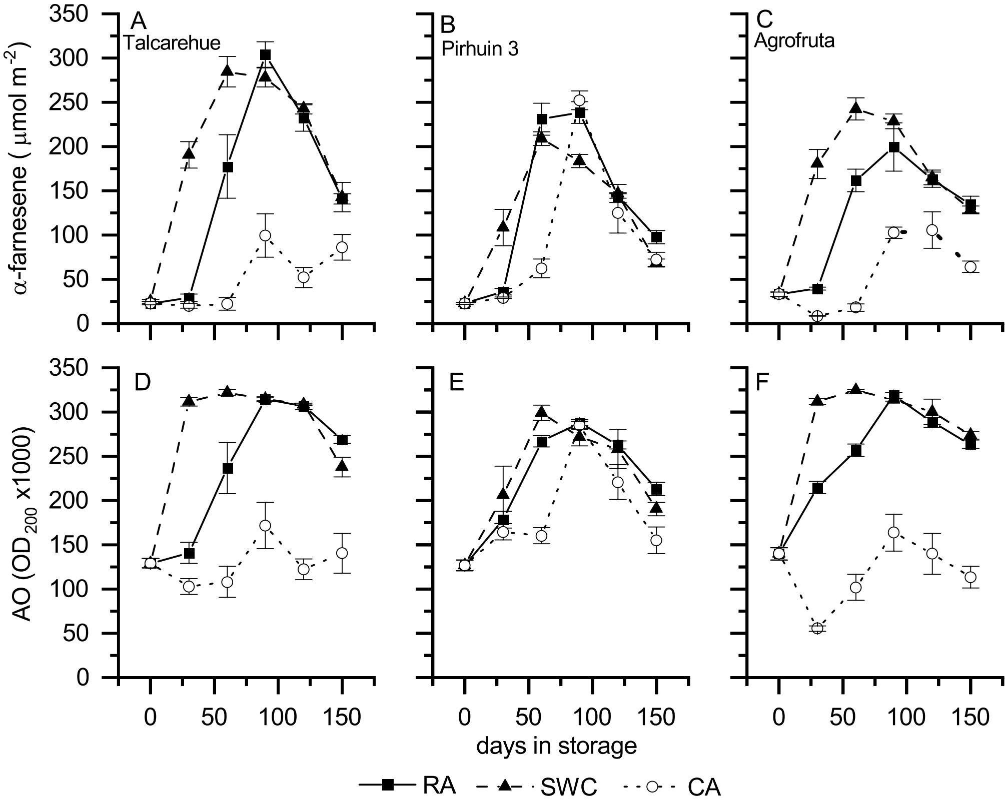

A
Talcarehue
B
Pirhuin 3
C
Agrofruta
D
E
F
α-farnesene (μmol m⁻²)
AO (OD200 x1000)
days in storage
RA
SWC
CA

Fig. 4.