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INFLUENCE OF HARVEST DATE AND STORAGE CONDITIONS ON THE CHANGES OF SELECTED QUALITATIVE CONDITIONS OF 'CONCORDE' PEARS

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A B S T R A C T

The study was carried out during the two storage seasons of 2008/2009 and 2009/2010. The subject of this study was the checking of the influence of the harvest dates being 4-days apart, and checking of the different storage conditions (CA 0.8% CO_2:2% O_2, CA 2% CO_2:2% O_2, CA 3% CO_2:3% O_2 and NA – normal atmosphere) on the selected quality parameters of 'Concorde' pears. The pears were first stored for 150 days in 0-0.5 ^{o}C. Once the fruit was out of the storage it was stored in simulated shelf-life conditions for an additional 7 days at a temperature of 17 ^{o}C. An evaluation of pear quality was conducted after each harvest date, after taking them out of the cold storage and after simulated shelf-life. Flesh firmness, soluble solids content and titratable acidity were determined, and pear health was evaluated. Harvest date had a significant impact on the maturity of fruit, and values of the investigated quality parameters of pears, during the harvest. During the subsequent harvests, the value of the starch index and soluble solids content in pears increased, whereas Streif's maturity index, flesh firmness and titratable acidity decreased. Harvest date and storage conditions also had a significant influence on the investigated qualitative attributes of pears determined after storage, and the simulated shelf-life period. Pears stored in controlled atmosphere conditions were firmer and had higher titratable acidity than fruit stored in common cold storage. Delay in the harvest date resulted in fast softening of fruit, significant reduction of titratable acidity, and higher susceptibility to putrefaction caused most of all by the gloeosporium rot. A serious problem observed during long term storage of 'Concorde' pears was sensitivity to flesh damage caused by CO_2, and high susceptibility to senescent scald.

Key words: pears, harvest date, cold storage, controlled atmosphere, firmness, titratable acidity, soluble solids, fruit quality, storage disorders

INTRODUCTION

Storability of pears is strictly dependent on the cultivar, fruit maturity during harvest and storage conditions (Elgar et al., 1997). Fruit maturity during harvest is a main factor influencing the quality of stored pears (Chen et al., 1994; Sugar and Powers, 1994). Harvest date has a significant importance for keeping a high fruit quality during storage (Streif, 1995). Pears harvest date is most often determined based on a few factors, such as: flesh firmness (F), soluble solids content (R) and starch decomposition (S) (Johnson and Luton 1996; Höhn et al., 1999). Based on the factors mentioned above, maturity index (F/RS) was determined according to Streif (1983). Depending on the cultivar, the value of the Streif's index for an optimum pear harvest date should be, 0.14-0.06 (Höhn et al., 2005). Starch content and its decomposition pattern are reliable pear maturity indices, because the starch content is strictly connected with fruit physiological maturity (Garriz et al., 2008). Höhn et al. (2005) reported that the starch index (1-10 scale, where 1 means lack of decomposition, and 10 – total starch decomposition) for the optimum pear harvest date is 4-6. Controlled atmosphere conditions allow for elongation of the pears storage period, and also are more efficient than common cold storage conditions, in maintaining high pear quality, and limiting losses (Ma and Chen, 2003). Controlled atmosphere storage is better for keeping high firmness, titratable acidity and green peel colour (Drake and Gix, 2000; Lopez et al., 2001). Typical controlled atmosphere for pears contains 1-3% O_2 and 0-5% CO_2 (Sugar, 2002). According to Höhn et al. (2005), pears should be stored in controlled atmosphere containing 1.5-5% O_2 and 2-3% CO_2. One of the attributes, which is different between pear and apple storage technology, is the necessity to additionally mature the pears after taking them out of common cold storage and a controlled atmosphere. This extra step is done to allow the pears to reach the proper consumption maturity (Tomala et al., 2006). Pears in optimum consumption maturity should have a distinctive smell, juiciness, and "buttery" consistency, as if they melt in one's mouth (Eccher Zerbini et al., 2002). Turner et al. (2005) report, that pear maturing process in 20^{o}C temperature takes 7-10 days. The aim of the study was to determine the influence of harvest date and storage conditions on quality and storage properties of 'Concorde' pears.

MATERIAL AND METHODS

The study was carried out in the two seasons of 2008/2009 and 2009/2010 on 'Concorde' pears. The fruit comes from the Experimental Orchard of the Department of Pomology and Apiculture of the Agricultural University in Garlica Murowana, Poland. Pear trees were grafted on *Pyrus caucasica* rootstock and planted in the spring of 2002.

Each season the pears were harvested on three dates, at 4 day intervals (11, 15, 19 September 2008 and 10, 14, 18 September 2009). Starch index was determined and Streif's maturity index calculated for the pears harvested on each of the dates. The pears were stored for 150 days at temperatures of 0-0.5 °C and 90-92% humidity, in common cold storage (NA – normal atmosphere) and in controlled atmosphere (CA): 0.8% CO_2:2% O_2, 2% CO_2:2% O_2 and 3% CO_2:3% O_2. After the pears were taken out of storage they were allowed to mature for 7 days at a temperature of 17 °C (simulated shelf-life). Measurements and analyses were conducted after each harvest, after storage time, and after simulated shelf-life. Samples of 16 pears per treatments were used. The following parameters were determined for the pears: flesh firmness, soluble solids content and titratable acidity. Postharvest disease occurrence was also determined. The starch index was determined using the standard iodine test, and scored on a scale from 1 to 10. Flesh firmness was measured on opposite sides of fruit using a FT 327 penetrometer (8 mm probe). Soluble solids content was measured in freshly prepared juice using an Atago PR-101 refractometer. Titratable acidity was measured in a water extract of the juice (20 ml juice in 100 ml of water) by tritrating with 0.1 N NaOH to pH 8.1 using a CX-501 multifunction meter. Results were recorded as the percentage of malic acid equivalent. Data were statistically elaborated separately for each season using variance analysis. Storage disorders data, expressed as percent, were subjected earlier to Bliss' transformation. Differences between the means were tested with multiple Duncan's test at $p = 0.05$, using a Statistica 8.0 program.

RESULTS AND DISCUSSION

Each year of the study, the significant influence of the harvest date on the starch index and Streif's index for 'Concorde' pears was presented. (Tab. 1). Subsequent harvest dates showed that starch content reduction took place more quickly. The same results have been reported by Eccher Zerbini et al. (2002) and Garriz et al. (2008), after observing faster starch hydrolysis in pears with each harvest date. During the first year of study, only the pears harvested on the second date (4.9), and during second year pears from each harvest (4.0-5.8) had a starch index meeting the optimum harvest maturity. The Streif's index value significantly decreased with each harvest date. Eccher Zerbini et al. (2002) also reported decreasing value of this index along with elongation of the pear harvest time. Values of the index calculated for 'Concorde' pears harvested on the first harvest date were higher. Values of the index, for the pears harvested on second and third date, were equal to the typical values (0.06-0.11) for pears during the optimum readiness for harvest period, and the beginning of long term storage in cold storage (Höhn et al., 1999; Błaszczyk, 2006).

Table 1. Starch index (scale (1-10) and Streif's maturity index F/(RS) of 'Concorde' pears at harvest, as affected by harvest date in the 2008-2009 season

Year	Starch index			Mean for year	Streif's index			Mean for year
	I	II	III		I	II	III	
2008	3.5 a*	4.9 b	7.1 c	5.2 b	0.17 c	0.11 b	0.07 a	0.12 b
2009	4.0 a	4.4 b	5.8 c	4.7 a	0.15 c	0.11 b	0.08 a	0.11 a
Mean for harvest	3.8 a	4.7 b	6.5 c	-	0.16 c	0.11 b	0.08 a	-

*Means followed by the same letter, separately for each year, do not differ significantly at p = 0.05

Table 2. Flesh firmness, titratable acidity and soluble solids content of 'Concorde' pears at harvest, as affected by harvest date

Quality factor	Harvest	2008	2009	Mean for harvest
Flesh firmness[kG]	I	7.4 c*	7.4 c	7.4 c
	II	7.2 b	6.7 b	6.9 b
	III	7.0 a	6.3 a	6.6 a
Mean for year		7.2 b	6.8 a	-
Titratable acidity [% of malic acid]	I	0.23 b	0.25 c	0.24 c
	II	0.21 a	0.23 b	0.22 b
	III	0.20 a	0.20 a	0.20 a
Mean for year		0.21 a	0.23 b	-
Soluble solids content [%]	I	12.2 a	12.5 a	12.4 a
	II	12.8 b	13.5 b	13.1 b
	III	13.8 c	14.2 c	14.0 c
Mean for year		12.9 a	13.4 b	-

*Explanatios, see Table 1

Harvest date had also a significant influence on the values of the qualitative attributes such as firmness, titratable acidity and soluble solids content (Tab. 2). According to many authors, delay in the harvest date results in poorer firmness of the fruit (Eccher Zerbini et al., 2002; Andrea et al., 2003; Ribeiro et al., 2003; Crouch et al., 2005; Burger et al., 2005). The results of my studies confirm this opinion. Mielke et al. (2005) observed that, decrease in 'Concorde' pear firmness resulting from the later harvest date was statistically irrelevant. In this study, a prolonged pear harvest period resulted in decrease of the titratable acidity. Titratable acidity decrease connected with delayed harvest date was also observed by Elgar et al. (1997) and Mielke et al. (2005). Soluble solids content in pears increased in the subsequent harvest dates. The above mentioned relationships for pears of this cultivar were also reported by Mielke et al. (2005).

Table 3. Flesh firmness [kG] of 'Concorde' pears after storage, as affected by harvest date and storage conditions

Year	Harvest	Storage conditions (CO_2:O_2)				Mean for harvest
		0.8:2	2:2	3:3	air	
After storage						
2008/2009	I	3.6 ef*	3.8 gh	3.9 h	2.9 b	3.6 c
	II	3.4 cd	3.5 de	3.8 gh	2.9 b	3.4 b
	III	3.4 cd	3.5 de	3.7 fg	2.5 a	3.3 a
Mean for storage conditions		3.5 b	3.6 c	3.8 d	2.8 a	-
2009/2010	I	3.8 de	4.0 ef	4.2 f	3.7 cd	3.9 c
	II	3.7 cd	3.8 de	3.6 bc	3.5 b	3.6 b
	III	3.5 b	3.6 bc	3.5 b	3.2 a	3.4 a
Mean for storage conditions		3.7 b	3.8 c	3.8 c	3.5 a	-
After shelf life						
2008/2009	I	2.2 ef	2.2 ef	2.3 f	1.9 bc	2.2 c
	II	2.1 de	2.1 de	2.1 de	1.8 ab	2.0 b
	III	2.0 cd	2.0 cd	2.0 cd	1.7 a	1.9 a
Mean for storage conditions		2.1 b	2.1 b	2.1 b	1.8 a	-
2009/2010	I	2,3 fg	2.1 de	2.4 g	1.8 b	2.2 c
	II	1.7 b	1.8 b	2.2 ef	1.7 b	1.9 b
	III	1.6 ab	1.7 b	2.0 cd	1.5 a	1.7 a
Mean for storage conditions		1.9 b	1.9 b	2.2 c	1.7 a	-

*Explanatios, see Table 1

After storage and a simulated shelf-life period, the 'Concorde' pears, harvested at the earliest date, and stored in a controlled atmosphere, were usually the firmest ones. The least firm pears could be observed in those from the last harvest, which had been stored in common cold storage (Tab. 3). Eccher Zerbini et al. (2002) also reported, that after storage the pears harvested at the later date had lesser firmness. It is also confirmed in the reports of other authors (Recasens et al., 1997; Błaszczyk and Ben, 1999; Lopez et al., 2001), that pears stored in common cold storage lose firmness faster than these stored in controlled atmosphere. There is no unequivocal confirmation of the influence the elevated CO_2 concentration in controlled atmosphere has on retaining better pear firmness, as reported by Drake (1994) or Eccher Zerbini et al. (2002). Higher temperatures during the supplementary maturing period of pears after storage caused pears to soften faster. According to Vaysse et al. (2005), firmness of pears in optimal consumption maturity should be approximately 1.5 kG. Pears stored in common cold storage, and in pears

Table 4. Titratable acidity [% of malic acid] of 'Concorde' pears after storage, as affected by harvest date and storage conditions

Year	Harvest	Storage conditions (CO_2:O_2)				Mean for harvest
		0.8:2	2:2	3:3	air	
After storage						
2008/2009	I	0.16 de*	0.17 ef	0.18 f	0.14 c	0.16 c
	II	0.14 c	0.15 cd	0.15 cd	0.12 ab	0.14 b
	III	0.12 ab	0.13 b	0.14 c	0.11 a	0.12 a
Mean for storage conditions		0.14 b	0.15 c	0.16 d	0.12 a	-
2009/2010	I	0.19 cd	0.22 e	0.22 e	0.15 b	0.20 c
	II	0.18 c	0.20 d	0.20 d	0.12 a	0.18 b
	III	0.18 c	0.19 cd	0.19 cd	0.11 a	0,17 a
Mean for storage conditions		0.18 b	0.20 c	0.20 c	0,13 a	-
After shelf life						
2008/2009	I	0.14 de	0.15 ef	0.16 f	0.12 bc	0.14 c
	II	0.12 bc	0.14 de	0.15 ef	0.11 ab	0.13 b
	III	0.11 ab	0.12 bc	0.13 cd	0.10 a	0.11 a
Mean for storage conditions		0.12 b	0.14 c	0.15 d	0.11 a	-
2009/2010	I	0.17 e	0.19 f	0.19 f	0.14 c	0.17 b
	II	0.16 de	0.17 e	0.17 e	0.11 b	0.15 a
	III	0.16 de	0.17 e	0.17 e	0.10 a	0.15 a
Mean for storage conditions		0.16 b	0.18 c	0.18 c	0.12 a	-

*Explanatios, see Table 1

from the 2009/2010 season - from the second and third harvest, stored in a controlled atmosphere of 0.8:2 and 2:2, after the simulated shelf-life period, had a firmness level similar to that of fruit from the best consumption maturity period.

Titratable acidity level of pears decreased during storage (Błaszczyk and Łysiak, 2001; Ma and Chen, 2003; Wawrzyńczak et al., 2006). After storage and maturing, the highest titratable acidity was observed in fruit harvested at the earliest date and stored in the controlled atmosphere (Tab. 4). The greatest titratable acidity decrease was observed in the case of pears harvested at the latest date and stored in common cold storage. According to Mielke et al. (2005), composition of the controlled atmosphere has little or no influence on the titratable acidity in pears. Study results present better retainment of the titratable acidity in the case of pears stored in a controlled atmosphere of 3:3, than those stored in a controlled atmosphere of 0.8:2. They also confirm the opinion of Błaszczyk and Ben (1999) and Calvo et al. (2002) that controlled atmosphere conditions are far better than normal at-

Table 5. Soluble solids content [%] of 'Concorde' pears after storage, as affected by harvest date and storage conditions

Year	Harvest	Storage conditions (CO_2:O_2)				Mean for harvest
		0.8:2	2:2	3:3	air	
After storage						
2008/2009	I	14.1 d*	14.3 e	14.3 e	12.2 a	13.7 a
	II	14.5 f	14.7 h	14.5 f	12.6 b	14.1 b
	III	14.6 g	14.8 i	14.8 i	13.6 c	14.4 c
Mean for storage conditions		14.4 b	14.6 d	14.5 c	12.9 a	-
2009/2010	I	14.0 f	14.2 g	13.1 c	12.7 a	13,5 a
	II	14.2 g	13.6 de	13.1 c	12.9 b	13.5 a
	III	14.0 f	14.3 g	13.7 e	13.5 d	13.9 b
Mean for storage conditions		14.1 c	14.0 c	13.3 b	13.0 a	-
After shelf life						
2008/2009	I	14.2 c	14.3 d	14.2 c	13.3 a	14.0 a
	II	14.9 g	14.9 g	14.6 e	13.4 b	14.4 b
	III	14.9 g	15.0 h	14.8 f	14.3 d	14.8 c
Mean for storage conditions		14.7 c	14.7 c	14.5 b	13.7 a	-
2009/2010	I	13,1 c	13.6 f	13.1 c	12.6 a	13.1 a
	II	13.2 d	13.7 fg	13.3 de	12.9 b	13.3 b
	III	13.3 de	13.6 f	13.4 e	14.2 f	13.6 c
Mean for storage conditions		13.2 a	13.6 c	13.3 b	13.2 a	-

*Explanatios, see Table 1

mosphere conditions as regards limiting the decrease of titratable acidity.

Wawrzyńczak et al. (2008) believe, that soluble solids content in pears changes slightly during storage. It usually increases after storage and while maturing (Höhn and Dätwyler, 1994), but according to Ma and Chen (2003) and Wawrzyńczak et al. (2006) that cannot be treated as a consistent rule. The highest soluble solids content, both after storage and the maturing period, were usually observed in the case of the pears stored in controlled atmosphere, harvested at the latest date (Tab. 5). The lowest value of the soluble solids content were observed in the case of pears harvested at the earliest date and stored in common cold storage. There are different opinions about the influence of controlled atmosphere on the process of soluble solids content changes. Calvo et al. (2002) and Mielke et al. (2005) claim, that controlled atmosphere has no influence on the soluble solids content. Eccher Zerbini et al. (2002) have proof that this influence exists. The results of this studies show, that a controlled 2:2 atmosphere had the best influence on maintaining high soluble solids content in stored pears.

Table 6. Storage disorders [%] in 'Concorde' pears after storage and shelf life, as affected by harvest date and storage conditions

Year	Harvest	Storage conditions (CO_2:O_2)				Mean for harvest
		0.8:2	2:2	3:3	air	
Fungal decay						
2008/2009	I	0.0 a*	0.0 a	0.0 a	6.6 bc	1.6 a
	II	6.2 b	7.2 c	8.0 d	12.3 f	8.4 b
	III	7.0 c	7.1 c	8.8 e	12.9 g	9.0 c
Mean for storage conditions		4.4 a	4.8 b	6.3 c	10.6 d	-
2009/2010	I	0.0 a	2.2 b	2.4 b	7.6 ef	3.0 a
	II	0.0 a	3.2 c	4.8 d	8.0 f	4.0 b
	III	2.3 b	8.5 g	7.5 e	11.8 h	7.5 c
Mean for storage conditions		0.8 a	4.6 b	4.9 b	9.1 c	-
Physiological disorders						
2008/2009	I	0.0 a	0.0 a	0.0 a	21.3 e	5.3 a
	II	6.3 b	0.0 a	0.0 a	32.1 f	9.6 b
	III	10.1 d	6.5 bc	6.8 c	43.7 g	16.8 c
Mean for storage conditions		5.5 b	2.2 a	2.3 a	32.4 c	-
2009/2010	I	0.0 a	0.0 a	0.0 a	10.1 d	2.5 a
	II	0.0 a	0.0 a	0.0 a	13.9 e	3.5 b
	III	2.3 b	2.3 b	6.2 c	26.3 g	9.3 c
Mean for storage conditions		0.8 a	0.8 a	2.1 b	16.8 c	-

*Explanatios, see Table 1

Postharvest disease occurrence can cause big losses during fruit storage. 'Concorde' pears' susceptibility to disease depends on the harvest date and storage conditions (Tab. 6). The highest percentage of rotten fruit was found in pears from the third harvest date which had been stored in normal atmosphere conditions. Fruit from the earliest harvest were less affected by fungal diseases. Higher susceptibility to putrefaction of the most ripe pears, from the later harvest, is reported by Drake and Gix (2000), Błaszczyk (2003), Lafer (2005). A serious problem related with long term storing of 'Concorde' pears in normal atmosphere is their high susceptibility to senescent scald. Another observation, made mostly in the case of pears from the latest harvest, stored in controlled atmosphere conditions, is fruit damage in which flesh and cavities turn brown, caused by CO_2. According to Lammertyn et al. (2000) intensity of fruit damage caused by CO_2 increases with subsequent harvest dates.

CONCLUSIONS

The influence of harvest date on the quality of pears depends on the

studied attribute. Flesh firmness and titratable acidity decreased in subsequent harvest dates, while soluble solids content increased. Controlled atmosphere was more efficient than normal atmosphere in maintaining high quality of stored pears. The result was better firmness, lower loss of titratable acidity and higher soluble solids content. Delay in harvest date caused faster maturation of pear fruit, resulting in faster softening of fruit, the biggest reduction/loss of titratable acidity and the highest susceptibility to storage disorders. Long term storage of 'Concorde' pears in normal atmosphere conditions can be connected with the risk of mass scald of senescent.

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WPŁYW TERMINU ZBIORU I WARUNKÓW PRZECHOWYWANIA NA ZMIANY WYBRANYCH CECH JAKOŚCIOWYCH GRUSZEK ‘CONCORDE’

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S T R E S Z C Z E N I E

Doświadczenie przeprowadzono w dwóch sezonach przechowalniczych 2008/2009 i 2009/2010. Badano wpływ przeprowadzonego w 4-dniowych odstępach terminu zbioru oraz zróżnicowanych warunków przechowywania (KA 0.8% CO_2:2% O_2, KA 2% CO_2:2% O_2, KA 3% CO_2:3% O_2 i NA – normalna atmosfera) na wybrane parametry jakości owoców. Gruszki przechowywano przez 150 dni w temperaturze 0-0.5 ^oC. Po wyjęciu z chłodni owoce przetrzymywano dodatkowo przez 7 dni w temperaturze 17 ^oC (warunki symulowanego obrotu). Jakość gruszek oceniano po każdym terminie zbioru oraz po wyjęciu owoców z chłodni i po okresie symulowanego obrotu. Oznaczano jędrność miąższu, zawartość ekstraktu i kwasowość oraz oceniano zdrowotność gruszek. Termin zbioru istotnie wpływał na stan dojrzałości owoców oraz wartości badanych parametrów jakościowych gruszek w czasie zbioru. W kolejnych terminach zbioru wartość indeksu skrobiowego i zawartość ekstraktu w gruszkach wzrastały, a wartość wskaźnika dojrzałości Streifa, jędrność miąższu oraz kwasowość się zmniejszały. Termin zbioru oraz warunki przechowywania miały również istotny wpływ na wartości badanych cech jakościowych gruszek oznaczonych po przechowywaniu i po okresie symulowanego obrotu. Gruszki przechowywane w warunkach kontrolowanej atmosfery wyróżniały się większą jędrnością i wyższą kwasowością w porównaniu z owocami przechowywanymi w chłodni zwykłej. Opóźnienie terminu zbioru powoduje natomiast szybkie mięknięcie owoców, dużą redukcję kwasowości oraz zwiększoną podatność gruszek na gnicie wywołane przede wszystkim przez gorzką zgniliznę. Poważnym problemem występującym przy długoterminowym przechowywaniu gruszek odmiany ‘Concorde’ jest jej wrażliwość na uszkodzenia miąższu powodowane przez dwutlenek węgla oraz dużą podatność na oparzeliznę starczą.

Słowa kluczowe: gruszki, termin zbioru, normalna atmosfera, kontrolowana atmosfera, jędrność, kwasowość, zawartość ekstraktu, jakość, choroby przechowalnicze