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Impact of Rootstock and Tree Position on the Biochemical Quality and Nutritional Stability of Pears During Storage

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Abstract

The nutritional value of fruit is essential for human health; however, these attributes may be lost or degraded during storage. Fruit behaviour during the storage period is strongly influenced by pre-harvest production factors. In this study, biochemical quality parameters were analysed post-harvest, as well as during and after storage in ultra-low oxygen (ULO) conditions. Three pear varieties ('Williams', 'Abate Fetel', and 'Conference') were evaluated on two rootstocks (quince and wild pear seedling) across three plot positions (top, middle, and base) over two consecutive years. The analyses included total phenolic content (TPC), antioxidant capacity (AOC), soluble solids content (SSC), and individual sugar profiles (glucose, fructose, sucrose, and sorbitol). The results indicate that the rootstock significantly influenced the analysed fruit characteristics in cultivars investigated. Rootstock had a highly statistically significant impact on SSC of 'Abate Fetel' and 'Conference', whereas the difference was not significant for 'Williams'. All cultivars showed lower TPC and AOC on seedling rootstock. Conversely, the effect of tree position on the studied parameters and the stability of nutritional traits during storage was not statistically significant. It was concluded that the cultivars exhibited distinct behaviours under the storage regime depending on the factors observed. During storage, 'Williams' maintained a high nutritional value, particularly regarding phenolic and sugar content and strong antioxidant capacity. In contrast, 'Abate Fetel' and 'Conference' showed a decline in nutritional properties, which adversely affected overall fruit quality.

Keywords: fruit quality; total phenolic content; DPPH Assay; individual sugars; ULO storage

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1. Introduction

Fruit storage aims to extend the availability of fresh produce throughout the year, a goal that must be achieved without compromising fruit quality. With advanced storage technologies, pears can remain available on the market until the subsequent harvest, providing a significant advantage for consumers of this fruit species. Fruit quality at the time of harvest is critical for long-term storage, and the preservation of quality in stored fruit primarily depends on a variety of factors, including environmental conditions, agrotechnical measures, and harvest timing, as well as post-harvest conditions [1–3]. Post-harvest, the primary objective is to maintain fruit quality and appeal during storage-specifically preserving appearance and structure, alongside aroma and nutritional value -as these quality factors fundamentally drive consumer purchasing decisions [4,5].

The nutritional value and antioxidant activity of pears are highly significant for human health [6,7]. While the content of secondary metabolites in the fruit primarily depends on the cultivar [8,9], it can be substantially depleted under suboptimal storage conditions. Therefore, it is of particular

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importance to maintain the antioxidant content in the fruit, especially phenolic compounds, as well as the natural sugars essential for human nutrition.

The storage potential of pear fruit may depend on the specific scion/rootstock combination. The choice of rootstock significantly influences on fruit quality [10,11] and storage capacity [12]. Various rootstocks exert an influence on cultivar traits, resulting in nuanced variations in fruit quality. Furthermore, rootstocks can affect plant metabolism, which is manifested through changes in the synthesis of primary and secondary metabolites, thereby directly influencing the organoleptic properties and nutritional value of pears [13]. Research has showed that different rootstock types can substantially modify the biochemical composition of the fruit, including phenolic levels, antioxidant activity, and sugar concentrations [7]. The most commonly used rootstocks for pear production are wild pear seedlings (Pyrus communis L.) and quince (MA, BA 29). Each of these rootstocks has advantages and disadvantages within intensive orchard systems [14]. Given their varying physiological characteristics and adaptations to production environments [15], rootstocks can significantly impact the sugar and phenolic content of the fruit [15–17].

The position of the fruit on the tree significantly influences pear quality [4]. While selective harvesting remains a common practice, the specific position of trees on sloped terrains within large-scale orchard complexes is often overlooked during the harvest process. Previous research has indicated that the fruit quality of a single cultivar can vary significantly between individual trees [18] and is dependent on slope exposure and the tree's position within the production plot [19,20]. Specifically, reduced light intensity leads to a decrease in the concentration of biochemical components in fruit. Improved light interception and terrain slope can significantly impact fruit quality, even within the same geographical region and soil type [21].

The objective of this study was to evaluate the biochemical characteristics of pear varieties ('Williams', 'Abate Fetel', and 'Conference') grafted onto two rootstocks (quince and wild pear seedling) across three canopy positions (top, middle, base) over two consecutive years. Biochemical characteristics were assessed at harvest, as well as during and after storage under ultra-low oxygen (ULO) conditions.

2. Materials and Methods

2.1. Object and Material of the Study

Fruit sampling was conducted in the "Agroimpex Nova" commercial pear orchard located in Jablanica (Gradiška, Bosnia and Herzegovina) during 2 growing seasons. The orchard is situated on sloped pseudogley soil with a gradient of 5–7%. The total orchard area is 120 ha, with pear production covering 66 ha. The trees were planted in 2007, making them six years old at the start of the study. The trees were trained as slender spindle with a north-south row orientation and equipped with a drip irrigation system. The study included three commercial pear cultivars: 'Williams', 'Abate Fetel', and 'Conference', grafted onto two rootstocks: wild pear seedling and quince MA. For each cultivar/rootstock combination, trees were selected from three positions within the plot: top, middle, and base. To ensure uniformity, the first five trees in each row were bypassed, and sampling was performed on the subsequent ten trees. Fruits for analysis were collected from each individual tree (nine fruits per tree) using a random sampling method, resulting in a total of 90 fruits for each cultivar/rootstock/position combination. These samples were further divided into three groups of 30 fruits each for analysis at different intervals: post-harvest, mid-storage, and full storage duration. The optimal harvest time was determined using destructive maturity methods on representative samples for each combination.

2.2. Storage Conditions

Each cultivar was stored under individual low oxygen (ULO) conditions according to the following specific regimes: 'Williams'–temperature −0.5 to 0 °C, relative humidity (RH) 93–95%, CO2 2%, O2 2%; 'Abate Fetel'–temperature −0.5 to 0 °C, RH 93–95%, CO_2 1%, O_2 3%; and 'Conference'–

temperature −0.5 to 0 °C, RH 93–95%, CO_2 0.8%, O_2 2–3%. Fruit quality assessments were conducted at three intervals. For 'Williams' and 'Conference', mid-storage and full-storage analyses were performed one and two months post-harvest, respectively. For 'Abate Fetel', these intervals were 1.5 months and three months post-harvest. After removal from storage, all fruits were conditioned at room temperature for 24 h prior to analysis.

2.3. Total Phenolic Content

The total phenolic content (TPC) of the fruit was determined using a modified Folin-Ciocalteau method [22]. For sample preparation, 5 g of fruit tissue was weighed and mixed with 15 mL of methanol, followed by homogenization using a mixer (VELP Scientifica, Europe). The samples were then allowed to stand for 1 h at room temperature in darkness to ensure complete extraction. Subsequently, the mixture was centrifuged at 2000 x g 15 min (CENTRIC 322A, Domel, Slovenia). The supernatant was filtered, and the filtrate was diluted to a final volume of 25 mL with distilled water. A 1 mL aliquot of the fruit extract was mixed with 10 mL of distilled water and 0.5 mL of Folin-Ciocalteau (FC) reagent (Sigma-Aldrich, Switzerland). After 5 min, 2 mL of 7,5% Na2CO3 was added. After 2 h, absorbance was measured at 765 nm using a spectrophotometer (UV-3100PC, VWR, China). Each sample was prepared in triplicate, and the results are expressed as mean values with standard error. A calibration curve was prepared using gallic acid (Lachner, Czech Republic) at concentrations ranging from 0.005 to 0.25 mg/mL. The total phenolic concentration was calculated from the linear regression equation, and the results are expressed in mg GAE/100 g of fresh weight (FW).

2.4. Antioxidant Capacity (DPPH Assay)

The antioxidant activity (AOC) of the sample was determined by quenching stable free 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals (Sigma-Aldrich, Switzerland), following the procedure described by Liyana-Pathirana and Shahidi [23]. Sample preparation was conducted according to a modified method by Tehrani et al. [24]. Specifically, 5 g of pear pulp was weighed and mixed with 15 mL of methanol. After a one-hour extraction period to ensure complete extraction, the supernatant was filtered, and the sample was diluted with methanol to a final volume of 25 mL. From this stock solution, five different concentrations were prepared, ranging from 8 to 56 mg/mL. In 1 mL of each different concentration of five sample 1 mL of 0.135 mM methanolic solution of DPPH was added. The mixture was mixed and allowed to stand for 30 min in the dark. Subsequently, the absorbance was measured at 517 nm using a spectrophotometer (UV-3100PC, VWR, China). The control sample contained methanol instead of the fruit extract. Based on the diagram which shows antiradical activity in relation to the different concentrations of the sample the EC50 value (represents the effective concentration at which 50% of DPPH radicals were quenched) was determined. Results are expressed as mg ml^{-1} of FW.

2.5. Solible Solid Content

The soluble solids content (SSC) of the fruit juice was determined using a digital refractometer (Atago Co., Ltd., Japan). The juice, obtained by squeezing and filtering the pear pulp, was applied directly to the refractometer sensor. The results were expressed as °Brix for 30 sample od fruit.

2.6. Individual Sugars Content

The concentrations of glucose, fructose, sucrose, and sorbitol in the pear fruit were determined using high-performance liquid chromatography (HPLC; Agilent 1100, USA) equipped with an ELSD 1260 detector (Infinity Evaporative Light-Scattering Detector). The fruit sample (homogenized pulp) was centrifuged at 13 200 x g 10 min (Eppendorf 5415D Centrifuge, Marshall Scientific, Germany). The resulting supernatant was diluted in a 1:5 ratio with a mixture of acetonitrile and water (65:35, v/v). Sugar separation was achieved using colimn 4,6 mm x 250 mm, 5 µm (Prevail carbohydrate ES column, Grace Davison Discovery Sci-ence, IL, USA). The mobile phase consisted of (A) water and

(B) an acetonitrile:acetone mixture (75:25, v/v), delivered isocratically at a flow rate of 1 mL/min. The column temperature was maintained at 30 °C, and the injection volume was 5 μL. The ELSD temperature was set to 50 °C, with a nebulizer pressure of 3.4 bar. Individual sugar concentrations were calculated using calibration curves based on external standards. Results are expressed as g/L.

2.7. Statistical Analysis

The measured parameters are presented as mean values with standard deviation (X ± SD) and the coefficient of variation. Principal Components Analysis (PCA) was peformed in order to study grouping and dispersion patterns among studied treatment groups, as well as correlation of measured characteristics. Statistical and graphical analyses were carried out using IBM SPSS Statistics software, version 22 (IBM Corp., Armonk, NY, USA).

3. Results

3.1. Influence of Rootstock, Tree Position, and Storage Duration on Total Phenolic Content

The results for total phenolic content, in relation to rootstock, tree position within the plot, and the analysis period throughout the study years, are presented in separate tables for each pear cultivar.

Table 1. Total phenolic content (mg GAE/100 g) in 'Williams' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		**2013**								**2014**							
Rootstock		Seedling				Quince				Seedling				Quince			
Position	**Period**	X ± Sx			Vc	X ± Sx			Vc	X ± Sx			Vc	X ± Sx			Vc
Top	Post harvest	338,1	±	12,84	6,58	220,0	±	16,68	13,13	448,5	±	15,56	6,01	720,8	±	41,41	9,95
	Mid-storage	334,7	±	21,91	11,34	368,5	±	21,44	10,08	492,9	±	14,88	5,23	568,9	±	40,59	12,36
	Full storage	329,4	±	16,09	8,46	373,6	±	14,08	6,53	538,1	±	22,31	7,18	511,5	±	18,28	6,19
Middle	Post harvest	236,4	±	16,79	12,30	442,2	±	39,72	15,56	480,7	±	29,08	10,48	702,8	±	43,50	10,72
	Mid-storage	220,7	±	10,89	8,55	357,6	±	22,89	11,09	526,7	±	25,33	8,33	725,6	±	47,04	11,23
	Full storage	356,6	±	20,13	9,78	322,5	±	18,08	9,71	448,3	±	17,05	6,59	535,4	±	28,16	9,11
Base	Post harvest	213,2	±	20,42	16,59	313,3	±	16,37	9,05	541,9	±	17,21	5,50	795,9	±	30,23	6,58
	Mid-storage	204,0	±	11,02	9,36	454,7	±	32,21	12,27	486,5	±	19,99	7,12	361,1	±	29,52	14,16
	Full storage	174,5	±	10,13	10,06	366,7	±	18,12	8,56	306,4	±	12,24	6,92	490,2	±	33,31	11,77

X ± Sx—mean values with standard deviation, Vc—coefficient of variation.

According to Table 1, the highest TPC was recorded in fruits grown on quince rootstock at the plot base post-harvest in 2014 (795.9 mg GAE/100 g). However, the lowest TPC was observed in 2013 in fruits on seedling rootstock at the same position following the storage period (174.5 mg GAE/100 g).

In 2013, fruits at the plot base had higher TPC on quince compared to seedling across all analysis periods. Regarding the other two positions, higher phenolic levels were observed in fruits on quince at the plot middle from harvest to mid-storage; however, upon removal from cold storage, higher values were recorded for seedling-grown fruits at this position. At the plot top, a higher TPC was noted on seedling rootstock at harvest. Additionally, a decline in TPC was observed during extended storage on seedling rootstock, with the exception of fruits from the plot middle after removal from storage. In 'Williams' pears on quince, an increase in phenolic content was observed during storage for fruits from the plot top, while no clear patterns were identified for the other two positions.

In the second year of the study, the following observations were made: in fruits grown on seedling rootstock at the plot top, phenolic content increased during storage, whereas a completely opposite trend was observed for those on quince rootstock. At the plot middle, similar behavior was exhibited on both rootstocks; specifically, a decrease in TPC occurred after the mid-storage period. At the plot base, the highest TPC for both rootstocks was recorded at harvest, with no distinct patterns emerging during further storage.

Table 2. Total phenolic content (mg GAE/100 g) in 'Abate Fetel' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		2013								2014							
Rootstock		Seedling				Quince				Seedling				Quince			
Position	**Period**	X ± Sx			Vc	X ± Sx			Vc	X ± Sx			Vc	X ± Sx			Vc
Top	Post harvest	764,5	±	35,71	8,09	638,3	±	56,09	15,22	634,6	±	32,20	8,79	505,6	±	32,02	10,97
	Mid-storage	710,3	±	34,24	8,35	591,1	±	36,92	10,82	692,7	±	49,71	12,43	654,6	±	32,34	8,53
	Full storage	1134,6	±	35,90	5,48	848,6	±	47,18	9,63	536,7	±	32,72	10,56	434,4	±	28,82	11,49
Middle	Post harvest	972,6	±	40,77	7,26	702,4	±	51,78	12,77	569,7	±	21,90	6,66	532,0	±	39,19	12,76
	Mid-storage	918,7	±	44,13	8,32	928,2	±	73,11	13,68	628,2	±	33,08	9,12	719,0	±	34,58	8,33
	Full storage	1136,5	±	43,76	6,67	753,4	±	36,23	8,33	392,7	±	26,93	11,88	447,1	±	17,37	6,73
Base	Post harvest	634,5	±	36,74	10,03	861,7	±	37,76	7,59	582,6	±	49,51	14,72	591,3	±	36,01	10,55
	Mid-storage	626,1	±	38,10	10,54	855,2	±	58,81	11,91	456,4	±	35,36	13,42	672,4	±	47,83	12,32
	Full storage	691,3	±	48,13	12,06	1510,0	±	57,36	6,58	502,7	±	26,58	9,16	406,8	±	16,72	7,12

X ± SD—mean values with standard deviation, Vc—coefficient of variation.

The highest TPC in 'Abate Fetel' fruits was recorded on quince rootstock at the plot base in 2013 (1,510.0 mg GAE/100 g). On the other hand, the lowest content was observed on seedling rootstock at the plot middle upon removal from cold storage during the second year of the study (392.7 mg GAE/100 g).

In 2013, fruits on seedling rootstock showed the highest average phenolic levels at the plot middle, followed by the top, while the lowest values were recorded at the plot base. On quince rootstock, however, the highest TPC was observed at the plot base, showing a decreasing trend towards the plot top. Observations during the first year of storage revealed a distinct decline in phenolics during the first half of the storage period, followed by a subsequent increase during extended storage. A deviation from this trend occurred in fruits on quince rootstock at the plot middle during the second year.

In 2014, 'Abate Fetel' fruits on seedling rootstock had a higher TPC at the plot top compared to those on quince rootstock; however, this trend was not observed at the plot middle or base. During the second year, the highest TPC in 'Abate Fetel' on seedling rootstock was recorded at the plot top, with a decreasing trend toward the base. However, on quince rootstock, the highest average phenolic levels were found at the plot middle, followed by the base, and the lowest at the top. In the second year showed an increase in TPC during the first half of the storage period, then declining during extended storage. A deviation from this pattern occurred in fruits on seedling rootstock at the plot base, where an increase in phenolics was noted after the mid-storage period; however, it is important to emphasize that this increase was only indicative.

Table 3. Total phenolic content (mg GAE/100 g) in 'Conference' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		2013								2014							
Rootstock		Seedling				Quince				Seedling				Quince			
Position	**Period**	X ± Sx			Vc	X ± Sx			Vc	X ± Sx			Vc	X ± Sx			Vc
Top	Post harvest	339,0	±	11,64	5,95	253,2	±	13,39	9,33	217,0	±	10,10	8,06	140,3	±	8,61	10,63
	Mid-storage	326,8	±	16,72	8,86	649,2	±	49,70	12,46	267,4	±	12,83	8,31	219,0	±	12,69	10,04
	Full storage	343,7	±	13,73	6,92	393,8	±	27,53	12,11	196,5	±	14,38	12,68	248,3	±	13,20	9,21
Middle	Post harvest	259,1	±	9,20	6,15	113,2	±	5,503	8,42	231,7	±	13,47	10,08	230,4	±	17,97	13,51
	Mid-storage	401,5	±	23,89	10,31	741,1	±	38,93	9,10	164,4	±	13,49	14,22	139,8	±	10,26	12,71

	Full storage	228,9 ± 12,96	9,81	433,7 ± 15,80	6,31	153,9 ± 16,49	18,56	196,0 ± 7,219	6,38
Base	Post harvest	150,3 ± 6,69	7,72	131,1 ± 5,291	6,99	198,9 ± 11,65	10,15	253,8 ± 7,649	5,22
	Mid-storage	399,5 ± 12,34	5,35	448,5 ± 26,20	10,12	195,1 ± 10,55	9,37	237,5 ± 20,06	14,53
	Full storage	238,7 ± 16,55	12,10	412,9 ± 31,04	13,02	140,8 ± 13,06	16,05	215,2 ± 18,75	15,09

X ± SD—mean values with standard deviation, Vc—coefficient of variation.

In the 'Conference' cultivar, the highest TPC was recorded in fruits on quince rootstock at the plot top during mid-storage in 2013 (649.2 mg GAE/100 g). On the other hand, the lowest TPC had fruits on the same rootstock at the plot middle at harvest during the same year (113.2 mg GAE/100 g).

In 2013, an average decline in TPC was observed from the plot top toward the base for fruits on both rootstocks. During the storage period, both rootstocks also was an increase in phenolics in the first half of storage, followed by a sharp decline during extended storage. However, this pattern was not observed in fruits on seedling rootstock at the plot top, as no significant increase was recorded during the first half of the storage duration.

During the second year, fruits on seedling rootstock showed a decreasing trend in phenolic content from the plot top to the base, whereas those on quince rootstock reached their highest TPC at the base and the lowest at the middle. At the plot base, a higher TPC was recorded on quince compared to seedling rootstock across all analysis periods, while no similar behavior was observed at the other two positions. For fruits on seedling rootstock at the middle and base, as well as those on quince at the base, TPC decreased during extended storage, whereas other groups exhibited varying patterns during cold storage.

3.2. Influence of Rootstock, Tree Position, and Storage Duration on Antioxidant Capacity

Table 4. Antioxidant activity (EC_{50}) of 'Williams' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		2013				2014			
Rootstock		Seedling		Quince		Seedling		Quince	
Position	**Period**	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc
Top	Post harvest	139,4 ± 9,94	12,3	131,8 ± 8,19	10,8	50,3 ± 1,81	6,2	41,2 ± 1,59	6,7
	Mid-storage	88,8 ± 4,42	8,6	62,9 ± 3,39	9,3	38,5 ± 1,90	8,6	41,6 ± 2,24	9,3
	Full storage	43,7 ± 2,31	9,1	82,6 ± 6,35	13,3	36,2 ± 1,29	5,8	35,8 ± 1,86	9,0
Middle	Post harvest	44,8 ± 3,37	13,0	104,6 ± 4,92	8,2	49,9 ± 2,91	10,1	31,2 ± 1,90	10,5
	Mid-storage	57,2 ± 3,32	10,1	46,2 ± 2,49	9,3	40,8 ± 2,20	9,4	37,7 ± 1,83	8,4
	Full storage	56,8 ± 2,47	7,5	47,8 ± 3,39	12,3	44,8 ± 3,55	13,7	36,3 ± 2,84	13,6
Base	Post harvest	134,5 ± 6,88	8,9	165,6 ± 12,48	13,4	50,2 ± 3,09	10,7	35,8 ± 2,50	12,1
	Mid-storage	78,8 ± 4,60	10,1	45,1 ± 2,62	10,1	45,6 ± 3,84	14,6	36,6 ± 2,16	10,2
	Full storage	70,4 ± 5,49	13,5	46,4 ± 3,84	14,5	43,3 ± 4,08	16,3	33,0 ± 1,68	8,8

X ± SD—mean values with standard deviation, Vc—coefficient of variation.

Data from Table 4 showed that 'Williams' pear was higher AOC in 2014 compared to 2013. The lowest AOC was recorded for 'Williams' on quince rootstock at the plot base post-harvest in the first year of the study (EC_{50} = 165.6), whereas the highest AOC was observed in fruits from the plot middle on the same rootstock during the same sampling period in the second year (EC_{50} = 31.2).

In 2013, on average, the highest AOC was found in 'Williams' fruits at the plot middle on both rootstocks. On seedling rootstock, 'Williams' showed the lowest AOC at the plot base, while on quince, the lowest activity was registered at the plot top. Fruits from the top and middle positions had higher AOC on seedling rootstock, whereas a lower AOC was recorded on quince at the plot base. On both rootstocks, this cultivar showed the lowest AOC at harvest (except for fruits on seedling rootstock at the plot middle), which increased during the first half of the storage period. Extended storage of fruits on seedling rootstock resulted in improved AOC, whereas no significant changes were observed for fruits on quince rootstock during prolonged storage.

In 2014, fruits on quince rootstock exhibited superior AOC across all plot positions compared to those on seedling rootstock. It was observed that 'Williams' on both rootstocks showed higher AOC at the plot top, with a decreasing trend toward the base. Fruits from the top and base positions reached their peak AOC upon removal from cold storage, whereas fruits from the plot middle did not follow this pattern. Also, for all studied groups, the lowest AOC was recorded at harvest, with the exception of fruits on quince rootstock at the plot middle.

Table 5. Antioxidant activity (EC_{50}) of 'Abate Fetel' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		2013				2014			
Rootstock		Seedling		Quince		Seedling		Quince	
Position	Period	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc
Top	Post harvest	47,4 ± 4,12	15,1	89,3 ± 3,57	6,9	28,0 ± 2,49	15,4	26,7 ± 1,25	8,1
	Mid-storage	19,3 ± 1,38	12,3	46,2 ± 2,91	10,9	26,3 ± 2,76	18,2	26,6 ± 0,98	6,4
	Full storage	20,9 ± 1,66	13,7	17,4 ± 0,97	9,7	28,3 ± 1,87	11,4	28,6 ± 1,15	6,9
Middle	Post harvest	34,2 ± 2,01	10,2	28,2 ± 0,88	5,4	26,5 ± 1,39	9,1	23,9 ± 1,32	9,6
	Mid-storage	21,2 ± 1,49	12,2	50,0 ± 2,07	7,2	31,7 ± 1,58	8,7	25,8 ± 0,78	5,3
	Full storage	24,7 ± 2,34	16,4	19,9 ± 0,77	6,7	31,2 ± 1,82	10,1	28,3 ± 0,98	6,0
Base	Post harvest	41,3 ± 3,18	13,3	40,1 ± 2,59	11,2	23,9 ± 1,69	12,2	23,9 ± 1,12	8,2
	Mid-storage	39,4 ± 2,29	10,1	9,1 ± 0,34	6,6	35,5 ± 1,80	8,8	22,8 ± 1,02	7,8
	Full storage	17,3 ± 1,44	14,5	18,6 ± 0,99	9,3	26,2 ± 2,04	13,5	30,7 ± 1,78	10,0

X ± SD—mean values with standard deviation, Vc—coefficient of variation.

Data presented in Table 5 indicate a superior AOC in 'Abate Fetel' fruits during 2014 across both rootstocks. In the analysis of the observed rootstock/position/storage, the highest AOC was in fruits grown on quince rootstock at the plot base after the mid-storage period in 2013 (EC_{50} = 9.1). However, the lowest AOC was also recorded on quince rootstock, but at the plot top during the harvest period in 2013 (EC_{50} = 89.3).

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In 2013, fruits on quince showed higher AOC at the plot base, whereas a superior AOC was in fruits on seedling rootstock at the other two positions. For 'Abate Fetel' on quince, a decreasing trend in AOC was observed from the plot base toward the apex; in contrast, for fruits on seedling rootstock, the lowest AOC was recorded specifically at the plot base. Across all positions, fruits on seedling rootstock showed the lowest AOC at harvest, which increased during storage, with no significant differences observed throughout the remainder of the storage period. A similar tendency was observed on quince at the plot top and base, while fruits from the plot middle was a lower EC50 value after the mid-storage period.

The second year had superior AOC in fruits grown on quince rootstock. For 'Abate Fetel' on this rootstock, the highest AOC was observed at the plot base, decreasing toward the top. In contrast, for fruits on seedling rootstock, the peak AOC was recorded specifically at the plot top.

Table 6. Antioxidant activity (EC_{50}) of 'Conference' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		**2013**				**2014**			
Rootstock		Seedling		Quince		Seedling		Quince	
Position	**Period**	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc
Top	Post harvest	47,7 ± 2,03	7,4	31,9 ± 2,09	11,4	60,7 ± 2,25	6,42	75,4 ± 3,09	7,1
	Mid-storage	48,3 ± 2,57	9,2	77,5 ± 8,17	18,3	66,4 ± 4,23	11,0	65,3 ± 2,13	5,7
	Full storage	63,2 ± 2,03	5,6	44,2 ± 1,82	7,1	66,5 ± 3,17	8,3	93,9 ± 5,78	9,9
Middle	Post harvest	84,5 ± 4,94	10,1	99,7 ± 10,2	17,8	55,5 ± 3,87	12,1	80,9 ± 2,98	6,4
	Mid-storage	56,4 ± 2,44	7,5	24,6 ± 1,28	9,0	51,9 ± 1,97	5,6	72,5 ± 4,20	10,0
	Full storage	72,3 ± 3,13	7,5	39,2 ± 1,44	6,4	70,3 ± 2,46	6,1	99,5 ± 5,55	9,7
Base	Post harvest	69,9 ± 4,18	10,4	79,0 ± 5,76	12,6	70,4 ± 3,79	9,3	66,7 ± 2,83	7,4
	Mid-storage	51,3 ± 2,88	9,7	30,3 ± 1,76	10,1	57,3 ± 2,38	7,2	17,8 ± 0,57	5,6
	Full storage	57,6 ± 3,94	12,0	47,6 ± 1,91	7,0	77,1 ± 5,60	12,6	75,0 ± 3,85	8,9

X ± SD—mean values with standard deviation, Vc—coefficient of variation.

Fruits on seedling rootstock showed approximately equal AOC in both study years, whereas those on quince rootstock showed higher AOC during the first year. The lowest EC_{50} value was recorded in 'Conference' on quince rootstock at mid-storage in 2014 (EC_{50} = 17.8), while the highest value was also observed on quince at harvest in 2013 (EC_{50} = 99.7).

During the first year, 'Conference' on quince rootstock showed similar AOC across all positions, whereas fruits on seedling rootstock had significantly lower AOC at the plot middle compared to the top and base. The peak AOC occurred within the first month of storage, with a decreasing trend during extended storage. A deviation was observed in fruits on quince rootstock at the plot top, which exhibited higher AOC at harvest than during storage.

In the second year, superior AOC was in fruits on seedling rootstock at the plot top and center, while a lower EC_{50} value was recorded for fruits on quince at the plot base. Analyzing the impact of the rootstock factor, no clear regularity was found, but rather diverse fruit behavior. Across all observed rootstock/position/storage, it was evident that the fruits reached their peak AOC during the first half of storage, followed by a decline in AOC during prolonged storage.

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3.3. Influence of Rootstock, Tree Position, and Storage Duration on Solible Solid Content

Table 7. Soluble solids content (SSC) of 'Williams' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		**2013**				**2014**			
Rootstock		Seedling		Quince		Seedling		Quince	
Position	**Period**	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc
Top	Post harvest	15,9 ± 0,208	7,1	14,6 ± 0,298	11,2	10,1 ± 0,115	6,2	10,2 ± 0,184	9,9
	Mid-storage	17,4 ± 0,204	6,4	16,0 ± 0,203	7,0	11,0 ± 0,115	5,3	10,9 ± 0,321	16,2
	Full storage	17,4 ± 0,175	5,5	16,5 ± 0,148	4,9	11,0 ± 0,111	5,5	10,6 ± 0,152	7,8
Middle	Post harvest	14,6 ± 0,208	7,8	15,7 ± 0,204	7,1	10,1 ± 0,166	9,0	10,4 ± 0,257	13,5
	Mid-storage	16,1 ± 0,239	8,1	16,6 ± 0,245	8,1	10,8 ± 0,239	12,1	11,1 ± 0,194	9,5
	Full storage	16,5 ± 0,246	8,2	15,8 ± 0,155	5,4	11,2 ± 0,161	7,9	10,7 ± 0,184	9,4
Base	Post harvest	13,0 ± 0,172	7,2	13,8 ± 0,391	15,5	10,5 ± 0,183	9,5	10,7 ± 0,197	10,1
	Mid-storage	14,4 ± 0,214	8,1	15,9 ± 0,252	8,7	10,6 ± 0,122	6,3	10,6 ± 0,183	9,4
	Full storage	14,3 ± 0,192	7,3	15,5 ± 0,225	7,9	10,2 ± 0,188	10,1	10,3 ± 0,177	9,4

X ± SD—mean values with standard deviation, Vc—coefficient of variation.

According to Table 7, the highest SSC was recorded in stored fruits on seedling rootstock from the plot top in 2013 (17.4 °Brix). The lowest SSC was in fruits on seedling rootstock at the plot top and middle post harvest in 2014 (10.1 °Brix).

Regardless of tree position and sampling period, a significant difference in SSC was noted between the study years, whereas no differences were found between rootstocks within a single year. Fruits from the plot top showed the greatest variation in SSC across the two years, while the smallest difference was recorded in fruits from the plot base. No significant differences in SSC were found between rootstocks across various sampling periods, nor between the harvest and the full storage period on the same rootstock. However, an increasing trend in SSC during extended storage was observed in 'Williams' pears.

Table 8. Soluble solids content (SSC) of 'Abate Fetel' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		**2013**				**2014**			
Rootstock		Seedling		Quince		Seedling		Quince	
Position	**Period**	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc
Top	Post harvest	15,3 ± 0,288	10,3	17,1 ± 0,204	6,5	10,0 ± 0,210	11,5	10,7 ± 0,215	11,0
	Mid-storage	15,8 ± 0,236	8,2	18,4 ± 0,204	6,1	10,0 ± 0,299	16,3	11,1 ± 0,173	8,5
	Full storage	17,2 ± 0,221	7,0	18,5 ± 0,208	6,2	11,5 ± 0,263	12,6	11,9 ± 0,172	7,9
Middle	Post harvest	14,2 ± 0,305	11,8	16,1 ± 0,210	7,2	11,0 ± 0,215	10,7	10,8 ± 0,164	8,3
	Mid-storage	15,2 ± 0,336	12,1	17,2 ± 0,197	6,3	10,7 ± 0,270	13,8	10,0 ± 0,268	14,6
	Full storage	15,7 ± 0,320	11,1	17,6 ± 0,288	9,0	11,8 ± 0,307	14,3	10,1 ± 0,195	10,5

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Base	Post harvest	13,7 ± 0,236	9,4	16,2 ± 0,354	12,0	11,6 ± 0,219	10,3	11,3 ± 0,192	9,3
	Mid-storage	16,5 ± 0,338	11,2	17,5 ± 0,199	6,2	11,7 ± 0,325	15,1	11,7 ± 0,254	11,9
	Full storage	15,4 ± 0,183	6,5	18,3 ± 0,183	5,5	12,2 ± 0,199	8,9	11,2 ± 0,135	6,6

X ± SD—mean values with standard deviation, Vc—coefficient of variation.

The highest SSC was recorded in fruits on quince rootstock at the plot top after the full storage period in 2013 (18.5 °Brix). The lowest SSC was observed in fruits on seedling rootstock at the same position post-harvest in 2014, which remained constant during the first 45 days of storage (10.0 °Brix).

The data indicate no significant differences in SSC among fruits from various plot positions across the rootstocks, nor between fruits from the same position on seedling and quince, when analyzed by individual years. A continuous increase in SSC was observed during extended storage for both rootstocks. The most substantial increase during the storage period was recorded in fruits grown on seedling rootstock from the top of plot.

Table 9. Soluble solids content (SSC) of 'Conference' pear fruit on two rootstocks from different tree positions within the plot during storage in 2013 and 2014.

Year		**2013**				**2014**			
Rootstock		Seedling		Quince		Seedling		Quince	
Position	**Period**	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc	X ± Sx	Vc
Top	Post harvest	16,0 ± 0,237	8,1	14,4 ± 0,223	8,4	11,1 ± 0,278	13,7	10,6 ± 0,221	11,4
	Mid-storage	15,1 ± 0,327	11,9	15,4 ± 0,223	7,9	12,3 ± 0,159	7,1	11,5 ± 0,241	11,5
	Full storage	15,8 ± 0,292	10,1	17,3 ± 0,374	11,8	12,5 ± 0,210	9,2	10,9 ± 0,203	10,2
Middle	Post harvest	14,4 ± 0,296	11,3	14,9 ± 0,257	9,5	11,6 ± 0,144	6,8	10,4 ± 0,245	12,8
	Mid-storage	17,2 ± 0,234	7,5	16,1 ± 0,334	11,4	11,5 ± 0,142	6,8	10,9 ± 0,232	11,7
	Full storage	15,8 ± 0,204	7,0	18,5 ± 0,259	7,7	12,0 ± 0,215	9,9	11,2 ± 0,257	12,6
Base	Post harvest	14,9 ± 0,254	9,4	14,4 ± 0,204	7,7	11,9 ± 0,137	6,3	11,5 ± 0,292	13,9
	Mid-storage	15,9 ± 0,208	7,2	16,7 ± 0,190	6,2	12,5 ± 0,153	6,7	11,7 ± 0,265	12,4
	Full storage	15,2 ± 0,225	8,1	15,2 ± 0,212	7,6	12,3 ± 0,254	11,3	12,1 ± 0,215	9,7

X ± SD—mean values with standard deviation, Vc—coefficient of variation.

The highest SSC was observed in fruits on quince rootstock from the plot middle after two months of storage in 2013 (18.5 °Brix), whereas the lowest SSC was recorded on the same rootstock and position at post harvest in 2014 (11.2 °Brix).

In 'Conference' pears, the rootstock significantly influenced SSC, with fruits on seedling rootstock exhibiting higher values compared to those on quince. In 2013, notable differences in SSC were observed between fruits from the plot middle throughout the entire storage process and those from the plot base, while smaller differences were recorded for fruits from the plot top. During the second year, no significant variation was observed among fruits from different tree positions during storage.

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3.4. Influence of Rootstock, Tree Position, and Storage Duration on Individual Sugars Content

Based on the obtained data for SSC in the fruit, a more detailed analysis of individual sugar content was conducted for each evaluated group during the second year of the study.

Table 10. Fructose, sorbitol, glucose, and sucrose content (g/L) in 'Williams' pear fruit on seedling rootstock from different tree positions within the plot during storage.

Rootstock		Seedling								
Position	Period	Fructose	%	Sorbitol	%	Glucose	%	Sucrose	%	Total
Top	Post harvest	81,3	65,11	30,0	23,98	13,6	10,91	0,0	0,0	124,9
	Mid-storage	98,8	61,53	39,9	24,86	21,9	13,61	0,0	0,0	160,6
	Full storage	94,3	65,95	29,7	20,74	19,0	13,31	0,0	0,0	143,0
Middle	Post harvest	74,7	67,37	24,2	21,80	12,0	10,82	0,0	0,0	110,9
	Mid-storage	89,55	48,31	60,9	63,57	28,5	29,76	6,4	6,6	185,3
	Full storage	104,4	65,21	33,7	21,05	22,0	13,74	0,0	0,0	160,1
Base	Post harvest	88,7	67,30	28,7	21,77	14,4	10,93	0,0	0,0	131,7
	Mid-storage	80,2	64,45	25,7	20,66	15,2	12,19	3,4	2,7	124,4
	Full storage	86,4	68,94	22,8	18,16	16,2	12,91	0,0	0,0	125,4

The highest total sugar content in 'Williams' pears on seedling rootstock was recorded at the plot middle after one month of storage (185.3 g/L), with sorbitol representing the largest proportion (63.57%), followed by fructose (48.31%), glucose (29.76%), and sucrose (6.6%). It is noteworthy that in all other observed samples, fructose was the dominant sugar, followed by sorbitol and glucose, while sucrose was detected in only two groups. The lowest total sugar content was observed at the same plot position at harvest (110.9 g/L), comprising 67.37% fructose, 21.80% sorbitol, and 10.82% glucose, with no sucrose detected.

Regarding plot positions, the highest total sugar concentrations were found at the plot middle, followed by the top, and the lowest at the base. At all positions, 'Williams' on seedling rootstock had the highest levels of fructose, followed by sorbitol and glucose. A very low sucrose content was registered at the plot base and middle (6.4% and 3.4%, respectively), while fruits from the plot top contained no sucrose.

Comparing harvest and storage periods, fruits from the top and middle reached their peak sugar levels during the first half of storage, followed by a decline, whereas fruits from the plot base maintained more stable sugar levels throughout the storage period.

Table 11. Fructose, sorbitol, glucose, and sucrose content (g/L) in 'Williams' pear fruit on quince rootstock from different tree positions within the plot during storage.

Rootstock		Seedling								
Position	Period	Fructose	%	Sorbitol	%	Glucose	%	Sucrose	%	Total
Top	Post harvest	88,7	64,70	30,4	22,14	18,0	13,16	0,0	0,0	137,1
	Mid-storage	89,7	61,45	31,1	21,33	22,1	15,16	3,0	2,05	146,0
	Full storage	106,6	64,75	32,8	19,93	25,2	15,32	0,0	0,0	164,7
Middle	Post harvest	43,5	67,86	13,1	20,40	7,5	11,75	0,0	0,0	64,1
	Mid-storage	67,7	66,87	20,5	20,29	13,0	12,85	0,0	0,0	101,2
	Full storage	97,7	65,92	28,5	19,24	22,0	14,84	0,0	0,0	148,2
Base	Post harvest	63,7	67,67	19,0	20,22	11,4	12,11	0,0	0,0	94,2
	Mid-storage	68,9	67,77	19,5	19,12	13,3	13,11	0,0	0,0	101,7
	Full storage	65,3	70,61	15,2	16,38	12,0	13,00	0,0	0,0	92,5

'Williams' pears on quince rootstock showed the highest total sugar content at the plot top upon removal from cold storage (164.7 g/L), comprising 64.75% fructose, 19.93% sorbitol, and 15.32% glucose. Sucrose was not detected in these fruits. The lowest sugar concentration was recorded at the

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plot middle in the harvest period (64.1 g/L), where fructose also predominated and sucrose was absent. In general, 'Williams' pears exhibited either no sucrose or only negligible amounts, regardless of the evaluated factors or sample groupings.

The highest sugar content was observed at the plot top, with a decreasing trend toward the plot base. While fruits from the top and middle positions showed their minimum sugar levels at harvest and peak levels upon removal from cold storage, those from the plot base reached maximum concentrations after one month, followed by a slight decline in all individual sugars after two months of cold storage.

Table 12. Fructose, sorbitol, glucose, and sucrose content (g/L) in 'Abate fetel' pear fruit on seedling rootstock from different tree positions within the plot during various sampling periods.

Rootstock					Seedling					
Position	Period	Fructose	%	Sorbitol	%	Glucose	%	Sucrose	%	Total
Top	Post harvest	77,4	59,19	27,9	21,32	25,5	19,49	0,0	0,0	130,8
	Mid-storage	77,8	61,05	25,9	20,37	23,7	18,58	0,0	0,0	127,4
	Full storage	68,3	63,86	20,1	18,78	18,6	17,37	0,0	0,0	107,0
Middle	Post harvest	77,8	58,43	30,1	22,65	25,2	18,91	0,0	0,0	133,1
	Mid-storage	78,2	60,74	25,9	20,09	24,7	19,17	0,0	0,0	128,7
	Full storage	65,7	64,00	17,3	16,84	19,7	19,16	0,0	0,0	102,7
Base	Post harvest	81,7	58,63	31,5	22,59	26,2	18,78	0,0	0,0	139,4
	Mid-storage	85,1	55,81	38,2	25,06	29,2	19,13	0,0	0,0	152,4
	Full storage	83,8	62,10	25,2	18,68	25,9	19,22	0,0	0,0	134,9

The lowest total sugar content in 'Abate Fetel' pears on seedling rootstock was recorded at the plot middle upon removal from cold storage (102.7 g/L). As with the other cultivars, fructose represented the largest proportion of the total sugar content, while sucrose was not detected. The highest total sugar concentration was observed in fruits from the plot base during mid-storage (152.4 g/L), comprising 85.1 g/L fructose, 38.2 g/L sorbitol, and 29.2 g/L glucose.

Regarding the different plot positions, the highest sugar levels were observed at the plot base, while the content in fruits from the top and middle was nearly identical on average. Monitoring 'Abate Fetel' throughout the storage process led to the following conclusions: fruits from the plot top had a decreasing trend in sugar levels during extended storage, with a slight deviation in fructose content during the mid-storage; fruits from the plot middle showed the highest concentration of individual sugars at harvest, with no significant changes during the first 45 days, followed by a decline during prolonged storage; in fruits from the plot base, an increase in sugar content occurred during the mid-storage, whereas the lowest recorded proportions of sugars were observed during full storage.

Table 13. Fructose, sorbitol, glucose, and sucrose content (g/L) in 'Abate Fetel' pear fruit on quince rootstock from different tree positions within the plot during storage.

Rootstock					Seedling					
Position	Period	Fructose	%	Sorbitol	%	Glucose	%	Sucrose	%	Total
Top	Post harvest	77,4	59,21	28,1	21,51	25,2	19,28	0,0	0,0	130,7
	Mid-storage	89,4	57,43	34,7	22,28	31,6	20,29	0,0	0,0	155,6
	Full storage	88,8	55,33	36,8	22,95	34,8	21,72	0,0	0,0	160,4
Middle	Post harvest	85,6	56,31	38,6	25,43	27,8	18,27	0,0	0,0	151,9
	Mid-storage	79,8	59,16	28,6	21,23	26,4	19,60	0,0	0,0	134,9
	Full storage	90,9	57,07	34,7	21,78	33,7	21,16	0,0	0,0	159,3
Base	Post harvest	86,0	57,17	39,0	25,96	25,4	16,87	0,0	0,0	150,4
	Mid-storage	94,6	55,64	39,9	24,45	35,5	20,91	0,0	0,0	170,0
	Full storage	85,0	60,04	30,7	21,70	25,8	18,26	0,0	0,0	141,6

The highest total sugar content in 'Abate Fetel' pears was recorded at the plot base at mid-storage (170.0 g/L), with fructose representing the largest proportion (55.64%), followed by sorbitol (24.45%), and glucose (20.91%). Fruits of this cultivar grown on quince rootstock contained no sucrose. The lowest total sugar content was observed at the plot top during the harvest period (130.7 g/L). As shown in Table 12, fructose was clearly the predominant sugar across all observed groups, followed by sorbitol and glucose.

Similar results were recorded for this cultivar on quince rootstock. Specifically, for 'Abate Fetel' on quince, the highest sugar content was on average registered at the plot base, while lower and approximately equal concentrations were recorded at the top and middle positions. At the plot base, an increase in all individual sugars occurred during the first half of storage, followed by a decline in sugar concentrations after the full storage period. However, in fruits from the plot middle, a decrease in sugar content was observed at the beginning of storage, with a subsequent increase upon removal from cold storage. For fruits from the plot top, higher sugar levels were recorded after three months of storage compared to the results obtained at harvest.

Table 14. Fructose, sorbitol, glucose, and sucrose content (g/L) in 'Conference' pear fruit on seedling rootstock from different tree positions within the plot during various sampling periods.

Rootstock		**Seedling**								
Position	Period	Fructose	%	Sorbitol	%	Glucose	%	Sucrose	%	Total
Top	Post harvest	83,0	56,85	27,9	19,11	21,2	14,52	13,9	9,52	146,0
	Mid-storage	62,6	51,10	29,0	23,67	16,4	13,39	14,5	11,84	122,5
	Full storage	71,3	53,53	29,6	22,22	20,7	15,54	11,6	8,71	133,2
Middle	Post harvest	60,0	51,37	27,6	23,63	13,5	11,56	15,7	13,44	116,8
	Mid-storage	59,1	48,44	28,9	23,69	16,3	13,36	17,7	14,51	122,0
	Full storage	71,5	52,19	33,2	24,23	20,7	15,11	11,6	8,47	137,0
Base	Post harvest	56,0	47,82	29,3	25,02	12,0	10,25	19,8	16,91	117,1
	Mid-storage	57,0	49,61	26,0	22,63	14,0	12,18	17,9	15,58	114,9
	Full storage	72,9	52,05	31,9	22,77	21,8	15,56	13,5	9,62	140,1

Fruits of the 'Conference' cultivar from the plot top had the highest total sugar content at harvest (146.0 g/L), comprising 56.85% fructose, 19.11% sorbitol, 14.52% glucose, and 9.52% sucrose. Notably, 'Conference' fruits contained sucrose, whereas this sugar was not detected in 'Williams' and 'Abate Fetel' pears. The lowest total sugar content was recorded in fruits from the plot base during mid-storage (114.9 g/L); in these samples, fructose was the predominant sugar, followed by sorbitol and sucrose, with glucose being the least abundant.

On average, the highest sugar levels were observed at the plot top, while lower and comparable concentrations were recorded at the plot middle and base. Fruits from all plot positions had an increase in fructose, sorbitol, and glucose levels during extended storage, while sucrose concentrations showed a declining trend.

Table 15. Fructose, sorbitol, glucose, and sucrose content (g/L) in 'Conference' pear fruit on quince rootstock from different tree positions within the plot during various sampling periods.

Rootstock		**Seedling**								
Position	Period	Fructose	%	Sorbitol	%	Glucose	%	Sucrose	%	Total
Top	Post harvest	67,0	57,22	20,5	17,51	13,9	11,87	15,7	13,41	117,1
	Mid-storage	75,6	58,88	22,4	17,45	17,5	13,63	12,9	10,05	128,4
	Full storage	74,4	53,72	24,7	15,72	26,2	16,68	21,8	13,88	157,1
Middle	Post harvest	68,4	52,98	31,0	24,01	18,5	14,33	11,2	8,68	129,1
	Mid-storage	72,2	57,58	20,9	16,67	18,9	15,07	13,4	10,69	125,4
	Full storage	90,4	58,82	24,4	15,88	25,1	16,33	13,8	9,98	153,7
Base	Post harvest	64,2	51,69	24,7	19,89	12,9	10,39	22,4	18,04	124,2

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Mid-storage	66,5	51,19	25,3	19,48	14,1	10,85	24,0	18,48	129,9
Full storage	70,5	53,65	23,0	17,50	17,6	13,39	20,3	15,45	131,4

In 'Conference' pears on quince rootstock, the highest total sugar content was recorded in fruits from the plot top upon removal from cold storage (157.1 g/L). Fructose was the predominant sugar (53.72%), followed by glucose (16.68%), sorbitol (15.72%), and sucrose (13.88%). The lowest total sugar content was observed in fruits from the same plot position at harvest; similarly, fructose represented the highest proportion (57.22%), while glucose was the least abundant (11.87%).

Data indicate that the highest average sugar content was recorded in fruits from the plot middle, followed by the top, while the lowest levels were found in fruits from the plot base. Fruits from the plot top had peak sugar content after the full storage period (with a minor deviation in fructose content, which showed no significant changes during storage). In fruits from the plot middle, an increasing trend in fructose, glucose, and sucrose was observed during storage, with a slight deviation in sorbitol levels during mid-storage period. At the plot base, extended storage led to an increase in fructose and glucose concentrations, while sorbitol and sucrose levels declined.

3.5. PCA Analysis

Principal Component Analysis (PCA), a multivariate method for dimensionality reduction, accounted for 65.18% of the total variation within the first two components for 2013. The first principal component (PC1, 45.97%) was predominantly characterised by glucose concentration in the positive direction, and by AOC and sucrose in the negative direction. The second principal component (PC2, 19.21%) was mainly defined by sorbitol concentration in the positive direction and TPC in the negative direction. Regarding correlations among the measured characteristics, high positive correlations were observed among the sugars, particularly between total sugars, glucose, and fructose. Furthermore, a strong negative correlation was found between the DPPH values (EC_{50}) and TPC; specifically, higher AOC corresponded to a more robust TPC. Variety-based grouping was observed as expected, although with some overlap. Within individual varieties, distinct grouping patterns related to the studied treatments were identified, whereas tree position did not have a significant observable impact. Across all varieties, a consistent transition pattern was evident from the post-harvest phase to the full storage phase. This transition moved from the upper left to the lower right quadrant of the PCA plot—primarily along PC1 from the negative to the positive direction, and along PC2 from the positive to the negative direction. This pattern indicates a simultaneous increase in sugars, SSC, and TPC, coupled with decreasing DPPH (EC50) values, reflecting improved AOC. In 'Abate Fetel', a clear distinction was observed between rootstocks: fruits grown on seedling rootstocks grouped along the negative part of PC1, while those on quince rootstocks grouped along the positive part. This separation suggests higher sugar concentrations in fruits harvested from trees on quince rootstock.

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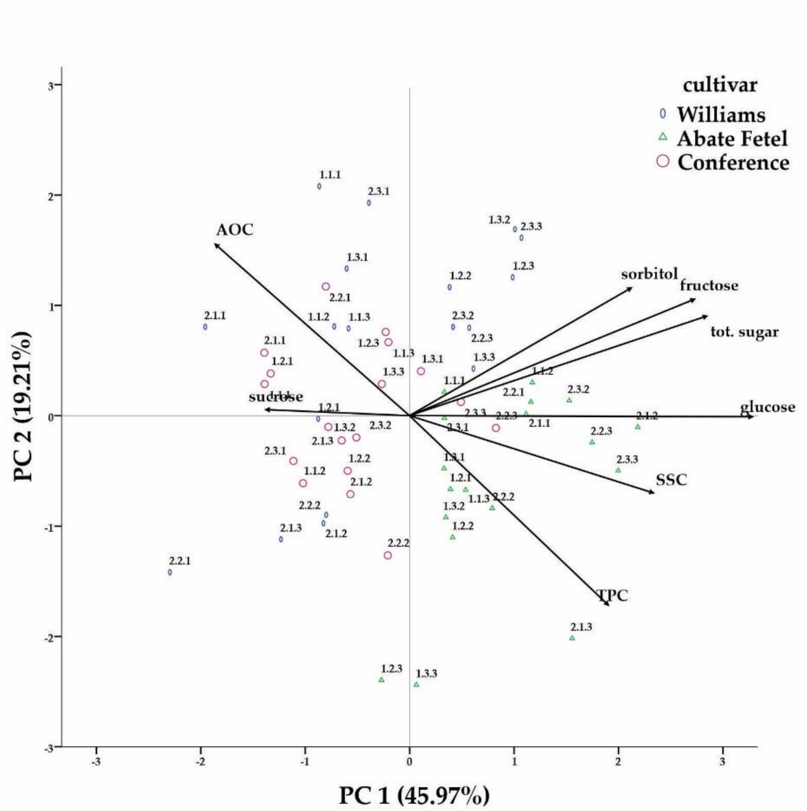

Figure 1. Principal Component Analysis (PCA) with vectors (A, upper left) representing the measured characteristics and study cases represented as dots (1: 'Williams', 2: 'Abate Fetel', 3: 'Conference') described per studied cultivar and three numbers for each dot representing studied factors: the first number is type of rootstock (1: seedling, 2: quince), the second number is tree position on the production plot (1: base, 2: middle, 3: top) and the third number is sampling period (1: post-harvest, 2: mid-storage, 3: full storage).

The studied cultivars are grouped together in Figure 2 according to the characteristics measured in 2014. The treatments showed different patterns of effect for each cultivar. In 'Williams', the main separation is between fruits grown on seedling rootstock, which are grouped together with higher DPPH values, and fruits on quince rootstock, which predominantly have lower DPPH values, indicating better antioxidant capacity. In 'Williams', there is also an observable pattern of increasing sugar content and lower total phenolic content (TPC) in the stages after harvest. In 'Abate Fetel', a pattern of lower TPC and higher sugar content is observed towards the end of the storage period. In 'Conference', there is a pattern of higher soluble solids content (SSC) with advancing ripening stages during storage. In this variety, fruits grown on seedling rootstock are grouped with higher SSC, while those grown on quince rootstock have lower SSC.

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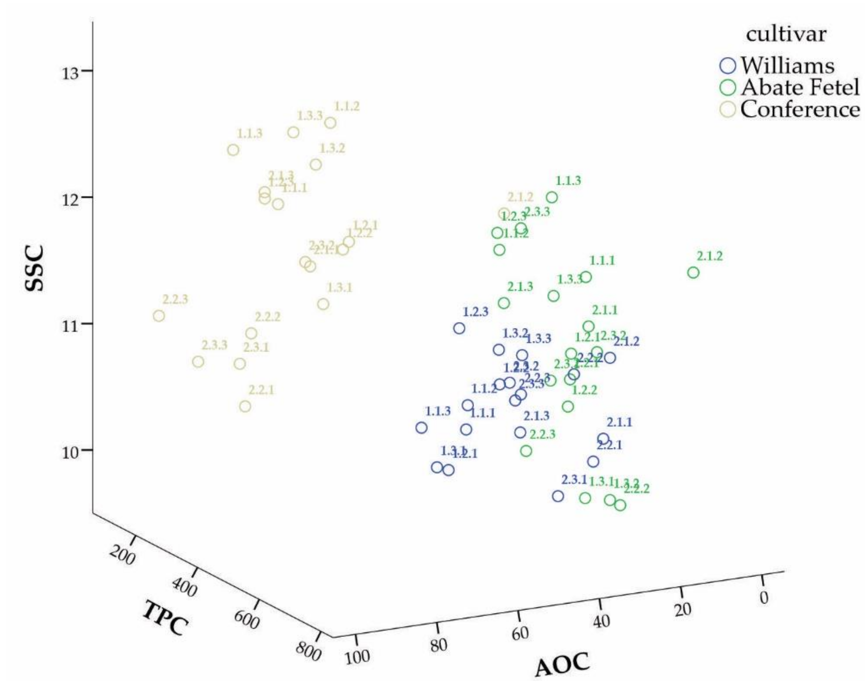

Figure 2. Studied varieties and treatments as per measured total phenolic content (TPC), antioxidant capacity (AOC), and soluble solids content (SSC) described per studied variety and three numbers for each dot representing studied factors: the first number is type of rootstock (1: seedling, 2: quince), the second number is tree position on the production plot (1: base, 2: middle, 3: top) and the third number is sampling period (1: post-harvest, 2: mid-storage, 3: full storage).

4. Discussion

4.1. Influence of Rootstock, Tree Position, and Storage Duration on Total Phenolic Content

The obtained data illustrate the distinct behavior of the observed pear cultivars over two study years across different rootstocks and tree positions within the plot under storage treatment. The concentration of TPC in pear fruits can be influenced by pre-harvest factors, particularly light exposure and the tree's position on a sloped production plot. Tree position is a critical aspect of pear fruit ripening and quality, significantly influencing the metabolic profile and leading to variations in TPC during storage [25]. Sera et al. [25] further state that the final fruit quality after ripening varies according to tree position. The results of the present study also confirm that tree position impacts TPC in the fruit.

Rootstock is recognized as one of the most significant factors in pear production [26]. Previous research has confirmed that rootstocks significantly influence the concentration of nutrients and bioactive compounds in fruits [27,28], which is further supported by the findings of this study. Our results showed that 'Williams' fruits on quince rootstock contained higher phenolic levels compared to those on seedling rootstock. However, Hudina et al. [29] established that 'Williams' on quince rootstock does not yield favorable results and reported a lower TPC in fruits on this rootstock.

Fruits of 'Abate Fetel' on quince rootstock displayed a marginally superior phenolic profile compared to those on seedling rootstock. Across all evaluated treatment combinations, the average TPC was 702,89 mg GAE/100 g of fresh fruit for quince, as opposed to 699.19 mg GAE/100 g of fresh fruit for seedling. These findings are consistent with Milošević et al. [30] who reported a TPC of 101.49 mg GAE/100 g of fresh fruit for this cultivar on 'Quince MA' rootstock. Our data further highlight a significant influence of the study year on the TPC during storage. In 2013, a transient decline in TPC was observed during the initial storage phase, followed by an accumulation during extended storage. Conversely, in the second study year, phenolic levels increased during early storage before declining during prolonged cold storage.

Consistent with previous research [31] 'Conference' had superior yields and fruit quality on quince rootstock. These authors noted that 'Conference' on quince generally maintains a higher TPC than on seedling rootstock. However, our findings reveal a distinct temporal pattern: extended storage of 'Conference' on quince leads to a steady increase in the phenolic complex, whereas on seedling rootstock, the peak phenolic content is reached at harvest. The robust phenolic structure of 'Conference' on quince was also corroborated by Hudina et al. [29] who observed that individual phenolic concentrations are notably higher on quince than on seedling rootstock.

4.2. Influence of Rootstock, Tree Position, and Storage Duration on Antioxidant Capacity

In the post-harvest management of pears, preserving antioxidant potential is a crucial parameter for maintaining fruit quality. A comprehensive understanding of storage dynamics is essential for defining post-harvest protocols, as inconsistent fruit quality-exacerbated by pre-harvest factors such as tree position and cultivar variability-can lead to substantial economic losses and diminished consumer satisfaction [25,32]. The physiological responses of pear fruits to ULO conditions, particularly regarding the preservation of antioxidant compounds, are heavily dependent on the fruit characteristics established during the cultivation process [33].

Specifically, the influence of tree position on fruit metabolism has been documented in European pear cultivars, indicating a direct correlation with the biochemical composition at harvest [25]. Furthermore, Bonora et al. [32]. reported that excessive irrigation leads to lower AOC during the pear storage process. Building upon these findings, it can be hypothesized that on large-scale production plots with sloped terrains, water accumulation may occur at specific positions due to soil impermeability or poor drainage, thereby adversely affecting overall fruit quality. However, this suggests that the varying antioxidant potential observed in the studied pear cultivars is directly linked to the specific tree positions within the orchard plot.

The results of this study indicate that 'Williams' pears exhibited superior AOC at the middle and top plot positions compared to the base, a trend that was not observed in 'Abate Fetel' and 'Conference'. Throughout the storage process, 'Williams' reached its peak AOC at the end of the storage period. Further analysis revealed that in the first study year, the strongest antioxidant effect occurred after two months of full storage, whereas in the second year, the antioxidant potential remained consistently high throughout the entire storage duration.

Milošević et al. [30]. reported that 'Abate Fetel' on 'Quince MA' rootstock possesses a high antioxidant potential (105,98 mg AA/g of fresh fruit). However, our findings show that 'Abate Fetel' on quince rootstock had slightly higher average effective concentration values (EC50 = 30,89) compared to seedling rootstock (EC50 = 29,07). Since higher values indicate lower radical scavenging activity, this suggests a weaker antioxidant potential for this cultivar when grown on quince rootstock.

Regarding 'Conference', Kevers et al. [34] reported an antioxidant activity of 2 749 μmol TE/100 g of fresh fruit at harvest. In comparison, our results (EC_{50} = 64.78 on seedling and EC50 = 77.73 on quince) suggest a robust AOC in our samples. Although Lysiak et al. (2021) [35] concluded that rootstock does not significantly influence the AOC of pears under controlled atmosphere conditions, our results demonstrate that storage duration plays a critical role. For 'Conference', the highest AOC was observed during the first month of storage, followed by a decline over time. While other studies [35] suggest that 'Conference' can be stored for up to six months without a significant loss in antioxidant capacity through specific treatments, our findings highlight a natural decreasing trend under the studied storage regime.

4.3. Influence of Rootstock, Tree Position, and Storage Duration on Solible Solid Content

The initial SSC is a key parameter for evaluating the long-term storage potential of fruit [35]and is a primary determinant of its sensory and nutritional quality [36]. Pasa et al. [37] highlighted that fruits on seedling rootstocks exhibit lower SSC in the fruit flesh juice compared to those grafted on quince. According to these authors, 'Williams' pears on seedling rootstock reached 10.3 °Brix, while those on quince ranged from 11.53 to 12.04 °Brix. Our findings revealed higher SSC values for both seedling (13.07 °Brix) and quince (13.11 °Brix) rootstocks. These results indicate an increase in SSC during the mid-storage, followed by a slight decline after two months. This trend is attributed to the degradation of polysaccharides into monosaccharides, which typically elevates SSC values during the initial storage phase. However, SSC may decrease during prolonged storage as the fruit utilizes stored energy reserves for respiration [35].

According to the data in Table 8, no significant differences in SSC were observed among 'Abate Fetel' fruits from different plot positions. The SSC reached its peak at the end of the storage period, indicating a clear increasing trend during prolonged storage, which subsequently results in sweeter fruits. Specifically, the average SSC value at the end of storage was more than 1 °Brix higher than at harvest. An increase in SSC of 1–2 °Brix during the storage of pome fruits has also been documented by Ali et al. [38].

Further analysis revealed that for the 'Conference' cultivar, the rootstock did not significantly influence the SSC. Specifically, the SSC in fruits on seedling rootstock was 13.78 °Brix, compared to 13.58 °Brix on quince. However, these findings contrast with those of [37] who reported a significant rootstock effect on SSC in 'Conference' and concluded that fruits on quince rootstock accumulate higher levels of SSC compared to other rootstocks. According to those authors, the SSC in pear fruits across various rootstocks ranged from 10.42 to 13.25 °Brix. The present study also demonstrates that tree position does not significantly affect the SSC in 'Conference' pears. While our results indicate that extended storage leads to an increase in SSC for this cultivar, some studies have reported no significant changes in SSC, even during prolonged cold storage [35].

4.4. Influence of Rootstock, Tree Position, and Storage Duration on Individual Sugars Content

The results of this study demonstrate higher sugar concentrations in 'Williams' pears grown on seedling rootstock compared to those on quince, with fructose representing the predominant sugar and sucrose the least abundant. The dominance of fructose and the marginal levels of sucrose in pear fruits are consistent with findings from other authors [40–42]. Specifically, Hudina and Štampar [42] reported that 'Williams' fruits contain 39.9 kg^{-1} fructose, 17.5 kg^{-1} sorbitol, and 4.8 kg^{-1} glucose, with sucrose being the lowest at 3.4 kg^{-1}. In comparison, the 'Williams' samples in our study averaged 88.7 kg^{-1} fructose, 32.84 kg^{-1} sorbitol, 18.09 kg^{-1} glucose, and 1.09 kg^{-1} sucrose. Although numerous studies describe an increase in fructose, glucose, and sucrose levels during advanced ripening—consistent with the fact that fruits continue the ripening process in cold storag—our findings reveal a divergence based on the rootstock. Specifically, extended storage of fruits on seedling rootstock led to a decline in sugar content, while those on quince rootstock exhibited the opposite trend. A reduction in pear sugars during storage has also been documented by [43]. These researchers concluded that sugar content typically increases at the beginning of storage, remains stagnant during the first half, and subsequently declines during prolonged storage due to intensified respiration and accelerated starch hydrolysis.

Previous research indicates that the increase in soluble carbohydrates in 'Abate Fetel' fruits results from starch degradation [44] leading to a rise in sugar levels in stored fruits. In the present study, this behavior was observed in fruits on quince rootstock, which generally exhibited higher sugar concentrations than those on seedling rootstock. However, 'Abate Fetel' on seedling rootstock showed a decline in sugar content by the end of the storage period. A reduction in sugar levels in 'Abate Fetel' during cold storage under similar regimes was also confirmed by Toth-Markus et al. [15]. Notably, the results of this study indicate that fruits of this cultivar do not contain sucrose.

According to the data in Table 15, the 'Conference' cultivar contains the highest concentration of fructose, which is consistent with previous findings [46]. Regarding the spatial distribution within the plot, the lowest sugar levels in 'Conference' were recorded at the plot base. These results confirm the significant influence of light exposure and tree position on fruit sugar accumulation [47]. In contrast to the other analyzed cultivars, 'Conference' fruits contain a substantial amount of sucrose, nearly equivalent to their glucose levels. Some authors suggest that sucrose and soluble pectin are the components most significantly depleted during the storage of this cultivar in ULO storage [45].

5. Conslusion

The findings of this research highlight the varying degrees of influence that the analysed factors exert on the quality parameters of the investigated pear cultivars. Among all factors, rootstock was the most significant determinant of fruit quality in both study years. For the 'Williams' cultivar, seedling rootstock resulted in higher sugar content and superior AOC, while quince rootstock led to a higher TPC. In contrast, the 'Abate Fetel' and 'Conference' cultivars produced higher-quality fruit on quince rootstock compared to seedling rootstock. Although tree position within the plot did not have a statistically significant effect on fruit quality, a distinct spatial trend was observed: fruit from the middle of the plot had higher TPC and enhanced antioxidant potential compared to those harvested from the apex and base. Regarding post-harvest behaviour, the cultivars responded differently to the storage conditions. 'Williams' showed excellent stability and storage potential; its peak phenolic and sugar levels, as well as its highest AOC, were recorded at the end of the storage period, confirming its robust post-harvest performance as a summer cultivar. In contrast, 'Abate Fetel' and 'Conference' experienced a decline in their nutritional profile during storage, which adversely affected overall fruit quality. These results underscore the need for further detailed research into cultivar-specific ULO storage systems to optimise the preservation of nutritional and sensory quality for each pear variety.

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Abbreviations

The following abbreviations are used in this manuscript:

AOC	Antioxidant Capacity
DPPH	2,2-diphenyl-1-picrylhydrazyl
EC_{50}	Effective concentration at which 50% of DPPH radicals were quenched
ELSD	Evaporative light scattering detector
FC	Folin-Ciocalteu
FW	Fresh weight
GAE	Gallic acid equivalent
HPLC	High-performance liquid chromatography
PCA	Principle component analysis
SSC	Solible solid content
TPC	Total phenolic content
ULO	Ultra Low Oxygen

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