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Research Article

Preharvest Factors Affecting Quality on "Abate Fetel" Pears: Study of Superficial Scald with Multivariate Statistical Approach

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Although superficial scald (SS) is well characterized on apples, there are only a few insights concerning the influence that agronomic and management variability may have on the occurrence of this physiological disorder on pears. In this study, we aimed to improve our understanding of the effect of different preharvest factors on SS development using a multivariate statistical approach. Pears (*Pyrus communis* L.) cv "Abate Fetel" were picked during two consecutive seasons (2018-2019 and 2019-2020) from twenty-three commercial orchards from three growing areas (Modena, Ferrara, and Ravenna provinces) in the Emilia-Romagna region of Italy. Bioclimatic indices such as weather and soil, agronomic management such fertilization and irrigation, orchard features such as rootstock and training systems, and SS incidence were carried out at harvest and periodically postharvest in all producers. Two different storage scenarios (regular atmosphere and use of 1-MCP) were also evaluated. Our data in both seasons showed high heterogeneity between farms for SS symptoms after cold storage either in the regular atmosphere or with 1-MCP treatment. Nevertheless, in 2018, all the producers showed SS at the end of the storage season, but in 2019 some of them did not exhibit SS for up to 5 months. In fact, some preharvest factors changed considerably between the two seasons such as yield and weather conditions. Indeed, some factors seem to affect SS in both growing seasons. Some can increase its occurrences such as physiological and agronomical factors: high yields, late date of blooming, heavy downpours, improper irrigation management (low watering frequency and high volumes), nitrogen (included that deriving from organic matter), soil texture (presence of clay), orchard age, and canopy volume in relation to training system and rootstock. Others can decrease SS such as climatic and management factors: late harvest dates, rain, gibberellins, calcium, manure, absence of antihail nets or use of photoselective nets, and site (probably related to better soils toward the Adriatic coast). Initial preharvest variability is an important factor that modulates physiological plant stress and, subsequently, the SS after cold storage in "Abate Fetel" pears. Multivariate techniques could represent useful tools to identify reliable multiyear preharvest variables for SS control in pear fruit different batches.

1. Introduction

The need to investigate fruit quality and postharvest management during long-term storage is accentuated by the fact that many Italian farmers have increased their fall productions (e.g., apples, pears, and kiwifruits), notoriously more demanding in terms of their management in the postharvest phase to avoid relevant economic losses [1]. Superficial scald (SS) is one of the main causes of product loss in winter pears such as the "Abate Fetel" variety inside storage cold chambers [2, 3]. The symptom appears as a general browning of the skin, due to the necrosis of the superficial tissues of the epidermis [4]. The study of aetiology is complex, but two main factors can be identified: cold damage and oxidative stress [5–7]. Over the years, attention has also been focused on the volatile α-farnesene compound and its oxidation process, considered to be the main responsible for this disorder [8–10]. Nowadays, the rapid and nondestructive analysis of the VOC array carried out by PTR-ToF-MS identified 6-methyl-5-hepten-2-one (MHO) significantly associated with the development of the SS [11]. To prevent this disorder, until a few years ago, it was possible to treat in postharvest with ethoxyquin [12]. The ban on its use by the EU has raised considerable concerns. Nowadays, chemical treatments with 1-MCP to prevent SS provide results that are not fully acceptable: the main issue is the very slow poststorage maturation and a lack of consistency against SS [13]. "Abate Fetel" pears are affected by low oxygen and ethylene inhibitors, which can cause soft scald or inhibit its maturation even after normal shelf life, respectively [14]. Other methods of disorder mitigation include controlled atmosphere (CA) storage, dynamic CA regulated by chlorophyll fluorescence, oil wraps, and temperature conditioning [4]. However, relatively little is known about crop protectant postharvest practices [15], such as intermittent warming early in the cold storage period, which can be as effective as conventional chemicals [16]. Furthermore, the physiological development and subsequent ripening of the fruit of "Abate Fetel" can change dramatically depending on the previous years based on yields [17] and agronomic, climatic, or orchard management factors [18–20]. It is therefore evident that it is difficult to put in practice consolidated guidelines for the postharvest management of this variety. Horticultural researchers often must measure complex traits and develop relationships with treatments or associated variables. SS symptoms are just the final expression of a physiological disorder, which is multifactorial [20]. Identifying a single variable may not be possible, so we are forced to test many related variables. If the researcher uses univariate statistics to quantify differences or relationships, then the number of separate analyses required will equal the number of individual variables measured. Multivariate analysis reduces a large dataset to a small number of components, which can be scored along independent, linear axes. Variables strongly associated may share some underlying biological relationship. These associations are often useful for generating hypotheses or for understanding the behaviour of complex traits [21]. Many examples exist in the literature where multivariate analysis has been used successfully in plant sciences to develop novel hypotheses, to simplify large datasets, or to understand the response of complex traits [22, 23]. Hence, this research aims to investigate SS occurrence in "Abate Fetel" pears, which represents a model for postharvest storage disorders, to better understand the preharvest factors leading to a strong susceptibility of some producers' batches during storage and after shelf life. Advanced statistical tools are used to describe and identify best practices under the control of farmers or predictable variability of weather or soil that can help to manage, store, and sell "Abate Fetel" pears depending on their potential for storage in healthy conditions.

2. Materials and Methods

2.1. Plant Materials and Experimental Design. Twenty-three orchards of "Abate Fetel" pear located in the Emilia-Romagna region (Italy) in two consecutive seasons (2018-2019 and 2019-2020) were identified, characterized by a variable incidence, in the past, of poststorage SS. For each of them, we proceeded to a detailed characterization of the different crop management parameters, such as nitrogen and microelement application, irrigation regimes, application of plant growth regulators, soil texture and organic matter content, soil cover management, rootstock, training system, and presence/absence of hail nets. The productivity of the orchards, the temperatures and rain events, and the flowering and harvesting dates were also considered. To improve the characterization, surveys about preharvest factors were carried out with each producer considering their field diaries and experience about their orchards. At harvest, appropriate quantities of the product were then placed in a regular atmosphere (−0.5°C and >90% of relative humidity (RH)): eighteen boxes for each farm in the first year and twelve boxes in the second year. Thereafter, six boxes for each producer each year were treated with 1-MCP (Smart-Fresh^{TM}, AgroFresh Inc., Springhouse, PA, USA) and stored in a different room in the same company. After 3, 4, and 5 months of storage, the room was opened, following the calendar normally applied by the company.

2.2. Superficial Scald Assessment in "Abate Fetel" Pears. After 3, 4, and 5 months of cold storage plus 7 days at room temperature (20°C) and controlled humidity (60% of RH), the presence and extent of SS were 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% of SS, class 2 from 25% to 50% of SS, and class 3 over than 50% of SS after shelf life. A SS index was computed as follows [24]:

$$\text{scald index} = \sum_{0}^{4} \frac{(\text{index level})x\,(\text{fruits at this level})}{\text{total number of fruits}}. \quad (1)$$

2.3. Data Treatment and Statistical Analysis. All the data collected were subjected to multivariate analysis, to highlight which—among the factors considered—appears to be more related to the onset of SS. Multivariate statistical analyses, including canonical analysis (CA) and canonical correspondence analysis (CCA), were performed using the statistical software R [25] by addition of packages "candisc" [26] and "vegan" [27]. CA was applied to describe the evolution of SS through epochs and years and the effect of 1-MCP treatment. Afterwards, CCA was used to estimate the interactions between the frequencies of SS classes and the quantitative and qualitative variables. In the first case, the blue vector indicates the increase of the factor in a certain direction while in the second analysis the arrow means the presence of the factor (value 1; e.g., pear orchard with antihail nets). On the contrary, we have its absence or an opposite factor on the other side (value 0; e.g., training system such as fruit wall vs. spindle). Finally, we considered the total variability explained by two components (CCA1 and CCA2) and how each variable affects the first and the second component. Factors and SS data of each epoch (3, 4, and 5 months) and year (2018 and 2019) were combined in CCAs to elaborate the overall picture. In the latter algorithm, 1-MCP treatment was not considered because of its extremely different behaviour between two consecutive seasons.

3. Results and Discussion

3.1. Superficial Scald Development in "Abate Fetel" Pears. Although "Abate Fetel" pears certified by Protected Geographical Indication (IGP) should guarantee consistent quality levels, the unavoidable variability arises from growing environment and production systems, which influence major preharvest factors [28]. Similarly, our data in seasons 2018-2019 and 2019-2020 showed a high heterogeneity between farms after cold storage concerning SS development (Figure 1). In general, we observed that damage of SS increases with time during storage up to 5 months (from 1.1 and 1.2 to 3.1 and 3.2) in a cold room for all the producers in both seasons (Figure 1). However, in 2018 after 5 months almost all the batches had symptoms of SS, but in 2019 some of them did not yet have important SS symptoms after 5 months (Table 1). Regarding 1-MCP treatment (4.1 and 4.2), we noticed that it helped to prevent SS in season 2019-2020, but it was not effective in season 2018-2019 (Figure 1). Moreover, some producers (e.g., 451 in the first season and 222 or 242 in the second season) lost their ripening capacity after 5 months of cold storage or with 1-MCP treatment (data not shown). Some findings reported that "Abate Fetel" pears stored in a normal atmosphere after 4 months become sensitive to SS, can lose their ripening ability and remaining firm, and become dry and unable to reach a buttery and juicy texture, satisfactory for consumption [29, 30]. Nevertheless, some farms showed more symptoms than others with different SS indexes (Table 1), probably because of different locations and the current heterogeneity of preharvest factors. For instance, Moggia et al. (2015) [31] reported high variation in apple across sites in the occurrence of internal browning, reaching up to 48% in some locations. As evidence, multivariate analysis allowed a classification of orchards according to their geographical coordinates and incidence of physiological issues [31].

3.2. Environmental and Agronomic Factors Affecting Superficial Scald in "Abate Fetel" Pears. Some preharvest factors changed considerably between the two seasons such as yield and weather conditions (Table 1), which are reported to affect SS symptoms [32–36]. High variability of fruit peel browning was observed between different years and between producers with different geographic and climatic variables (Table 1). Nevertheless, over six years, the same types of disorder can appear within the same orchard [31] and, consequently, it could be forecasted.

Crop load management is particularly important because it can affect plant physiological status and susceptibility to storage disorders [34]. In both seasons, high yield increases SS, probably due to an unbalance between source-sink ratio and reduction of element concentration. In the first CCA, the high yield projection to the first axis is 0.61 in the direction of class 2 and class 3 (Figure 2), while in the second multivariate analysis production of less than 30 tons per hectare contributes to axis 1 of 0.57 to class 0 (Figure 3). Crop load, associated with warmer climate conditions at harvest, can affect the balance of carbohydrates and calcium in the fruit and leaves and, subsequently, affect postharvest secondary metabolism and, possibly, susceptibility to SS [37, 38]. Indeed, high vegetative vigour can lead to transpiration imbalances and fewer elements being allocated to the developing fruit [39]. On the other hand, other researchers reported that "Passe Crassane" pear from less productive trees have also been shown to be more susceptible to browning disorders [40].

Considering both seasons, we found that late harvest dates, expressed as days after full bloom (DAFB), can prevent the occurrence of SS (contribution to component 1 is 0.43 against SS; Figure 2). As evidenced, the harvest of "Abate Fetel" pears in 2019, when we had a low SS occurrence in fruit, was delayed by 14 days (Table 1). In contrast with this work, SS of "Abate Fetel" pears grown in Argentina in the same orchard and in the same season affected 18% and 33% of the fruit harvested on 23 January and 6 February, respectively [41]. On the other hand, many other papers reported that SS is more severe on early-harvested fruit than on later-picked apples and pears [42, 43]. Therefore, we assume that growing conditions modulating fruit biochemistry would contribute to the effect of the harvest day over SS occurrence, which may justify contrasting findings from different authors with fewer orchards and seasons [44]. In fact, it seems that late-harvested "Abate Fetel" pears have a biochemical profile, such as sugar ratio and antioxidant compounds, enabling them to address the stressful storage condition. Therefore, the increased susceptibility to SS of immature fruit may be attributed to low antioxidants [45].

Bloom date is the first important information to roughly predict the commercial harvest time for a variety. Anyway, a 3- to 4-week variation in bloom date for the same cultivar in the same environment has been reported, showing how phenology in every single year is affected by temperature [46, 47]. In Figure 2, we observed that a late full bloom, expressed as days from the beginning of the year, can increase the occurrence of SS during storage (contribution to component 1 is 0.78 toward SS). In fact, in 2019, we registered an earlier blooming of 10 days compared to 2018. On the other hand, the harvest day between producers was just 3 days delayed in the second year (in 2018 was 03/09 and in 2019 was 06/09). The earlier the bloom time, the longer generally the fruit growing season [48]. So, in 2018, we had a shorter season (146 DAFB) than 2019 (160 DAFB), when we evaluated just a few SS symptoms (Table 1), and, probably, the stock of cold protectant compounds such as secondary metabolites and sugar alcohols with osmoregulatory properties could increase in the fruit. Based on the 30- to 40-year data, global warming is affecting fruit quality; in general, earlier blooming and increase of temperatures (in particular close to maturity) led to more storage disorders [47, 49].

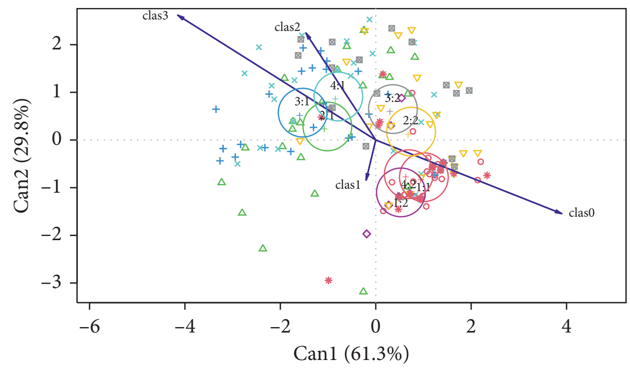

Figure 1: Discriminant canonical analysis (DCA) that describes the behaviour of superficial scald in "Abate Fetel" pears (the blue vectors are clas0 0%, clas1 1%–25%, clas2 26–50%, and clas3 51–100% of peel symptoms) and farm scores (coloured points) in two seasons (2018-2019 and 2019-2020). Percentages in parentheses represent the variance of each component (Can1 and Can2). The following abbreviations have been used for the epochs of sampling from cold rooms after 3 months in 2018 (1.1) and 2019 (1.2), 4 months in 2018 (2.1) and 2019 (2.2), 5 months in 2018 (3.1) and 2019 (3.2), and 5 months with 1-MCP in 2018 (4.1) and 2019 (4.2).

Table 1: Changes in preharvest factors (kilograms of nitrogen from fertilization, millimetres of rain during the growing season, yield in tons per hectare, harvest day expressed as day after full bloom (DAFB) and SS index after 5 months of storage of "Abate Fetel" producers between the first season (2018) and the second season (2019).

Producers	Nitrogen (kg)		Rain (mm)		Yield (t/ha)		Harvest day (DAFB)		SS index	
	1°Y	2°Y	1°Y	2°Y	1°Y	2°Y	1°Y	2°Y	1°Y	2°Y
111	70	151	236	279	45	29	146	162	40.8	14.2
121	31	219	302	281	52	28	146	160	50.0	8.3
131	79	45	226	313	54	41	145	151	61.7	45.8
212	128	82	287	347	40	27	152	165	37.1	25.0
222	67	43	320	354	22	11	152	160	41.7	0.8
242	141	44	152	467	23	5	149	163	35.8	3.3
262	84	110	188	406	40	20	149	164	58.8	16.7
272	9	37	356	416	20	15	147	159	25.0	2.5
282	49	115	124	387	29	21	147	163	50.4	31.7
292	44	20	185	405	15	19	145	163	20.4	48.3
311	339	150	281	339	23	4	146	162	45.8	4.2
321	58	80	248	319	17	10	146	162	58.8	20.0
331	94	73	196	368	41	12	146	162	56.3	39.2
341	98	148	217	332	16	8	153	150	55.4	41.7
351	135	209	256	309	24	20	143	150	20.8	30.8
412	83	168	197	408	38	13	144	157	37.5	23.3
432	62	71	276	448	45	13	146	161	62.9	23.3
442	107	64	194	411	33	13	140	159	54.6	15.8
451	3	79	244	293	40	28	141	165	2.5	5.0
461	75	70	209	301	57	22	143	168	21.3	5.0
472	99	100	375	454	35	16	144	154	45.0	28.3
482	55	120	403	327	35	6	145	151	28.3	7.5
492	133	103	248	354	30	11	146	160	57.1	12.5
Average	89	100	249	362	34	17	146	160	42.1	19.7

Indeed, DAFB cannot always be a precise indicator of fruit maturity, worsened by the fact that a broader bloom window can make fruit maturity even more heterogeneous and lead to errors in predicting optimal harvest dates to avoid SS [48]. The lack of fruit maturation uniformity impacts postharvest operations leading to the necessity to sort fruit in a more homogeneous way to tailor specific storage programs depending on the maturity at harvest to avoid storage issues [50].

Regarding preharvest factors, many studies on fruit quality at harvest highlighted the importance of weather conditions during fruit development [51]. Indeed, soil moisture and precipitation, higher than 120 mm, especially during cellular expansion, encourage vegetative growth and affect fruit maturation, explaining 39% of firmness variation [33, 52]. In the same way, SS in our work was affected by heavy downpours during summer (projection to component 2 is 0.19 toward class 3; Figure 3), which led to flooding and

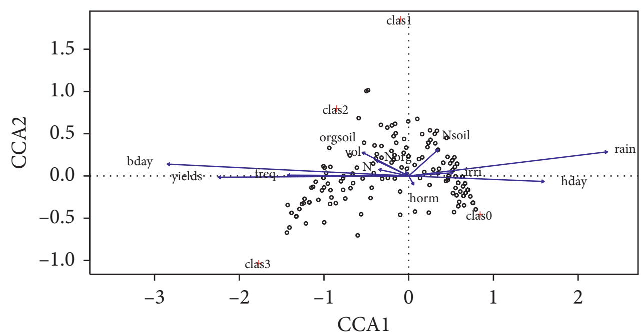

Figure 2: Canonical correlation analysis (CCA) of superficial scald classes of "Abate Fetel" pears (clas0 0%, clas1 1%–25%, clas2 26–50%, and clas3 51–100% of peel symptoms) against quantitative orchard features (blue vectors) and the scores of producers (black circles) in two seasons (2018-2019 and 2019-2020). Total variability explained (23%): CCA1 (95%); CCA2 (3%). The following abbreviations have been used: date of harvest (hday), full bloom date (bday), millimetres of rain (rain) and irrigation (irri) during the growing season, frequency of watering in days (freq), total (N) and organic nitrogen (Norg) expressed in kilograms in fertilizers, nitrogen in soil in percentage (Nsoil), organic matter in soil in percentage (orgsoil), volume of the canopy in m^3 (vol), yields of the orchards in tons (yields), and quantity in grams of gibberellins (horm).

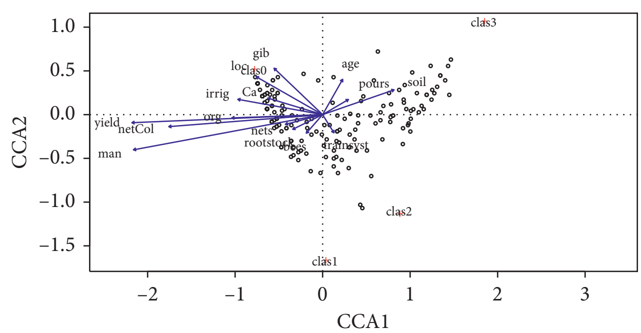

Figure 3: Canonical correlation analysis (CCA) of superficial scald classes of "Abate Fetel" pear (clas0 0%, clas1 1%–25%, clas2 26–50%, and clas3 51–100% of peel symptoms) against qualitative orchard features (blue vectors) and the scores of producers (black circles) in two seasons (2018-2019 and 2019-2020). Total variability explained (18%): CCA1 (93%); CCA2 (4%). The following abbreviations have been used: geographical position (loc) near the Adriatic sea (1) or far from Adriatic sea (0), use bees or pollinators (bees) yes (1) or no (0), use of organic matter (org) yes (1) or no (0), age of the orchard (age) <10 years (1) ≥ 10 years, use of gibberellins (gib) yes (1) or no (0), presence antihail nets (nets) yes (1) or no (0); rootstock (rootstock) weak (1) or strong (0), type of soil (soil) with abundant clay (1) or sand (0), type of irrigation (irrig) below canopy (1) or above canopy (0), training system (trainsyst) such as fruit wall (1) or spindle (0), use of calcium (Ca) yes (1) or no (0), origin of the organic matter used (man) cow manure (1) or poultry manure (0), heavy downpours (pours) during the season yes (1) or no (0), orchard average productivity (yield) ≤30 t/ha (1) or >30 t/ha (0), and presence of coloured nets or no-nets (netCol) yes (1) or no (0).

unbalance between fruit development and vegetative growth. Nevertheless, high soil moisture conditions are either the result of high irrigation or intense rainfall. Without considering fruit quality, the contribution of precipitations and irrigation against SS to component 1 is 0.64 and 0.14, respectively. To explain that, low precipitation conditions may be involved with calcium deficiency and, thereby, loss of cell turgor [53], as a result of reduced transportation of ions to and from cells [54]. In addition, it is possible that proteins specifically induced by low temperature and, associated with tolerance of cold damage, may have a longer-term effect [55]. It was postulated that preharvest temperatures below 10°degrees 2-3 weeks before harvest increase the content of unsaturated fatty acids such as oleic (C18 : 1) and linoleic (C18 : 2) acids to cope with this stress [44, 56]. Contrarily, it is also reported that low air temperature conditions reduce storability at harvest by diluting the calcium concentrations absorbed by the fruit [36]. However, precipitation events are closely related to low light intensities and low air temperatures and, as consequence, can affect the early drop of fruitlets between 30 and 60 DAFB [52] and, consequently, yield. In particular, in the second season (2019) which was rainy and with low SS, in general, yields were below average (Table 1).

Low density and larger trees, with lower temperature and light penetration inside the canopy [55], increase SS occurrence in stored pear fruit. In Figure 2, the contribution toward class 2 in components 1 and 2 of canopy volume is 0.10 and 0.25, respectively. Indeed, many fruit characteristics such as skin colour, flesh firmness, titratable acidity, soluble solids, and fruit size are influenced by the light [32, 57, 58], and therefore, defining the ripening distribution of fruit in the whole canopy could impact the storage process.

The ability of light to penetrate tree canopies and, therefore, to affect microclimate of fruit, is influenced by several factors including tree spacing, canopy architecture [59], rootstock, orchard management practices, such as pruning and thinning [60], and presence of antihail nets [61]. Regarding training system and rootstock, a slight correlation in Figure 3 was found in our trial where weak rootstocks and spindle-shaped trees, with small canopies, showed reduced SS. In particular, "Abate Fetel" trees grafted on quince contribute to components 1 and 2 of 0.08 and 0.19 against SS. On the other hand, the projection on component 2 of the variable represented by expanse tree architecture is 0.23 toward class 2. A study on the effect of training system and rootstock on poststorage fruit quality of "d'Anjou" pear found that the effect of training system on vigour and fruit nutrient content could contribute to poststorage concerns [62]. Indeed, fruit characteristics can greatly vary within expanse canopy that characterized orchards prone to SS in our study (Figure 3). In the Emilia-Romagna region, the harvest of pears is generally carried out with a single pick, and fruits are pooled together in the same bins. Consequently, high variability in quality exists in a single bin, which can impact postharvest fruit quality and storability and often results in repacking issues [32] and, therefore, fruit damages.

As far as the presence and colour of antihail nets, in Figure 3, we found that the shading effect of standard antihail nets can enhance the occurrence of SS after long-term storage. The contribution of antihail nets to component 2 towards class 1 is 0.12 and the projection of coloured or no-nets to component 1 is 0.46 against SS. It was shown that orchards with more exposure to sunlight produce better colour [63] and increased anthocyanins in fruit [64], offering better resistance to SS development [56]. Moreover, a study with multivariate analysis about within-tree factors of peach highlighted that lower light interception experienced under nets may have a detrimental effect on the flavour and may contribute to the variation in fruit quality at harvest [65]. Concerning the shade effect in fruit, it is often reported that the shaded side of the apple is more susceptible to storage disorders such as SS [66]. Superior SS protection on the sun-exposed side of the fruit may be related to elevated xanthophyll and anthocyanin levels and diminished susceptibility to photoinhibition, relative to the shaded side [67–69]. However, cultural practices such as antihail or anti-insect netting are employed in pear orchards by several growers in the Emilia-Romagna region. On the other hand, shading treatments with kaolin against sunburn affected fruit quality of "Packham's Triumph" pears increasing fresh weight and chlorophyll contents [70], as evidence of a slower climacteric outset.

Together with environmental factors, planting year and orchard site play an important role on SS in "Abate Fetel" pears, affecting vegetative self-shading and soil properties, respectively. In Figure 3, their contributions to component 2 are 0.46 and 0.49 towards class 3 and class 0, respectively. Indeed, not only weather and soil features can affect it, but also farm practices. Hence, in our research, young orchards appear to have more SS symptoms than older ones (Figure 3). Young trees, which probably have the characteristics of light-cropping trees, are considered to be more susceptible to storage disorders before harvest or during conservation [71, 72]. On the other hand, it is reported that high crop loads, especially in young orchards, can dramatically affect future productivity and fruit quality [72]. Moreover, in young apple trees, nitrogen is used to stimulate growth and excessive levels of this element can reduce fruit quality with fruits that are larger, greener, softer, more prone to drop, and more affected by storage issues [73]. Moreover, in our study, pear orchards near the Adriatic Coast (Ravenna and Ferrara provinces) had lower SS incidence than producers from inland areas (Modena and Bologna provinces). Agar et al. (1999) [74] observed that differences in ripening behaviour and response to ripening inhibitors might occur in the fruit of the same cultivar grown in different environments. They found that "Bartlett" pears from growing locations with cooler preharvest temperatures and/or from later harvests within a growing location had a different ability to ripen. By contrast, Chiriboga et al. (2013) [75] found that the variability of fruit quality of "Conference" pears after 105 days of cold storage was explained by the 1-MCP effect, followed by the shelf-life duration, harvest date, and to a lesser extent the orchard location.

Orchard location may act on the fruit sensitivity to SS in terms of availability of organic matter to spread in the orchard and texture of the soil. In the first case, it seems to prevent SS, and in the second case, the presence of clay apparently promotes it. In Figure 3, the projections of the organic matter and soil texture on the first component are 0.27 and 0.21. Soil factors determine in part fruit physiology and especially the ability of the fruit to regulate the initial physiological maturity at harvest [76], which can result in differences in ripening behaviour for fruit grown in different environments [77]. In fact, we observed that abundant clay in the soil can induce SS and, likely, increases organic matter content and soil moisture (Figures 2 and 3). This is partially in contradiction with the effects of precipitations and irrigation on SS (Figure 2). On the other hand, water stress may be a more critical factor than soil texture by the combination of high temperatures and low soil moisture aggravating SS development [36].

Nonetheless, soil texture affects the capacity of roots to extract, from the soil solution, nutrients such as nitrogen, which could be provided by fertilization or naturally occurring organic matter, affecting on the one hand vegetative growth and on the other hand soil fertility. Studies concerning the relationship between increased levels of nitrogen fertilizer and the incidence of storage disorders have reported variable results depending on the general nitrogen status of the orchard and the availability of other soil nutrients [71]. In Figure 2, nitrogen fertilization seems to promote SS (its contribution to the first axis is 0.09). We considered not only nitrogen from chemical fertilizers but also from organic matter, such as poultry manure spread in the orchards, which seems to have the same effect on SS with lower importance (Figure 2). Nitrogen fertilization promotes vegetative growth with consequent higher self-shading and chlorophyll content in fruit [78], but it can reduce flesh firmness and TSS content [79]. Thus, we assume that high nitrogen soil fertilization would increase fruit size but reduces storage quality and crop value. Furthermore, low N availability impacts fruit quality: organic “Abate Fetel” pears had more total polyphenols and higher ascorbic acid stimulated by hexoses than conventionally grown ones. Also, the sugar profile differed, with a higher ratio of monosaccharides/disaccharides [80]. Nevertheless, nutrients needed for trees are in the soil so the orchard floor represents a substantial portion of the orchard agroecosystem, and if properly managed, it can reduce fertilizer costs [81]. In our experience, the slower release of the naturally occurring nitrogen humidified inside an organic matter of soil seems to prevent the occurrence of SS in “Abate Fetel” pears (0.09 of contribution to the principal component; Figure 2). The total organic matter in soil has not the same effect on SS (Figure 2). Pears demand 50–60 kg ha^{-1} to retain good fruit quality and production. So, the role of reserves and N resorption in the fall from leaves or cover crops were key findings that led to a more efficient and sustainable N management for each region and orchard in order to optimize nutrient uptake and minimize leaching [81, 82].

Any given fertilizer program cannot be successful without an efficient irrigation program. Water is scarce in most pear districts for both quantity and quality [81]. Water availability was identified as the major factor controlling tree growth globally in the current climate change scenario [83]. In Figure 2, the amount of water supplied in “Abate Fetel” orchard in 2018 and 2019 was considered (0.14 of importance in component 1). As we discussed before, watering has the same effect on SS of precipitation (Figure 2), but the modality of water application had an additional effect (Figures 2 and 3). Where the time interval (days between two watering) was considered, we observed that larger volumes at the same time (i.e., longer time interval) induced higher SS (0.39 of importance in component 1). Along the same line, microirrigation helped to prevent SS after storage (0.25 of importance in component 1). In apples, water stress lowered the rate of firmness loss, indicating an alteration in the physiological mechanism of fruit ripening [84]. Nevertheless, extended dry periods increased the risk of storage disorders when followed by heavy rains or irrigation [85], such as heavy downpours and high irrigation volumes (Figures 2 and 3). In addition, increasing irrigation frequency may lessen high temperature effects on foliage plant growth [86]. At elevated temperatures, the oxygenating reaction of RUBISCO (ribulose bisphosphate carboxylase-oxygenase) increases more than the carboxylating one because CO_2 declines more rapidly with increasing temperature than does O_2 [39, 87]. Thus, photorespiration becomes proportionally more important [87], generating an unbalance between carbohydrate rates. Concerning the application of deficit irrigation during the season, early stressed “Nijisseiki” Asian pear had a higher concentration of sugars such as sucrose, glucose, fructose, and sorbitol with a cold protectant activity than nonstressed fruit. Nevertheless, early stressed fruit tended to have higher flesh spot decay although it was reduced in the late-stress treatment [34, 88].

Calcium is transported in the transpiration stream [89]. In “Niitaka” pear, water stress decreased the concentration of calcium in flesh during the early stage of fruit growth. Moreover, it increased peroxidase activity and may be due to limited calcium absorption [90]. As we can notice in Figure 3, producers that spray calcium in “Abate Fetel” pears during the vegetative season have less SS in pear fruit and its contribution in the first component is 0.16. This insight agrees with Drake et al. (1979) [37] and Bramlage et al. (1985) [38] who negatively correlated fruit calcium level and SS development and found SS to be more prevalent when peel calcium was <700 mg L^{-1} [91]. In “Abate Fetel” pears, 53% of untreated fruits and only 4.6% of those treated with 4.5% $CaCl_2$ were affected by soft scald after 210 days of storage [92]. By the way, Gerasopoulos and Richardson (1997) [93] suggested that fruit calcium concentration increases the chilling requirement for induction of ripening capacity.

Parthenocarpic fruits tend to have lower calcium concentrations [94], and, in general, fruits sprayed with gibberellins have lower seed numbers, lower calcium concentrations, and an increased incidence of storage disorders [95–97]. However, as we can notice in Figure 3, it seems that the use of gibberellins, instead of pollinators, during the blooming can prevent SS; eventually, by postponing fruit harvest maturity and extending growth season cause parthenocarpic behaviour (its contribution to the second axis is 0.60). However, we can notice in Figure 2 that the quantity of hormones such as gibberellins does not affect SS after storage, and its projection on component 2 is 0.14. In “Forelle” pears, gibberellins produced fruit with a large cell diameter (140.3 μm) and resulted in a low mealiness percentage and, consequently, with higher fruit quality [98]. Nevertheless, the incidence of storage issues in larger celled fruit was explained arguing that cell contact area between neighbouring cells is reduced making the cells prone to cell-to-cell debonding during ripening [99], resulting in tissue breakdown [100].

4. Conclusions

The pear industry in Italy is currently threatened by many issues and among them storage-related problems and fruit quality concerns. This works shows the extreme variability among producers and seasons in terms of appearance and severity of superficial scald (SS) as a physiological disorder in “Abate Fetel” pears with either normal atmosphere or 1-MCP cold storage. Weather patterns, soil characteristics, bloom date, and location, outside grower’s control, have an impact, but also yield, irrigation regime and volumes, fertilization, growth regulators, rootstock, and training system, which growers have a handle on, can affect SS in pears during storage. Our approach, using multivariate statistical techniques, has highlighted several key preharvest factors which could be grouped considering their biological relationships. In general, SS seems to be induced by several plant physiological stresses resulted from an improper yield management, without considering tree resources and weather conditions, an unbalance between reproductive and vegetative growth and self-shading effect, a short season and, consequently, few cold protectant compounds, and, finally, a soil deficiency caused by a not efficient governance of water supply and organic matter fertility. In the future, a widespread application of such statistical tools will be recommended to describe complex traits that impact fruit storage, with the goal of predicting and improving it. The major conclusion, however, is that pear batches from different orchards should be sorted for their potential to develop SS after shelf life before applying storage technologies or placing them in cold rooms where they become, perforce, all equal. The technology to do so is available but has not yet been tested with this goal. We hope to be able to continue developing effective, predictive approaches to fulfil this achievement.

Data Availability

The data used to support the findings of this study are included within this article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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