AHS
Advances in Horticultural Science

Fruit maturity and antioxidant activity affecting superficial scald development in 'Abate Fétel' pears

A. Bonora [1 (*)], A. Venturoli [1, 2], M. Venturi [1], A. Boini [1], L. Corelli Grappadelli [1]

[1] *Department of Agricultural and Food Science, University of Bologna, Viale Giuseppe Fanin, 46, 40127 Bologna, Italy.*

[2] *Current affiliation: Terremerse Soc. Coop., Via Cà del Vento, 21, 48012 Bagnacavallo (RA), Italy.*

Key words: Antioxidant capacity, fruit quality, preharvest factors, Pyrus communis, superficial scald, total phenolic content.

(*) **Corresponding author:**
a.bonora@unibo.it

Citation:
BONORA A., VENTUROLI A., VENTURI M. BOINI A., CORELLI GRAPPADELLI L., 2023 - *Fruit maturity and antioxidant activity affecting superficial scald development of 'Abate Fétel' pears.* - Adv. Hort. Sci., 37(1): 3-13.

Data Availability Statement:
All relevant data are within the paper and its Supporting Information files.

Competing Interests:
The authors declare no competing interests.

Received for publication 28 October 2022
Accepted for publication 17 November 2022

Abstract: Superficial scald (SS) is one of the main physiological disorders affecting postharvest of pears. Its onset is linked to oxidative processes. Antioxidant compounds such as ascorbic acid and phenolics could play a key role in preventing SS. Growing environment and fruit quality also have an influence on SS symptoms occurrence. The aim of this project is to understand the relationship between antioxidant activity, phenolic content, and development of SS in 'Abate Fétel' pear. Moreover, the effect on SS of fruit maturity at harvest was assessed using multivariate statistical approach. Data were collected in thirty orchards in the Emilia-Romagna region (Italy) in three seasons (2018, 2019 and 2020), and the fruit were stored in a regular atmosphere for 120 days. Antioxidant capacity was determined by 2,2-diphenyl-1-picrylhydrazy (DPPH) method and total phenol content by Folin-Ciocalteau colorimetric protocol. The results showed that 340 mg of ascorbate/100 g of FW and 300 mg of gallic ac./100 g of FW at least provide good protection against SS. Multivariate analysis indicated that pulp firmness and index of absorbance difference (I_{AD}) seem to keep low the SS occurrence, when at harvest are higher than 6.3 kg and 1.9, respectively. In conclusion, it would be possible to build a forecasting model to control SS that considers pre-harvest data and content of antioxidants in different orchards, to improve the postharvest management of 'Abate Fétel'.

1. Introduction

Superficial scald (SS) is one of the main physiological storage disorders of European pears (*Pyrus communis L.*). SS is a skin disorder that appears as brown or black patches on the fruit. SS is considered a chilling injury which induces a damage and death within the surface layers of cells in localized regions (Lurie and Watkins, 2012). During SS development necrosis of the hypodermal cortical tissue seems to be induced by oxidation products of the sesquiterpene (E, E)-α-farnesene (Bain and Mercer, 1963; Rowan *et al*., 2001). α-farnesene, accumulates at a relatively high

level in the fruit peel during low-temperature storage (Whitaker *et al*., 2009; Yazdani *et al.*, 2011; Lu *et al*., 2013; Calvo *et al*., 2015). The observation that SS could be inhibited by certain antioxidant treatments and low oxygen in the storage rooms atmosphere has provided evidence that development of the disorder was associated with oxidative processes (Huelin and Coggiola, 1970; Whitaker, 2004; Vanoli *et al.*, 2015). Thus, the conjugated trienols (CTols) that result from the oxidation of α-farnesene are assumed to play a causal role in the occurrence of SS (Whitaker, 2007; Giné Bordonaba *et al*., 2013). Nevertheless, it is generally accepted that the accumulation of both α-farnesene and CTols may be mediated by ethylene which is effectively correlated with SS development (Bai *et al*., 2009; Lu *et al*., 2013; Xie *et al.*, 2014; Yazdani *et al*., 2011). Therefore, it has been suggested that α-farnesene oxidations is a direct consequence of free radical reactions occurring during chilling injury and α-farnesene is not always required for the induction of SS but rather in aggravating the symptoms in fruit already compromised by oxidative stress (Rao *et al*., 1998; Rupasinghe *et al*., 2000). In this context, it has been suggested that superficial scald mainly results from an imbalance between the fruit capacity to generate antioxidants and the reactive oxygen species (ROS) produced during cold stress (Ahn *et al*., 2007; Guerra *et al*., 2012; Ju and Bramlage, 2019). Nevertheless, the antioxidant system in fruit includes an enzymatic and a non-enzymatic component that play an important role modulating oxidative damage to cell walls (Ahn *et al*., 2007; Lurie and Watkins, 2012; Li *et al*., 2016). Furthermore, non-enzymatic antioxidants can prevent oxidation-linked damages responsible for superficial scald through biosynthesis of phenolics that are involved in protective redox-linked pathways under cold stress (Larrigaudière *et al*., 2016; Sarkar *et al*., 2018). The nonenzymatic scavengers of reactive oxygen species include low molecular mass antioxidants with high-reducing potentials, such as ascorbic acid (AA) and glutathione (GSH). Ascorbic acid acts as an antioxidant compound since it can protect fruit membranes from lipid peroxidation (Shewfelt and Del Rosario, 2000) and acts against reactive O_2 species in concert with α-tocopherol (Jimenez *et al.*, 1997). Nevertheless, AA tends to decrease during storage and processing of fruit and vegetables (Haffner *et al*., 1997). A relationship was found between AA content and the susceptibility to browning during experimental storage under various brown core-inducing conditions (Pintó *et al*., 2001). In pears the antioxidant capacity is well explained by phenolics content (Galvis Sánchez *et al*., 2003). Several studies have demonstrated that these compounds are associated with resistance to SS development in apples and pears (Ju *et al*., 1996; Zhao *et al.*, 2016). Phenolic compounds are particularly sensitive to storage factors such as controlled atmosphere (Amiot *et al.*, 1993). Variability of phenolics in plant tissues depends on many pre-harvest factors, such fruit maturity and environmental conditions, including temperature, UV light, and nutrition (Markham *et al*., 1998; Rivero *et al*., 2001; Rühmann *et al*., 2002). Casero *et al*. (2004) used the partial least squares regressions (PLS), a multivariate technique, and found correlations between fruit quality attributes, such as fruit acidity and firmness, and storage disorders with nutrients such as calcium, potassium and phosphorus, both in the leaf and fruit. Moreover, PCA biplots were helpful in showing the segregation between SS classes and their associations with the various physicochemical attributes (Cronje *et al*., 2015). In pear, pulp firmness is one of the most relevant quality parameters (Saquet, 2019). Softer fruit had rounder cells separated by larger intercellular spaces than firmer fruit. On the other hand, firmer fruit have smaller cells with less interspace which means denser tissues and longer storage than soft fruit (Johnston *et al*., 2002). Moreover, the DA-meter, a handheld device that measures chlorophyll concentration several millimetres into the flesh of fruit providing the index of absorbance difference (I_{AD}) (Ziosi *et al*., 2008), can discriminate the ripening stage of climacteric fruit for postharvest tailored cold storage (Bonora *et al*., 2013; Gagliardi *et al*., 2014; Sadar and Zanella, 2019). Fruit ripeness is also well predicted by starch degradation using a multivariate statistical approach (Zude-Sasse *et al*., 2002). Conversely, in 'Abate Fétel' pear fruit the starch index is not always employed even if some studies have reported the use of this procedure to predict pear storability and postharvest issues (Kingston, 1992; Le Lezec and Belouin, 1994; Agar *et al*., 1999; Calvo *et al.*, 2011). In pears starch pattern degradation can be influenced by environmental and management factors such as temperatures, harvest date and deficit irrigation affecting the kinetics of starch accumulation and degradation (Watkins *et al*., 1982; Kramer, 1983; Lopez *et al*., 2013; Lindo-García *et al*., 2019). Total sugar content is an internal fruit quality trait that is crucial for consumer acceptance (Osorio

and Fernie, 2014). Total soluble solids in 'Abate Fétel' and 'Forelle' pear are mainly fructose, glucose and sucrose (Mesa *et al*., 2016), and they increase in concentration after storage since starch is converted via hydrolysis into sugars over time (Visser *et al*., 1968; Crouch and Huysamer, 2011; Rizzolo *et al*., 2015). Additionally, sorbitol accumulates in the fruit still attached to the tree (Mesa *et al*., 2016), acting as cryoprotectant in cellular structures during cold storage by preventing dehydration of membranes and proteins through an osmotic adjustment process (Busatto *et al*., 2018). Therefore, the aim of this work was to research relations between antioxidant activity, phenolic content, and SS development on 'Abate Fétel' pears. Furthermore, preharvest maturity and non-destructive postharvest quality parameters, as well as antioxidant activity and phenolic content, influencing the occurrence of superficial scald using multivariate analysis and regression trees were investigated to develop new reliable hypotheses of their effects in SS development, without compromising consumer acceptance and nutritive value.

2. Materials and Methods

Fruit material and superficial scald evaluation

Fruit were harvested during three consecutive seasons (2018, 2019 and 2020) from different 'Abate Fétel' orchards located in the Emilia-Romagna Region, Italy. Fruit from 30 and 23 farmers were collected and their maturity assessed in 2018 and in seasons 2019 and 2020, respectively. The farmers were indicated by three digit-numbers. In all seasons, two orchards with historical higher SS and two with lower SS were subjected to biochemical analysis at harvest and during storage. In 2018, eighteen 15 kg boxes for each farm were placed in a regular atmosphere (0.5°C and >90% of relative humidity - RH). After 3 (T1), 4 (T2), and 5 months (T3) of storage, the room was opened, following the calendar normally applied by the company. In 2019 and 2020 only six 15 kg boxes per orchard were harvested and placed with a regular atmosphere in a cold room which was opened after 4 months (T2). Afterwards, the presence of superficial scald was assessed in 30 fruits per farm. We defined four classes depending on the severity of symptoms in the skin of pears: class 0 where there was no peel browning, class 1 from 0% to 25% fruit peel showing SS, class 2 from 25% to 50% SS, and class 3 over 50% SS after shelf life. A SS index was computed as follows (Bonora *et al*., 2021):

$$\text{SS index} = \sum_{0}^{4} \frac{\text{(index level) x (fruit at this level)}}{\text{Total number of fruit}}$$

Analysis of the physical characteristics

In all seasons, 30 fruits per orchard at harvest (T0) were subjected to qualitative analysis such as fruit size, index of absorbance difference (I_{AD}), pulp firmness, soluble solid content and starch content. Moreover, non-destructive fruit quality such as size and I_{AD} after 4 months (T2) of cold storage were considered. Weight and dimensions (diameter and height) of each fruit were measured with an automatic caliper (S_Cal WORK, Sylvac, Switzerland) and an electronic balance (KB 1200-2N, KERN, Germany) connected to a notebook. Individual fruit ripeness expressed as I_{AD} was measured with the DA-meter 53500 (Sinteleia, Bologna, Italy) on the fruit side most exposed and less exposed to the sun. Individual fruit flesh firmness (FFF) was determined by FTA (Fruit Texture Analyser, Güss Instruments, Strand, Western Cape, South Africa) fitted with an 8 mm diameter tip, after removing the fruit peel from opposite sides at 180°. The mean value of fruit ripeness and firmness, from the two sides, was calculated. Soluble solid concentration (SSC;°Brix) was determined by measuring the refractive index of the juice for each fruit with a digital refractometer (PAL-1, Atago). The stage of starch hydrolysis was determined by dipping half-cut pears into a Lugol solution and scoring the fruit according to the Ctifl-EUROFRU scale (1-10; 1 = minimum, 10 = maximum starch hydrolysis) (Planton, 1995). Finally, at harvest (T0) and during storage (T1, T2, T3) pieces of the same size with pulp and peel of fruit from all the orchards in 2018 and from four representative farmers in 2019 and 2020 were frozen in liquid nitrogen and stored at -80°C. These plant materials have been used for quantification of antioxidant activity and total phenolic content.

Quantification of antioxidant activity

To estimate the antioxidant activity, the 2,2-diphenyl-1-picrylhydrazy (DPPH) method was used (Adapted from Brand-Williams *et al*., 1995). The DPPH working solution was prepared in 70% acetone (v/v), with a final concentration of 0.02 mg/mL (w/v) and stored at 4°C until needed. Afterwards, antioxidant compounds from 0.5 g of pear (flesh and peel) were extracted in 10 mL of acetone 70%. The frozen

material (0.5 g of pear) was homogenised in a Ultraturrax (IKA T25 digital ULTRA-TURRAX) with 10 mL of extraction solution (acetone 70%) for 2 minutes on ice. After vortexing, the tubes were sonicated in a bath-type sonicator for 15-20 minutes and the homogenates were centrifuged at 1,500 x *g* for 20 minutes at 5°C. Fruit extracts (0.1 mL) were allowed to react with 3.9 mL of the DPPH solution for 30 minutes in the dark, and the absorbance at 515 nm by UV-VIS spectrophotometer (Libra S80PC VBW UV/Vis, Biochrom), was measured. The DPPH working solution was considered as the blank and the calibration curve was made using ascorbic acid.

Total phenolic content

Phenolic compounds quantification was performed using the Folin-Ciocalteau colorimetric method (Adapted from Vieira *et al*., 2009). Total phenolics from 0.5 g of pear (flesh and peel) were extracted in 10 mL of 70% acetone. The frozen material (0.5 g of pear) was homogenised in a Ultraturrax (IKA T25 digital ULTRA-TURRAX) with 10 ml of extraction solution (acetone 70%) for 2 minutes on ice. After vortexing, the tubes were sonicated in a bath-type sonicator for 15-20 minutes. The homogenates were centrifuged at 1,500 x *g* for 20 minutes at 5°C. 250 µL of supernatant were added to 2 mL of deionized water and 250 µL of Folin reagent. After mixing, samples were incubated for 5 min and 5 mL of sodium carbonate (Na_2CO_3) and 5 mL of distilled water were added. Following 1 h incubation in the dark, absorbance was measured at 750 nm by UV-VIS spectrophotometer (Libra S80PC VBW UV/Vis, Biochrom). The phenolic concentrations were determined using gallic acid as a standard.

Data treatment and statistical analysis

All the results of antioxidants and phenolics were statistically evaluated by analysis of variance (ANOVA). Furthermore, these data were presented considering four key producers at harvest (T0), after 3 (T1), 4 (T2) and 5 months (T3) of regular air storage. These producers were selected according to the incidence of SS: two had a high incidence of SS (131 and 432) and the others had a low development of SS (272 and 351). Moreover, the fruit quality data were subjected to multivariate analysis to highlight which among the factors considered appears to be more related to the onset of superficial scald. Multivariate statistical analyses, such as canonical correspondence analysis (CCA) and recursive partitioning and regression trees (rpart) analysis, were performed using the statistical software R (R core team, 2020), by addition of packages "vegan" (Oksanen *et al*., 2019) and "rpart" (Therneau and Atkinson, 2019). CCA was used to estimate the interactions between the frequencies of SS classes and the numeric variables. The blue vector indicates the increase of the factors in a certain direction (SS class). Finally, we considered the total variability explained by two components (CCA1 and CCA2) and how each variable affects the first and the second component. Therefore, maturity data at harvest and SS after 4 months in all seasons were considered to elaborate the overall picture. Finally, rpart analysis was applied to detect which factors could contribute more to SS and to understand their thresholds. Green and red lights indicate a decrease or an increase in SS index, respectively.

3. Results

In 2018 antioxidant capacity in fruit during storage decreased significantly (Fig. 1 and Table 1). Regarding phenolic compound content in fruit of different producers, the differences were not statistically significant at harvest and during conservation (Table 1). This can be explained looking at the different producers' behaviour (Fig. 2). Indeed, two different trends can be observed during the first 3 months of storage: in 272 and 351 phenols tend to increase, while in 131 and 432 they decrease. Thereafter, phenols in 131, 432 and 351 increase from T1 to T2

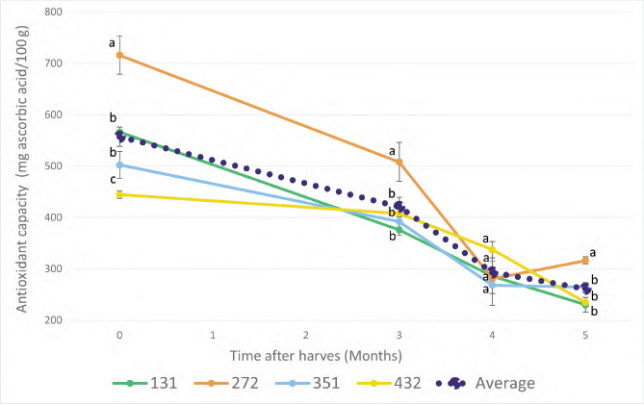

Fig. 1 - Evolution of antioxidant capacity in season 2018 (mg ascorbic acid/100 g of fresh fruit) of four farmers (131, 272, 351, 432) and their average trend. Bars represent standard error of the mean (±SEM). Points followed by the same letter in every sampling point are not significantly different from each other. Mean separation by LSD test (P≤0.05).

Table 1 - Mean and standard error of the mean (SEM) of SS index, antioxidant capacity, total phenolic content in season 2018 at harvest (T0), after 3 months (T1), 4 months (T2), 5 months (T3) in cold storage

Epochs	SS index	Antioxidant capacity (mg ascorbic acid/100 g of fresh fruit)	Total phenolic content (mg gallic acid/100 g of fresh fruit)
T0			
Mean	/	480.92 a	281.99
SEM	/	19.04	15.91
T1			
Mean	5.89 b	370.40 b	312.62
SEM	0.80	11.62	17.85
T2			
Mean	35.46 a	300.38 c	299.37
SEM	2.52	7.85	12.90
T3			
Mean	43.08 a	264.41 c	263.16
SD (%)	2.66	13.05	18.95
Significance (p<0.05)	***	***	NS
Levene test	NS	NS	NS

Data represent the average of fruit quality of 30 producers between epochs for each variable. Values followed by the same letter in columns are not significantly different from each other. Means separation by LSD test (P<0.05).
*** Significant at P≤0.001; NS = not significant.

before decreasing notably again. On the other hand, in 272 we note only a slightly decrease from T1 to T2.

In our study there is a clear distinction between T1, T2 and T3 in terms of SS occurrence in the first season (Table 1). In addition, figures 3, 4, and 5 confirms the great variability of the incidence of SS among the different producers in T2 in all seasons. The evolution of SS index in 2018 of the 30 producers is also shown in Table 1. At T1 the index is low while

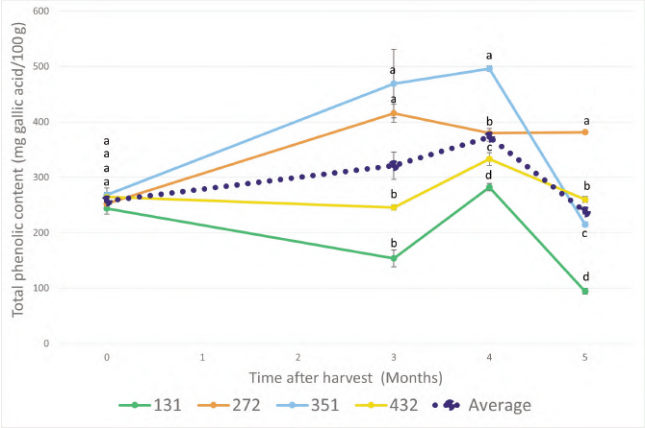

Fig. 2 - Evolution of total phenolic content in season 2018 (mg gallic acid/100 g of fresh fruit) of four selected farms (131, 272, 351, 432) and their average trend. Bars represent standard error of the mean (±SEM). Values followed by the same letter in every sampling point are not significantly different from each other. Mean separation by LSD test (P≤0.05).

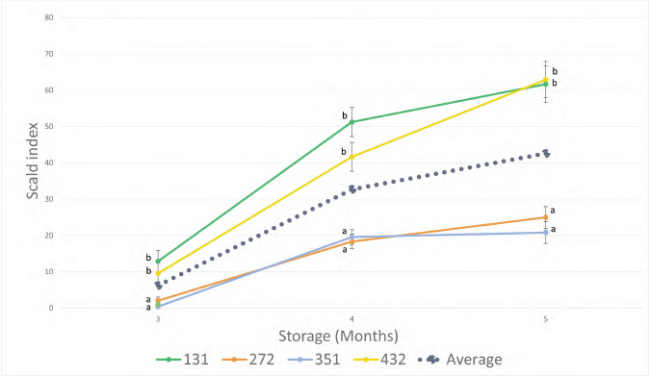

Fig. 3 - Evolution of superficial SS index of four selected farms (131, 272, 351, 432) and their average trend during storage in 2018. Bars represent standard error of the mean (±SEM). Values followed by the same letter in every sampling point after harvest are not significantly different from each other. Mean separation by LSD test (P≤0.05).

there is a considerable increase of SS incidence at T2 and at T3, while antioxidants decrease significantly. Among the key producers of the first season in figure 3, two farmers had a higher SS index (131, 432), while two producers had a lower SS index (272, 351). In detail, the results show that the producers with the lowest SS (351, 272) are those in which phenols increase during the first three months of storage (Fig. 2). Therefore, has been hypothesized that fruit were able to initially react and use these substances to protect themselves from oxidative stress.

Particularly, 351 accumulated phenols till 4 moths which drop from T2 to T3 even below 431, probably, consuming their reducing power instead of antioxidants avoiding polyphenol oxidase activity and browning. On the other hand, the producers (131, 432) with the greatest SS are those in which the phenols drop during the first three months of storage, even if they rise again in the following months (Fig. 2). Probably, the damage caused by oxidative stress is already underway. Notably, we found a drastic decrease of antioxidants between T1 and T2 in producer 272, even if denoted the highest initial antioxidant values at harvest (Fig. 1). Nevertheless, 272 had a low incidence of SS and this could be explained by the fact that during the first three months the antioxidants were high, and phenols increase reaching and keeping a certain threshold value till T3.

Weather and physiological factors in the second and the third season appear to also influence the average nonenzymatic scavengers' level and the SS occurrence (Fig. 4 and Fig. 5). Thus, we found a general high presence of antioxidants and low SS in 2019, characterized by a rainy and cold season. On the contrary, the protective compounds decreased, and SS increased in all producers in 2020 when the temperatures and yields were higher. Moreover, the data shows that antioxidants drop in the first three months of storage in all the four producers considered (Fig. 4 and Fig. 5). However, in both seasons the incidence of SS in producers 131 and 432 was higher

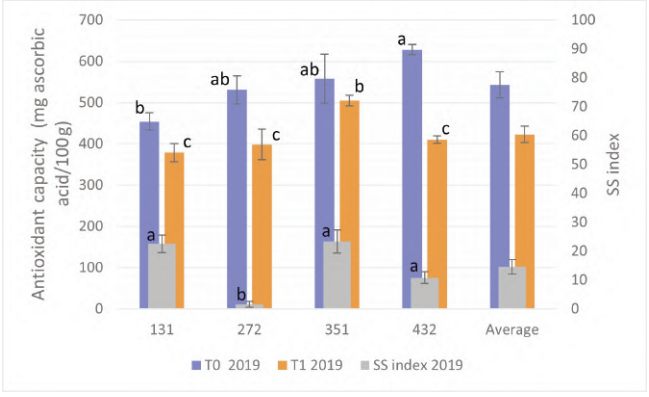

Fig. 4 - Evolution of antioxidant capacity (mg ascorbic acid/100 g of fresh fruit) and SS index after 4 months of cold storage (T2) in seasons 2019 of four farmers (131, 272, 351, 432) and their average trend. Bars represent standard error of the mean (±SEM). Values followed by the same letter between four producers are not significantly different from each other considering DPPH values at T0 and T1 or SS index during storage. Mean separation by LSD test (P ≤ 0.05).

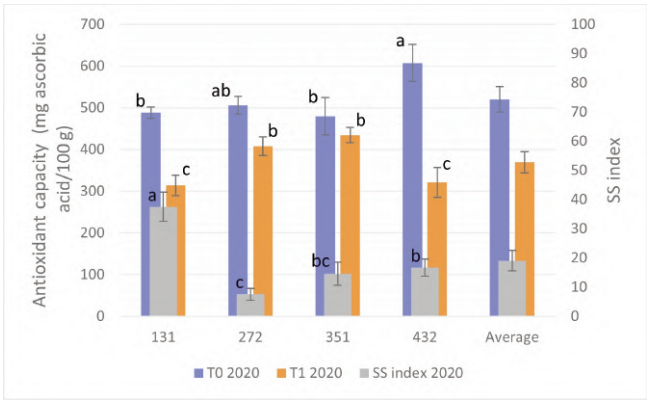

Fig. 5 - Evolution of antioxidant capacity (mg ascorbic acid/100 g of fresh fruit) and SS index after 4 months (T2) of cold storage in seasons 2020 of four farmers (131, 272, 351, 432) and their average trend. Bars represent standard error of the mean (±SEM). Values followed by the same letter between four producers are not significantly different from each other considering DPPH values at T0 and T1 or SS index during storage. Mean separation by LSD test (P≤0.05).

when the antioxidants decrease drastically after 3 months of cold storage, regardless of the level at harvest.

In figure 6 and figure 7, CCA and rpart analysis are applied to study the effects of maturity of 'Abate Fétel' pear at harvest and during storage against SS development at T2 during three consecutive seasons (2018, 2019 and 2020). The multivariate model

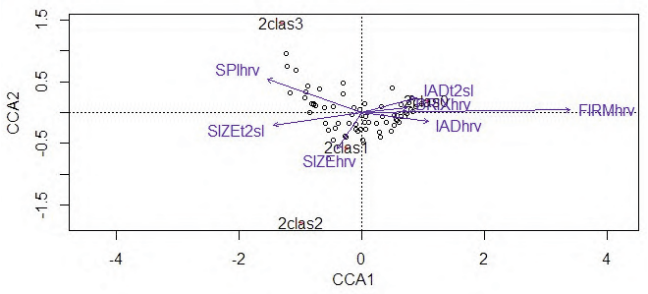

Fig. 6 - Canonical correlation analysis (CCA) of superficial scald classes in 'Abate Fétel' pear after 4 months of cold storage (clas0 0%, clas1 1%-25%, clas2 26-50%, and clas3 51-100% of peel symptoms) against qualitative orchard features at harvest during three seasons 2018, 2019 and 2020 (blue vectors) and the scores of producers (black circles). Total variability explained (53%): CCA1 (90%); CCA2 (8%). The following abbreviations have been used: weight of the fruit at harvest (SIZEhrv), weight of the fruit after 4 months of cold storage (SIZEt2sl), pulp firmness at harvest (FIRMhrv), soluble solid content at harvest (BRIXhrv), IAD-meter values at harvest (IADhrv), IAD values after 4 months of cold storage (IADt2sl), starch pattern index at harvest (SPIhrv).

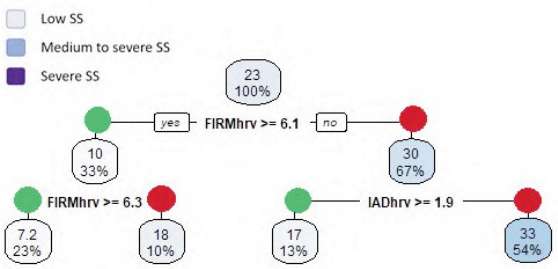

Fig. 7 - Recursive partitioning and regression tree (rpart) analysis, correlation between quality factor and Scald Index. Towards green point hypothesis (FIRMhrv≥ 6.1; FIRMhrv≥6.3; IADhrv≥1.9) is confirmed, to red point is not satisfied. Numbers in the circle represent Scald Index and the percentage of producer that are included in that value of scald index. The colour of the boxes represents the severity of SS: low SS (scald index: 0-15; most fruits do not show SS or show slight symptoms), medium to severe SS (scald index: 16-30; occurrence of progressively more severe symptoms), severe SS (scald index: >30; most fruit show severe symptoms and other very severe symptoms). The following abbreviations have been used: pulp firmness at harvest (FIRMhrv), index of absorbance difference at harvest (IADhrv).

explains 27% of the observed SS variability (CCA1 89% and CCA2 7%). In our study we found that flesh firmness at harvest can prevent SS after cold storage considering all seasons and its contribution to component 1 is 0,95 against SS (Fig. 6). The orchards (23%) with pulp firmness at harvest higher than 6.3 Kg developed low SS (7.2 SS index), while the SS index increased three times in the farms (67%) which, at harvest, scored less than 6.1 Kg of firmness (Fig. 7). However, in figure 6 we noted that bigger fruit at harvest and after storage are more prone to SS (its contribution to principal component is 0.11 at harvest and 0.40 after storage towards SS). In our research starch content at harvest in different producers and seasons influences SS during cold storage with an important contribution to component 1 and component 2 (0.43 and 0.51 respectively towards class 3 after 4 months). The non-destructive I_{AD}-meter values also contribute to preventing SS (Fig. 6), although its contribution to component 1 is lower than firmness and SPI (0.30 and 0.25, at harvest and during storage respectively against SS). Furthermore, in figure 7 we found a specific value of I_{AD} which contributed to SS occurrence for three consecutive years. Among the farms which scored firmness value lower than 6.1 (67%), a fraction (13%) with I_{AD} higher than 1.9 developed an average SS index of 17. The 54% with firmness and I_{AD} lower than 6.1 and 1.9 respectively denoted a SS index higher than 33. Moreover, we found that °Brix promotes resistance to SS during storage of 'Abate Fétel' pears in Emilia Romagna (Fig. 6) and Its contribution to component 1 is remarkable (0.20 against SS).

4. Discussion and Conclusions

As shown in our research, several studies confirm that antioxidant capacity, in particular ascorbic acid, drops during storage (Lee and kader, 2000; Franck *et al*., 2003), promoting a variable SS development in pear between orchards located in different environment (Bonora *et al.*, 2021). Indeed, Silva *et al*. (2010) reported that storage reduced differences in antioxidant capacity between producers at harvest. About phenolic content, fruit may react and produce more phenols when stored for few months. This behaviour is reported in apples by Leja *et al.* (2003) who showed that phenolic compounds are synthesised during storage. Moreover, Calvo *et al*. (2015) highlighted that in addition to the initial value of antioxidants, it is important the level of protective compounds be maintained.

Regarding quality factors affecting SS, Wang and Arzani (2019) also reported a good and negative correlation between high flesh firmness at harvest and SS development in 'd'Anjou' pears. Nevertheless, fruit with a high flesh firmness are more unripe (Stow, 1988) and more prone to contain less antioxidants (Kaur *et al*., 2021). Furthermore, larger fruit generally ripe faster and are characterised by lower firmness and dry matter after storage, by probably increased respiration rate, oxidative stress, and water loss as consequence (Gwanpua *et al.*, 2013). Accelerated senescence, and increased susceptibility to chilling injury have been reported to result from weight loss (Prange and Wright, 2023). On the other hand, the higher surface-volume ratio of larger fruit seems to prevent SS by a reduced evapotranspiration and weight loss during storage (Pasquariello *et al.*, 2013). Although Stow (1988) described starch pattern index as an unreliable method to determine optimum harvesting date of pears, Szczesniak and Ilker (1988) reported that parameters influencing storability and fruit textural characteristics of 'Forelle' pears include the starch content. In contrast with our study, the incidence of superficial scald in apple

declines when the starch pattern index advances (Watkins *et al*., 1982; Mditshwa *et al*., 2015). Concerning I_{AD} meter values, a three-year study by DeLong *et al*. (2014) to develop optimal harvest time for 'Honeycrisp' in Nova Scotia (Canada) led to fruit with a low incidence of disorders after 3 months of storage. Indeed, 'Abate Fétel' pears with higher I_{AD} values at harvest ripen less over 6 months of cold air storage (Rudell *et al*., 2017). In fact, the content of primary photoassimilates certainly supports the production of secondary metabolites such as antioxidants (Mellidou *et al*., 2021).

To conclude, the development of SS seems to be the consequence of the occurrence of many quality and biochemical traits. Therefore, it is important to highlight that it is not possible to consider only one variable at a time to find a solution in pears. We explored the possibility to use multivariate analyses to help understand the relationships between all the factors that may influence SS. Antioxidant capacity is essential in 'Abate Fétel' pear to prevent SS occurrence. Moreover, good pulp firmness, increased I_{AD} values, high total soluble solids and low starch degradation at harvest seems to have a positive impact on SS development. Furthermore, rpart analysis of fruit maturity at harvest confirms the importance of reaching threshold values, as indicators of potential fruit susceptibility to SS during storage, in addition to the absolute trends in multivariate analysis. Therefore, pre-harvest quality and antioxidant values at harvest can be compared with threshold values to discriminate batches of fruit based on their potential to develop SS symptoms. However, it is important to consider that for application purposes it would be necessary to develop faster systems for the quantification of fruit maturity and antioxidant capacity at harvest in the orchards or during storage, using reliable, non-destructive methods. Accordingly, the fruit industry may consider a predictive software to help manage the storage, minimising SS in pears and improving cold room fulfilment and energy efficiency, by recording at harvest antioxidant data and fruit maturity indexes in different 'Abate Fétel' orchards.

References

AGAR I.T., BIASI W.V., MITCHAM E.J., 1999 - *Exogenous ethylene accelerates ripening responses in Bartlett pears regardless of maturity or growing region.* - Postharvest Biol. Technol., 17: 67-78.

AHN T., PALIYATH G., MURR D.P., 2007 - *Antioxidant enzyme activities in apple varieties and resistance to superficial scald development.* - Food Res. Int., 40: 1012-1019.

AMIOT M.J., AUBERT S., NICOLAS J., 1993 - *Phenolic composition and browning susceptibility of various apple and pear cultivars at maturity.* - Acta Horticulturae, 343: 67-69.

BAI J., YIN X., WHITAKER B.D., DESCHUYTTER K., CHEN P.M., 2009 - *Combination of 1-Methylcyclopropene and ethoxyquin to control superficial scald of "Anjou" pears.* - HortTechnology, 19: 521-525.

BAIN J.M., MERCER F.J., 1963 - *The submicroscopic cytology of superficial scald, a physiological disease of apples.* - Austral. J. Biol. Sci., 16: 442-449.

BONORA A., MUZZI E., FRANCESCHINI C., BOINI A., BORTOLOTTI G., BRESILLA K., PERULLI G.D., VENTURI M., MANFRINI L., GRAPPADELLI L.C., 2021 - *Preharvest factors affecting quality on "Abate Fétel" pears: study of superficial scald with multivariate statistical approach.* - J. Food Quality, 2021: 1-11.

BONORA E., STEFANELLI D., COSTA G., 2013 - *Nectarine fruit ripening and quality assessed using the index of absorbance difference (IAD).* - Int. J. Agron., 2013: 1-9.

BRAND-WILLIAMS W., CUVELIER M., BERSET C., 1995 - *Use of a free radical method to evaluate antioxidant activity*. - LWT - Food Sci. Technol., 28: 25-30.

BUSATTO N., FARNETI B., COMMISSO M., BIANCONI M., IADAROLA B., ZAGO E., RUPERTI B., SPINELLI F., ZANELLA A., VELASCO R., FERRARINI A., CHITARRINI G., VRHOVSEK U., DELLEDONNE M., GUZZO F., COSTA G., COSTA F., 2018 - *Apple fruit superficial scald resistance mediated by ethylene inhibition is associated with diverse metabolic processes*. - Plant J., 93: 270-285.

CALVO G., CANDAN A.P., CIVELLO M., GINÉ-BORDONABA J., LARRIGAUDIÈRE C., 2015 - *An insight into the role of fruit maturity at harvest on superficial scald development in "Beurré D'Anjou" pear.* - Sci. Hortic, 192: 173-179.

CALVO G., CANDAN A.P., GOMILA T., 2011 - *Post-harvest performance of "Abate Fetel" pears grown in Argentina in relation to harvest time.* - Acta Horticulturae, 909: 725-730.

CASERO T., BENAVIDES A., PUY J., RECASENS I., 2004 - *Relationships between leaf and fruit nutrients and fruit quality attributes in Golden Smoothee apples using multivariate regression techniques.* - J. Plant Nutr., 27: 313-324.

CRONJE A., CROUCH E.M., MULLER M., THERON K.I., VAN DER RIJST M., STEYN W.J., 2015 - *Canopy position and cold storage duration affects mealiness incidence and consumer preference for the appearance and eating quality of "Forelle" pears.* - Sci. Hortic., 194: 327-336.

CROUCH E.M., HUYSAMER M., 2011 - *Cell wall compositional differences between mealy and non-mealy "Forelle" pear during ripening*. - Acta Horticulturae,

877: 1005-1010.

DELONG J., PRANGE R., HARRISON P., NICHOLS D., WRIGHT H., 2014 - *Determination of optimal harvest boundaries for honeycrisptm fruit using a new chlorophyll meter.* - Canadian J. Plant Sci., 94(2): 361-369.

FRANCK C., BAETENS M., LAMMERTYN J., VERBOVEN P., DAVEY M.W., NICOLAÏ B.M., 2003 - *Ascorbic acid concentration in cv. Conference pears during fruit development and postharvest storage.* - J. Agric. Food Chem., 51(16), 4757-4763.

GAGLIARDI F., SERRA S., ANCARANI V., BUCCI D., PICCININI L., NOFERINI M., MUSACCHI S., COSTA G., 2014 - *Preliminary results on Cv. "Abbé Fétel" productivity and fruit quality in relation to tree architecture.* - Acta Horticulturae, 1058: 151-158.

GALVIS SÁNCHEZ A.C., GIL-IZQUIERDO A., GIL M.I., 2003 - *Comparative study of six pear cultivars in terms of their phenolic and vitamin C contents and antioxidant capacity.* - J. Sci. Food Agric., 83: 995-1003.

GINÉ BORDONABA J., MATTHIEU-HURTIGER V., WESTERCAMP P., COUREAU C., DUPILLE E., LARRIGAUDIÈRE C., 2013 - *Dynamic changes in conjugated trienols during storage may be employed to predict superficial scald in "Granny Smith" apples.* - Lwt, 54: 535-541.

GUERRA R., GARDÉ I.V., ANTUNES M.D., DA SILVA J.M., ANTUNES R., CAVACO A.M., 2012 - *A possibility for non-invasive diagnosis of superficial scald in "Rocha" pear based on chlorophyll a fluorescence, colorimetry, and the relation between α-farnesene and conjugated trienols.* - Sci. Hortic., 134: 127-138.

GWANPUA S.G., VERLINDEN B.E., HERTOG M.L.A.T.M., VAN IMPE J., NICOLAI B.M., GEERAERD A.H., 2013 - *Towards flexible management of postharvest variation in fruit firmness of three apple cultivars* - Postharvest Biol. Technol., 85: 18-29.

HAFFNER K., JEKSRUD W.K., TENGESDAL G., 1997 - *L-ascorbic acid contents and other quality criteria in apples* (Malus domestica *Borkh.) after storage in cold store and controlled atmosphere.* - In: MITCHAM E.L. (ed.) *In CA '97 Proceedings. Vol. 2. Apples and Pears. Postharvest Horticultural Series*, No. 16, University of California, Davis, CA, USA, pp. 308.

HUELIN F.E., COGGIOLA I.M., 1970 - *Superficial scald, a functional disorder of stored apples VII. Effect of applied α-farnesene, temperature and diphenylamine on scald and the concentration and oxidation of α-farnesene in the fruit.* - J. Sci. Food Agric., 21: 584-589.

JIMENEZ A., HERNANDEZ J.A., DEL RIO L.A., SEVILLA F., 1997 - *Evidence for the presence of the ascorbate-glutathione cycle in mitochondria and peroxisomes of pea Leaves.* - Plant Physiol., 114: 275-284.

JOHNSTON J.W., HEWETT E.W., HERTOG M.L.A.T.M., 2002 - *Postharvest softening of apple (*Malus domestica*) fruit: a review.* - New Zeland J. Crop Hortic. Sci., 30(3): 145-160.

JU Z., BRAMLAGE W.J., 1999 - *Phenolics and lipid-soluble antioxidants in fruit cuticle of apples and their antioxidant activities in model systems.* - Postharvest Physiol. Technol., 16(2): 107-118.

JU Z., YUAN Y., LIU C., ZHAN S., WANG, M., 1996 - *Relationships among simple phenol, flavonoid and anthocyanin in apple fruit peel at harvest and scald susceptibility.* - Postharvest Biol. Technol., 8(2): 83-93.

KAUR A., SHARMA S., SINGH N., 2021 - *Biochemical changes in pear fruits during storage at ambient conditions*. - Adv. Hort. Sci., 35(3): 293-303.

KINGSTON C.M., 1992 - *Maturity indices for apple and pear.* - Hortic. Rev., 13: 402.

KRAMER P.J., 1983 - *Problems in water relations of plants and cells.* - International Review Cytology, 85: 253-286.

LARRIGAUDIÈRE C., CANDAN A.P., GINÉ-BORDONABA J., CIVELLO M., CALVO G., 2016 - *Unravelling the physiological basis of superficial scald in pears based on cultivar differences.* - Sci. Hortic., 213: 340-345.

LE LEZEC M., BELOUIN A., 1994 - *Test de régression de l'amidon des poires.* - Arboriculture Fruitière, 474: 34-35.

LEE S.K., KADER A.A., 2000 - *Preharvest and postharvest factors influencing vitamin C content of horticultural crops.* - Postharvest Biol. Technol., 20(3): 207-220.

LEJA M., MARECZEK A., BEN J., 2003 - *Antioxidant properties of two apple cultivars during long-term storage.* - Food Chem., 80(3): 303-307.

LI L., XIA Y., XU C., HE J., GUAN J., 2016 - *The incidence of superficial scald in "Wujiuxiang" pears (*Pyrus Pyrifolia *cv. Wujiuxiang) during and after controlled atmosphere storage.* - J. Food Qual., 39: 201-208.

LINDO-GARCÍA V., LARRIGAUDIÈRE C., ECHEVERRÍA G., MURAYAMA H., 2019 - *New insights on the ripening pattern of ' Blanquilla ' pears?: A comparison between on- and o ff -tree ripened fruit*. - Postharvest Biol. Technol., 150: 112-121.

LOPEZ G., BEHBOUDIAN M.H., GIRONA J., MARSAL J., 2013 - *Responses of "Conference" pear to deficit irrigation: Water relations, leaf discrimination against 13CO_2, Tree starch content, growth, and recovery after rewatering.* - J. Plant Growth Regul., 32: 273-280.

LU X.G., MA Y.P., ZHANG L.H., LIU X.H., 2013 - *Interactions of α-farnesene, conjugated trienols, and anti-oxidant activity during the development of superficial scald in "Fuji" apple* - J. Hortic. Sci. Biotechnol., 88: 277-284.

LURIE S., WATKINS C.B., 2012 - *Superficial scald, its etiology and control.* - Postharvest Biol. Technol., 65: 44-60.

MARKHAM K.R., RYAN K.G., BLOOR S.J., MITCHELL K.A., 1998 - *An increase in the luteolin: Apigenin ratio in Marchantia polymorpha on UV-B enhancement*. - Phytochemistry, 48: 791-794.

MDITSHWA A., VRIES F., VAN DER MERWE K., CROUCH E., OPARA U.L., 2015 - *Antioxidant content and phytochemical properties of apple Granny Smith at different harvest times*. - South African J. Plant Soil, 32: 221-226.

MELLIDOU I., KOUKOUNARAS A., KOSTAS S., PATELOU E., KANELLIS A.K., 2021 - *Regulation of vitamin c accumulation for improved tomato fruit quality and alleviation of abiotic stress*. - Genes, 12(5).

MESA K., SERRA S., MASIA A., GAGLIARDI F., BUCCI D., MUSACCHI S., 2016 - *Seasonal trends of starch and soluble carbohydrates in fruits and leaves of 'Abbé Fétel' pear trees and their relationship to fruit quality parameters.* - Sci. Hortic., 211: 60-69.

OKSANEN J., BLANCHET F.G., FRIENDLY M., KINDT R., LEGENDRE P., McGLINN D., MINCHIN P.R., O'HARA R. B., SIMPSON G.L., SOLYMOS P., STEVENS, M.H.H., SZOECS E., WAGNER H., 2019 - *vegan: community ecology package (r package version 2.5-6)* - r foundation for statistical computing. https://cran.r-project.org/web/packages/vegan/index.html

OSORIO S., FERNIE A.R., 2014 - *Fruit ripening: primary metabolism,* pp. 15-27. - In: NATH P., M. BOUZAYEN, A.K. MATTOO, and J.C. PECH (eds) *Fruit ripening: Physiology, signalling and genomics.* - CABI, Wallingford, Oxfordshire, UK, pp. 321.

PASQUARIELLO M.S., REGA P., MIGLIOZZI T., CAPUANO L.R., SCORTICHINI M., PETRICCIONE M., 2013 - *Effect of cold storage and shelf life on physiological and quality traits of early ripening pear cultivars.* - Scientia Horticulturae, 162: 341-350.

PINTÓ E., LENTHERIC I., VENDRELL M., LARRIGAUDIÈRE C., 2001 - *Role of fermentative and antioxidant metabolisms in the induction of core browning in controlled-atmosphere stored pears.* - J. Sci. Food Agric., 81: 364-370.

PLANTON G., 1995 - *Le test amidon des pommes*. - Le Point, 6: 1-4.

PRANGE R.K., WRIGHT A.H., 2023 - *A review of storage temperature recommendations for apples and pears.* - Foods, 12: 466.

RAO M.V., WATKINS C.B., BROWN S.K., WEEDEN N.F., 1998 - *Active oxygen species metabolism in "White Angel" x "Rome Beauty" apple selections resistant and susceptible to superficial scald.* - J. Am. Soc. Hortic. Sci., 123: 299-304.

RIVERO R.M., RUIZ J.M., GARCÌA P.C., LÓPEZ-LEFEBRE L.R., SÁNCHEZ E., ROMERO L., 2001 - *Resistance to cold and heat stress: accumulation of phenolic compounds in tomato and watermelon plants.* - Plant Sci., 160: 315-321.

RIZZOLO A., GRASSI M., VANOLI M., 2015 - *Influence of storage (time, temperature, atmosphere) on ripening, ethylene production and texture of 1-MCP treated "Abbé Fétel" pears.* - Postharvest Biol. Technol., 109: 20-29.

ROWAN D.D., HUNT M.B., FIELDER S., NORRIS J., SHERBURN M.S., 2001 - *Conjugated triene oxidation products of α-farnesene induce symptoms of superficial scald on stored apples.* - J. Agric. Food Chem., 49: 2780-2787.

RUDELL D.R., SERRA S., SULLIVAN N., MATTHEIS J.P., MUSACCHI S., 2017 - *Survey of 'd'Anjou' pear metabolic profile following harvest from different canopy positions and fruit tissues.* - HortSci., 52: 1501-1510.

RÜHMANN S., LESER C., BANNERT M., TREUTTER D., 2002 - *Relationship between growth, secondary metabolism, and resistance of apple.* - Plant Biol., 4: 137-143.

RUPASINGHE H.P.V., PALIYATH G., MURR D.P., 2000 - *Sesquiterpene α-farnesene synthase: Partial purification, characterization, and activity in relation to superficial scald development in apples.* - J. Am. Soc. Hortic. Sci., 125: 111-119.

SADAR N., ZANELLA A., 2019 - *A study on the potential of IAD as a surrogate index of quality and storability in cv. "Gala" apple fruit.* - Agronomy, 9(10): 642.

SAQUET A.A., 2019 - *Storage of pears.* - Sci. Hortic., 246: 1009-1016.

SARKAR D., ANKOLEKAR C., GREENE D., SHETTY K., 2018 - *Natural preservatives for superficial scald reduction and enhancement of protective phenolic-linked antioxidant responses in apple during post-harvest storage.* - J. Food Sci. Technol., 55: 1767-1780.

SHEWFELT R.L., DEL ROSARIO B.A., 2000 - *The role of lipid peroxidation in storage disorders of fresh fruits and vegetables.* - HortSci., 35: 575-579.

SILVA F.J.P., GOMES M.H., FIDALGO F., RODRIGUES J.A., ALMEIDA D.P.F., 2010 - *Antioxidant properties and fruit quality during long-term storage of "rocha" pear: Effects of maturity and storage conditions.* - J. Food Qual., 33: 1-20.

STOW J.R., 1988 - *The effect of cooling rate and harvest date on the storage behaviour of 'Conference' pears.* - J. Hortic. Sci., 63: 59-67.

SZCZESNIAK A.S., ILKER R., 1988 - *The meaning of textural characteristics -Juiciness in plant foodstuffs.* - J. Texture Stud., 19: 61-78.

THERNEAU T., ATKINSON B., 2019 - *rpart: recursive partitioning and regression trees.* - r package version 4.1-15.

VANOLI M., GRASSI M., BIANCHI G., BUCCHERI M., RIZZOLO A., 2015 - *'Conference' and 'Abbé Fétel' pears treated with 1-methylcyclopropene: physiological and quality implications of initial low oxygen stress and controlled atmosphere storage*. - Adv. Hort. Sci., 29(2-3): 84-96.

VIEIRA F.G.K., COPETTI C., DA SILVA CAMPELO BORGES G., GONZAGA L.V., DA COSTA NUNES E., FETT R., 2009 - *Activity and contents of polyphenols antioxidants in the whole fruit, flesh and peel of three apple cultivars*. - Archivos Latinoamericanos de Nutricion, 59: 101-106.

VISSER T., SCHAAP A.A., DE VRIES D.P., 1968 - *Acidity and sweetness in apple and pear.* - Euphytica, 17: 153-167.

WANG Y., ARZANI K., 2019 - *European pear*, pp. 305-327. - In: TONETTO DE FREITAS S., and S. PAREEK (eds.) *Postharvest physiological disorders in fruit and vegetable.* - CRC Press, Boca Raton, FL, USA, pp. 510.

WATKINS C.B., REID M.S., HARMAN J.E., PADFIELD C.A.S.,

1982 - *Starch iodine pattern as a maturity index for granny smith apples: 2. Differences between districts and relationship to storage disorders and yield.* - New Zeal. J. Agric. Res., 25: 587-592.

WHITAKER B., 2004 - *Oxidative stress and superficial scald of apple fruit.* - HortSci., 39: 933-937.

WHITAKER B.D., 2007 - *Oxidation products of α-farnesene associated with superficial scald development in d'Anjou pear fruits are conjugated trienols.* - J. Agric. Food Chem., 55: 3708-3712.

WHITAKER B.D., VILLALOBOS-ACUÑA M., MITCHAM E.J., MATTHEIS J.P., 2009 - *Superficial scald susceptibility and α-farnesene metabolism in "Bartlett" pears grown in California and Washington.* - Postharvest Biol. Technol., 53: 43-50.

XIE X., SONG J., WANG Y., SUGAR D., 2014 - *Ethylene synthesis, ripening capacity, and superficial scald inhibition in 1-MCP treated "d'Anjou" pears are affected by storage temperature.* - Postharvest Biol. Technol., 97: 1-10.

YAZDANI N., ARZANI K., MOSTOFI Y., SHEKARCHI M., 2011 - *α-Farnesene and antioxidative enzyme systems in Asian pear (*Pyrus serotina *Rehd.) fruit.* - Postharvest Biol. Technol., 59: 227-231.

ZHAO J., XIE X., SHEN X., WANG Y., 2016 - *Effect of sunlight-exposure on antioxidants and antioxidant enzyme activities in "d'Anjou" pear in relation to superficial scald development.* - Food Chem., 210: 18-25.

ZIOSI V., NOFERINI M., FIORI G., TADIELLO A., TRAINOTTI L., CASADORO G., COSTA G., 2008 - *A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit* - Postharvest Biol. Technol., 49: 319-329.

ZUDE-SASSE M., TRUPPEL I., HEROLD B., 2002 - *An approach to non-destructive apple fruit chlorophyll determination.* - Postharvest Biol. Technol., 25(2): 123-133.