INFLUENCE OF ROOTSTOCK ON THE QUALITY OF 'JONAGOLD' APPLES AT HARVEST AND AFTER STORAGE

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(Received April 14, 2008/Accepted June 10, 2008)

A B S T R A C T

The investigations were carried out in the experimental orchard at Warsaw-Wilanów (central Poland) in the years 1998-2001. Trees were planted in the autumn of 1994 in very fertile, loamy alluvial soil. The obtained results confirm that rootstocks affect fruit ripening significantly. PB-4 and M.26 rootstocks delayed the ripening of apples, as opposed to B 9, M.9, P 22, B 146 and P 60, which provoked the earlier ethylene production; therefore, fruits from trees on the latter ones should be picked earlier. During storage, apples from trees on M.9 showed a lower ethylene production rate than fruits from trees on PB-4 or P 22. In all years of the study the lowest firmness was noted in apples from trees on M.26, both at harvest and after storage. In general, rootstock M.9, especially its subclone 984, affected this parameter positively. Rootstock also influenced the soluble solids content significantly; fruits from trees on P 60 or B 396 contained more soluble solids than those from trees on M.7 or PB-4. Fruit size depended on the tree vigour; superdwarfing rootstocks PB-4 and P 22 reduced the mean fruit weight.

Keywords: rootstock, fruit quality, ripening, ethylene, firmness, soluble solids

INTRODUCTION

Vegetative rootstocks used in modern orchards are characterised by great variability. Thus, they became an easy tool of regulating the tree growth, early fruiting and yielding. The effect of a rootstock on these traits, as well as, on the mineral nutrition of trees is well documented in the literature (Fallahi et al., 1985; Sadowski et al., 2004). However, scarce information concerning the effect of rootstock on physiological status and apple quality at harvest, as well as, after storage is available. What is more, the reported results are often contradictory (Fallahi et al., 1985; Autio et al., 1996). Dwarf orchards are becoming more and more popular around the world. However, in Europe the M.9 rootstock is often criticised (Maas and Wertheim, 2002). Therefore, in many countries trials were undertaken to find an alternative rootstock, more useful for specific biotic conditions.

The present investigation aimed at assessing the usefulness of 14 rootstocks of various origin and vigour, under the soil and climatic conditions of Central Poland. The trial was undertaken to evaluate the rootstock effect on the apple ripening and their quality at harvest and after storage.

MATERIAL AND METHODS

The investigations were carried out in the years 1998-2001 on apples from the experiment carried out by Sadowski et al. (1999, 2003) at Warsaw-Wilanów, on loamy alluvial soil. 'Jonagold' trees were planted in the autumn of 1994, with 4 m space between the rows and from 1 to 2 m space in the row – depending on the expected rootstock's vigour; trees on M.7, M.26 were spaced 2 m apart; on B 396, P 60 1.5 m; on M.9, B 9, P 16, PB-4 1.25 m; on B 146 and P 22 1 m. The experiment was set in 3 replications, each including 2-4 trees. The effects of 14 rootstocks of various vigour and origin were compared. The investigations included superdwarfing rootstocks – PB-4, P 22, P 16 and B 146 (57-146); dwarfing – M.9 and its subclones (EMLA, T337, T339, 984) and B 9, as well as, semi-dwarfing rootstocks – No 47, P 60, B 396 (62-396), M.26 and M.7. Considering the origin of plants, the investigations included the effect of English rootstocks (M.9 EMLA, M.26, M.7), Dutch (M.9 T337, M.9 T339), Polish (P 16, P 22, No 47, P 60), Russian (B 9, B 146, B 396), German (M.9 984) and Belorussian PB-4, obtained from free pollination of B 9.

Fruitlets were thinned twice, i.e. once chemically and then manually. The harvest date was calculated on the basis of induced ethylene. Apples were picked at one time. Picked apples (about 24 kg for each replication) were stored for six months at the temperature 0-1° C and relative air humidity of 90-95%,.The ethylene concentration in the core, the degree of starch hydrolysis and the average apple weight were determined immediately after harvest. The firmness, the soluble solids content and the titratable acidity were determined twice, i.e. after harvest and after storage. The percentage of natural losses was determined after storage. In each replication, all the determinations were done on 15 randomly selected fruits.

The results were elaborated statistically using the analysis of variance in a completely randomised design. The Newman-Keuls test was applied for the evaluation of significance of differences between means at the confidence level of p = 0.05.

RESULTS AND DISCUSSION

Weather conditions in a certain vegetation period were an important factor interacting with the effect of a given rootstock. The course of weather conditions (temperature, rainfall) often determined the harvest date and the storage ability of apples to a greater extent than the rootstock. This effect was particularly noticeable when the apple harvest dates in the successive years of investigations were compared. Under the conditions of central Poland, 'Jonagold' apples are usually picked at the end of the first decade of October. However, in the present study apples were harvested on September 25th in 1998; September 26th in 1999 and September 21st in 2000. Only in the last year of the investigation (2001) the harvest date was typical for this cultivar, i.e. October 8th. The first three years of the research were much warmer as compared to the long-term mean temperature and this favoured earlier ripening of apples.

Many reports emphasise the effect of the harvest date on apple quality and storage ability. On the one hand the process of fruit ripening is connected with the increased ethylene production, the intensity of respiration, the flesh firmness decrease and the shortening of storage ability; on the other hand – with the increase of fruit size, the improvement of skin colour, the soluble solids content, the taste and flavour of apples (Beaudry et al., 1993). Thus, the harvest date is a certain compromise between the storage ability and the quality of apples. In the present experiment the harvest date was determined by the induced ethylene method. The ethylene content in the cores revealed a significantly positive correlation with the induced ethylene and with the results of starch test (results not presented).

It is frequently stated in the literature that dwarfing rootstocks favour earlier fruit maturity. Such a relationship was noticeable in the experiments, in which the rootstocks of various vigour were compared (Wallace, 1930; Autio et al., 1996). On the other hand, in the case of a lower vigour, the differences in apple maturity were usually less noticealbe (Łysiak and Kurlus, 2000). In the present experiment such a relationship was only partly confirmed, because fruits from trees on relatively vigorous rootstocks (M.26, M.7) ripened later than apples from trees on other rootstocks (Tab. 1). It was also noted that apples from trees on super dwarfing rootstock PB-4 were the last to ripen and this was confirmed by various methods of evaluation of the fruit physiological status. During storage, however, apples from trees on PB-4 and P 22 rootstocks showed the highest ethylene production (results not presented). Rootstocks M.9, P 22, B 9, B 146 and B 39 delayed fruit ripening.

A lower apple weight was regularly observed in fruits from the trees on rootstocks such as PB-4 and P 22,

Table 1. Internal ethylene concentration and mean weight of ‘Jonagold’ apples depending on the rootstock and the year of investigation

Rootstock	Internal ethylene concentration [μl·l^{-1}]				Mean weight [g]			
	1998	1999	2000	2001	1998	1999	2000	2001
M.7	0.71 abcd*	1.69 a	0.94 ab	0.54 ab	231 b	222 b	241 d	253 c
M.26	0.36 a	2.40 ab	0.50 a	0.27 ab	227 b	212 ab	218 bcd	236 c
M.9 EMLA	0.59 abcd	3.18 bcd	2.26 c	0.52 ab	236 b	209 ab	216 bcd	234 c
M.9 T337	0.96 de	3.29 bcd	2.06 c	0.63 b	232 b	204 ab	229 bcd	244 c
M.9 T339	0.51 abc	2.45 ab	2.01 c	0.40 ab	223 b	214 ab	230 cd	228 bc
M.9 984	0.77 bcd	2.66 abc	2.90 d	0.59 b	217 b	185 ab	199 bc	250 c
P 16	0.88 cde	4.33 d	0.40 a	0.18 ab	236 b	211 ab	205 bc	227 bc
P 22	0.69 abcd	4.02 cd	–	0.38 ab	224 b	181 a	–	202 b
No 47	0.66 abcd	2.83 abc	1.12 b	0.36 ab	219 b	211 ab	219 bcd	228 bc
P 60	0.63 abcd	3.02 abcd	1.11 b	0.35 ab	215 b	210 ab	217 bcd	242 c
B 9	1.19 e	3.26 bcd	1.09 b	0.94 c	225 b	194 ab	203 bc	245 c
B 146	0.88 cde	4.07 cd	0.46 a	0.24 ab	220 b	179 a	219 bcd	231 bc
B 396	0.59 abcd	3.80 bcd	2.23 c	0.48 ab	226 b	202 ab	198 b	222 bc
PB-4	0.44 ab	–	0.41 a	0.09 a	188 a	–	155 a	178 a
Mean for year	0.70 b	3.16 d	1.35 c	0.43 a	223 c	203 a	211 b	230 d

*Explanations: the same letters in a column mark the means not differing at the confidence level p = 0.05

rather than from trees on M.7 (Tab. 2). This is in agreement with the results obtained by Maas and Wertheim (2002) and Sadowski et al. (1999, 2004). No clear relationship between the mean fruit weight and the soluble solid contents, the flesh firmness and the ethylene concentration in the core was observed in the present experiment. Thus, it was decided not to consider the fruit size in the statistical analysis of the results, contrary to Autio et al. (1996).

Until recently, consumers buying fruits have been motivated, first of all, by their external quality, i.e. size and skin blush and background colour. At present, flesh firmness, soluble solids content and acidity are becoming more and more important (Barritt, 2001). Thus, the possibility of affecting the flesh firmness or the soluble solids content in fruits through the choice of a proper rootstock, may be interesting. However, it should be noted that in many experiments the rootstock effect on the apple size was either not observed (Ystaas et al.,1997) or it was slight and inexplicit (Barden and Marini, 1992). On the other hand, in the investigations where such an effect was noted the obtained results were inexplicit and often even contradictory (Autio et al., 1996). In the present experiment the significant effect of the rootstock on the apple flesh firmness (Tab. 2), the soluble solids content (Tab. 3) and the acidity (Tab. 4) was demonstrated, both during harvest and after storage.

T a b l e 2 . Flesh firmness of ‘Jonagold’ apples at harvest and after storage depending on the rootstock and the year of investigation

Rootstock	Soluble solids contnt [%]							
	at harvest				after storage			
	1998	1999	2000	2001	1998	1999	2000	2001
M.7	15.8 a*	15.1 a	16.1 a	13.0 ab	15.5 a	14.5 a	12.4 a	10.3 a
M.26	15.4 a	16.7 b	16.5 a	14.2 b	14.8 a	15.9 b	12.8 abc	12.3 b
M.9 EMLA	15.7 a	16.7 b	16.6 a	12.9 ab	15.1 a	16.1 b	14.7 bc	12.0 b
M.9 T337	15.4 a	17.0 b	16.1 a	12.4 a	15.0 a	16.3 b	13.5 abc	10.9 ab
M.9 T339	16.4 a	17.0 b	16.3 a	13.1 ab	15.1 a	16.3 b	13.7 abc	11.3 ab
M.9 984	16.2 a	16.4 b	16.8 a	13.3 ab	15.0 a	16.0 b	12.6 ab	11.0 ab
P 16	16.3 a	17.0 b	16.8 a	13.3 ab	14.9 a	15.6 b	12.9 abc	11.6 b
P 22	16.1 a	16.9 b	–	13.4 ab	14.9 a	16.2 b	–	11.9 b
No 47	15.3 a	16.7 b	17.1 a	13.7 ab	14.6 a	16.1 b	14.0 abc	12.2 b
P 60	15.9 a	16.2 b	17.5 a	13.4 ab	15.0 a	15.8 b	14.9 c	12.1 b
B 9	15.8 a	16.0 b	16.7 a	13.4 ab	15.3 a	15.8 b	13.8 abc	12.1 b
B 146	15.4 a	16.8 b	16.5 a	13.4 ab	14.1 a	16.2 b	12.7 ab	11.7 b
B 396	16.6 a	17.0 b	16.6 a	13.5 ab	15.2 a	16.2 b	14.7 bc	11.9 b
PB-4	15.1 a	–	16.9 a	13.2 ab	14.1 a	–	13.9 abc	11.6 b
Mean for year	15.8 b	16.6 c	16.7 c	13.3 a	14.9 c	15.9 d	13.6 b	11.6 a

*Explanation: see table 1

T a b l e 3 . Soluble solids content in ‘Jonagold’ apples at harvest and after storage depending on the rootstock and the year of investigation

Rootstock	Flesh firmness [N]							
	at harvest				after storage			
	1998	1999	2000	2001	1998	1999	2000	2001
M.7	85.9a*	77.7 a	73.9 ab	66.9 a	49.9 a	56.6 abc	41.0 a	37.9 a
M.26	79.3a	77.2 a	71.0 a	66.5 a	57.6 b	56.3 abc	43.2 ab	37.3 a
M.9 EMLA	85.3a	81.8 ab	84.2 bc	69.9 a	57.9 b	56.2 abc	45.4 bc	41.2 b
M.9 T337	86.7a	86.7 b	83.3 bc	67.6 a	57.9 b	58.0 bc	44.2 ab	39.3 ab
M.9 T339	87.9a	84.3 ab	78.5 abc	67.9 a	60.6 b	54.0 ab	42.9 ab	39.2 ab
M.9 984	95.8b	83.5 ab	84.0 bc	67.7 a	58.5 b	59.5 c	48.4 c	40.3 ab
P 16	81.9a	84.4 ab	78.7 abc	69.2 a	55.4 b	54.6 abc	46.1 bc	37.8 a
P 22	81.7a	77.1 a	–	71.0 a	57.9 b	51.1 a	–	39.4 ab
No 47	83.9a	81.0 ab	74.7 ab	68.3 a	59.0 b	53.2 ab	42.3 ab	39.1 ab
P 60	83.6a	79.7 ab	76.8 ab	68.0 a	54.8 b	56.0 abc	44.5 ab	40.6 ab
B 9	86.5a	80.1 ab	69.2 a	67.1 a	56.6 b	53.2 ab	44.3 ab	40.5 ab
B 146	80.8a	79.5 ab	75.5 ab	69.2 a	57.4 b	55.8 abc	44.4 ab	39.3 ab
B 396	84.7a	79.9 ab	76.1 ab	67.7 a	57.2 b	53.3 ab	46.2 bc	39.2 ab
PB-4	79.9a	–	86.6 c	70.3 a	54.3 b	–	52.6 d	38.8 ab
Mean for year	84.6d	81.0 c	77.9 b	68.4 a	56.8 d	55.2 c	45.1 b	39.3 a

*Explanation: see Table 1

Table 4. Titratable acidity of apples at harvest and after storage depending on the rootstock and the year of investigation

Rootstock	Titratable acidity [% malic acid]			
	at harvest		after storage	
	2000	2001	2000	2001
M.7	0.613 b*	0.520 a	0.361 b	0.292 ab
M.26	0.602 ab	0.522 a	0.354 b	0.288 ab
M.9 EMLA	0.560 ab	0.475 a	0.329 ab	0.300 ab
M.9 T337	0.570 ab	0.477 a	0.333 ab	0.288 ab
M.9 T339	0.563 ab	0.479 a	0.336 ab	0.292 ab
M.9 984	0.573 ab	0.516 a	0.344 ab	0.292 ab
P 16	0.584 ab	0.489 a	0.357 b	0.305 ab
P 22	–	0.432 a	–	0.236 a
No 47	0.568 ab	0.489 a	0.325 ab	0.272 ab
P 60	0.547 a	0.473 a	0.341 ab	0.300 ab
B 9	0.558 ab	0.475 a	0.332 ab	0.333 b
B 146	0.550 a	0.469 a	0.334 ab	0.296 ab
B 396	0.586 ab	0.516 a	0.349 b	0.300 ab
PB-4	0.539 a	0.447 a	0.303 a	0.244 ab

*Explanation: see table 1

Subclones of M.9, in particular M.9 984, in contrast to M.26, B 9, M.7 and B 146, affected the firmness of apples positively. During storage, the highest firmness decrease was observed in fruits picked from trees on the most strongly growing rootstock, i.e. M.7.

Weather conditions in particular years of the investigation had a larger effect on the apple firmness than rootstocks. The conditions in the first two years of the study affected positively the value of this parameter. In the season of 2000/01, apples showed the highest decrease of firmness during storage. However, the weather conditions in the last year of the investigation affected this trait in an exceptionally negative way.

Generally speaking, the weather conditions in the investigation favoured a high soluble solids content in apples. Only in 2001 a significantly lower soluble solid content was noted in fruits, both at harvest and after storage. Summing up, it should be stated that apples harvested in the year 2001 were characterized by the lowest soluble solids content and firmness. Probably the cause of that were the lowest temperature and the highest total rainfall prior to harvest. At the same time, it should be underlined that, apart from the season effect, a significant rootstock effect on the soluble solids content and apple acidity was demonstrated. A low soluble solids content was observed in fruits obtained from the trees on vigorous rootstock M.7 and on super dwarfing rootstock PB-4.

In the West European countries more and more critical opinions concerning M.9 rootstock are being expressed. However, taking into consideration the results presented in this paper, it seems that finding an alternative to M.9 rootstock would be a very difficult task. M.9 rootstock hastens the harvest date of apples significantly. This rootstock affects positively apple quality, especially their firmness during harvest and after storage, as well as, the fruit size and their storage ability.

CONCLUSIONS

1. Rootstock affects the quality of apples, despite the fact that this effect is to a great extent modified by weather conditions during the vegetation period.
2. Apples from trees on the rootstocks PB-4, M.26 and M.7 ripen later than fruits from trees on M.9, B 9, P 22, B 396, B 146 and P 60.
3. Fruits from the trees on super-dwarfing rootstocks P 22 and PB-4 show the tendency to smaller size and higher natural losses during storage.
4. Under the conditions of an exceptionally high temperature during the vegetation period, apples tend to have lower flesh firmness and lower soluble solids content.

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WPŁYW PODKŁADKI NA JAKOŚĆ JABŁEK ‘JONAGOLD’ PODCZAS ZBIORU I PO PRZECHOWYWANIU

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STRESZCZENIE

Badania prowadzono w latach 1998-2001 na jabłkach odmian ‘Jonagold’ z sadu doświadczalnego w Warszawie-Wilanowie. Drzewa były sadzone jesienią 1994 roku na żyznej glebie typu mada. Otrzymane wyniki wskazują, że podkładka istotnie wpływała na dojrzewanie owoców. Jabłka z drzew na PB-4 i M.26 uzyskiwały dojrzałość zbiorczą później niż owoce z drzew na B 9, M.9, P 22, B 146 i P 60, które odznaczały się wyższym stężeniem etylenu w komorach nasiennych i w związku z tym powinny być zbierane wcześniej. W czasie przechowywania, jabłka z drzew na podkładce M.9 charakteryzowały się niższą intensywnością wydzielania etylenu niż owoce z drzew na podkładkach PB-4 lub P 22. We wszystkich latach badań najniższą jędrność zarówno w czasie zbioru, jak i po przechowywaniu notowano w przypadku jabłek z drzew na podkładce M.26. Natomiast podkładka M.9, zwłaszcza jej podklon 984, wpływała dodatnio na wartość tego wyróżnika jakości jabłek. Podkładka oddziaływała istotnie także na zawartość ekstraktu; owoce z drzew na podkładkach P 60 lub B 396 zawierały więcej ekstraktu niż owoce z drzew na podkładce M.7 lub PB-4. Wielkość owoców zależała od siły wzrostu drzew; superkarłowe podkładki PB-4 i P 22 powodowały drobnienie jabłek.

Słowa kluczowe: podkładka, jakość jabłek, dojrzewanie, etylen, jędrność, zawartość ekstraktu