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Apple rootstock trials at Warsaw University of Life Sciences-SGGW, Poland

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Abstract

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Evaluation of 22 dwarfing and semi-dwarfing apple rootstocks for several scion cultivars was conducted on fertile soil in the years 1995–2010. It was found that most of the new rootstocks performed similarly to M.9 EMLA with respect to vigour, yield, cropping efficiency and fruit mass. These rootstocks would not be, therefore, a good replacement for M.9 in Polish climatic conditions. The most promising rootstock was B 9 and some of its derivatives, e.g., B 146, B 396, P 59 and P 60. However, their suitability may be limited to particular cultivars grown under similar soil conditions.

Keywords: *Malus* × *domestica*; vigour; yield; cropping efficiency coefficient; fruit mass

For two or more millennia rootstocks have been used in apple growing around the world. However, the real revolution occurred in the previous century and consisted in the selection and introduction of vegetative rootstock clones with the ability to dwarf scions grafted or budded onto them. Undoubtedly, the greatest achievements in modern apple rootstock evaluation were achieved by the well-known pomologist Professor Ronald Hatton at the East Malling Research Station in England (Ferree, Carlson 1987). At the beginning of the 20th century he classified likely all the known apple rootstocks used in the major European nurseries. This work highlighted the prevailing diversity as well as the confusion that at times occurred among clones. After verification, these rootstocks, e.g., M.9, became standard rootstocks worldwide (Wertheim 1998).

In English studies, breeding was initiated which was aimed at obtaining clones which would be better adapted to the varied local climatic and biotic conditions of different countries. The resulting new rootstocks were intensively examined in the late 20th century. One of the active centres of these studies in Poland was the Department of Pomology, Warsaw University of Life Sciences-SGGW. This department has assessed numerous rootstocks on its very rich soil. Particular attention was paid to the rootstocks of domestic origin and those from other Eastern European countries with climatic conditions similar to that of Poland. This was justified on the basis of studies showing insufficient resistance to frost of M.9 rootstock in Poland. In one of these experiments, Czynczyk (1979) recorded a several-fold higher percentage of dead trees on M.9 rootstock than on M.26 or on B 9 after the winter of 1968/1969. Moreover, Zagaja (1977) noted that the decline of soil temperature to –11.5°C during the winter of 1971/1972 resulted in more than 85% of M.9 rootstock plants being killed or damaged by frost, while the percentage of damaged or killed M.26 or P 22 plants was less than 45% and 25%, respectively.

This publication summarises the results of apple rootstock studies conducted at the Department of

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Pomology of Warsaw University of Life Sciences-SGGW, Poland.

MATERIAL AND METHODS

A series of apple rootstock trials were carried out at the Department of Pomology, Warsaw University of Life Sciences-SGGW in the experimental orchard located at Warsaw-Wilanów (lat. 52.16°N, long. 21.10°E) on a silty loam alluvial soil. The studies were focused on the suitability of different rootstocks for selected apple cultivars. Experiments with particular cultivars were conducted in the following periods: 'Jonagold' (1995–2007), 'Fiesta' (1995–2006), 'Holiday' (1995–2005) and 'Elise' (1997–2010 and in 2000–2010 ('V' planting system)) (Table 1).

A pool of the genetically diverse apple rootstocks of foreign and domestic origin were compared with the English standard stocks, i.e., M.9 EMLA, M.26, M.27 and M.7. The foreign rootstocks included in the trials were PB-4 from Belarus and B 9, B 146, and B 396 from Russia. The examined Polish series of rootstocks contained the following clones: P 2, P 14, P 16, P 22, P 59, P 60 and No. 47. Some subclones of M.9 were also included, namely the German selections M.9 751 and M.9 984, French selections M.9 Pajam 1 and M.9 Pajam 2, Belgian selection M.9 RN29 and Dutch selections M.9 T337 and M.9 T339.

Maiden trees of the cvs. 'Jonagold' on 13 rootstocks, 'Fiesta' on 13 rootstocks and 'Holiday' on 11 rootstocks were planted in autumn 1994 (Sadowski et al. 1999). Cv. 'Elise' was planted on 21 rootstocks in spring 1997 (Słowiński, Sadowski 1999) and also on 18 rootstocks in a 'V' planting system in spring 2000 (Kowalczyk, Wrona 2011). Planting density was calculated in accordance with the expected cultivar tree vigour on a given rootstock based on the literature. Rootstocks used for particular cultivars and numbers of

Table 1. Rootstocks, apple cultivars and number of trees per hectare in trials at Warsaw-Wilanów

Rootstock	Cultivar				
	'Jonagold'	'Fiesta'	'Holiday'	'Elise'	'Elise' ("V" planting system)
B 9	2,000	2,424	–	2,198	4,082
B 146	2,500	3,030	–	–	4,082
B 396	1,250	–	–	1,389	2,632
P 2	–	–	–	1,389	4,082
P 14	–	–	–	1,389	2,632
P 16	–	2,424	3,200	3,226	6,250
P 22	2,500	3,030	4,000	3,226	–
No. 47	1,250	1,515	2,000	1,389	–
P 59	–	–	–	3,226	4,082
P 60	1,667	1,818	2,000	1,389	2,632
PB-4	2,500	2,424	–	3,226	6,250
M.7	1,250	1,515	2,000	1,389	–
M.9 EMLA	2,000	2,424	3,200	2,198	4,082
M.9 Pajam 1	–	–	–	2,198	4,082
M.9 Pajam 2	–	–	–	2,198	4,082
M.9 RN29	–	–	–	2,198	4,082
M.9 T337	2,000	2,424	3,200	2,198	–
M.9 T339	2,000	2,424	3,200	2,198	4,082
M.9 751	–	–	–	2,198	4,082
M.9 984	2,000	2,424	3,200	2,198	4,082
M.26	1,250	1,515	2,000	1,389	2,632
M.27	–	–	5,333	4,032	6,250

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trees per hectare are listed in Table 1. Experiments with cvs 'Jonagold', 'Fiesta' and 'Holiday' consisted of 3–12 single trees serving as replicates of each rootstock, and in two trials with 'Elise', each rootstock was represented by 5–7 or 10 trees per plot, respectively, in four replications. Tree training was standard spindle and typical orchard practices (together with fruitlet thinning) were standard for apple growing in Poland. Trunk diameters at the height of 30 cm above the ground were measured, and then converted to the trunk cross-sectional area (TCSA). Yields from individual replicates were weighed separately and subsequently converted to yield per tree or per TCSA, from which the cropping efficiency coefficient (CEC) was calculated. Mean fruit mass was also determined. Data were evaluated with analysis of variance using the Statgraphics *Plus* 4.0 programme. Mean separation was performed using the Newman-Keuls test at a level of significance of $P = 0.05$.

RESULTS

Significant differences in the relative tree size (TCSA) were noted among the rootstocks tested. Cv. 'Jonagold' trees were smallest (lowest TCSA) on P 22 or PB-4; these trees were almost four times larger on various M.9 subclones, B 9 and its derivatives P 60, B 396 and No. 47, as well as on M.26 (Table 2).

Cv. 'Fiesta' trees were significantly (about 70% to 40%) smaller on PB-4, P 22, P 16 and B 146 than those on M.9 EMLA as well as on the other M.9 subclones, No. 47 and P 60 (Table 3). Trees on the Dutch subclones M.9 T339 and T337 and M.26 did not differ significantly in size.

Cv. 'Holiday' trees were smallest on rootstocks M.27, P 16 and P 22, and about three times larger on P 60, the various subclones of M.9 and on No. 47 (Table 4). Trees of 'Jonagold', 'Fiesta' and 'Holiday' were usually the largest on M.7 rootstock. Cv. 'Elise' trees on P 59, PB-4, P 22 and M.27 were about half the size of those on M.9 T339, M.9 RN29, M.9 T337, B 9 or M.9 984 (Table 5). M.9 EMLA tree size was equal to that of trees grown on M.9 RN29, M.9 T337, B 9, M.9 984, P 2, P 60, B 396 and No. 47. Trees on the P 14 rootstock were larger than those on M.7 or M.26. Cv. 'Elise' trees in 'V' planting system were smallest on rootstocks PB-4 and P 59 and only one-third of the size of those on M.9 EMLA (Table 6). Most of the rootstocks did not differ in vigour from M.9 EMLA. However, trees on P 14 were more than twice as large as those on any M.9 subclone.

Cumulative yield per tree of 'Jonagold' was lowest on PB-4 and P 22 (Table 2). Trees on P 60 and M.9 T339 yielded nearly three times more, with values similar to trees on the other M.9 subclones, M.7, B 396 or B 9.

Cv. 'Fiesta' exhibited the lowest yield on PB-4, P 22, P 16 and B 146 (<100 kg per tree) (Table 3). Trees

Table 2. Tree size, yield and fruit mass of 'Jonagold' apples depending on rootstock

Rootstock	TCSA (autumn 2004)		Cumulative yield 1996–2007 (kg/tree)	CEC (kg/cm^2)	Fruit mass 2001–2005 (g)
	(cm^2)	(%)**			
P 22	13.5^{a*}	25	161^{a}	12.0^{e}	196^{a}
PB-4	14.9^{a}	28	124^{a}	8.5^{d}	216^{b}
B 146	28.7^{b}	54	302^{bc}	11.3^{e}	238^{cd}
P 60	48.9^{c}	91	385^{cd}	8.0^{d}	254de
B 396	49.4^{c}	92	336^{bcd}	6.8^{bcd}	263de
M.9 T339	49.3^{c}	92	419^{d}	8.5^{d}	255de
No. 47	50.7^{c}	95	290^{b}	5.5^{bc}	229^{bc}
M.9 T337	51.5^{c}	96	359^{bcd}	7.1^{bcd}	270^{e}
B 9	51.7^{c}	97	356^{bcd}	7.1^{bcd}	263de
M.9 984	53.6^{c}	100	366^{bcd}	6.9^{bcd}	274^{e}
M.9 EMLA	53.5^{c}	100	375^{bcd}	7.1^{bcd}	260de
M.26	57.1^{c}	107	289^{b}	5.1^{b}	242^{cd}
M.7	102.9^{d}	187	330^{bcd}	3.3^{a}	262de

*means within columns marked by the same letter do not significantly differ at $P = 0.05$; ** tree size on M.9 EMLA = 100%

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Table 3. Tree size and yield of ‘Fiesta’ apples depending on rootstock

Rootstock	TCSA (autumn 2004)		Cumulative yield 1996–2006 (kg/tree)	CEC (kg/cm^2)
	(cm^2)	(%)**		
PB-4	8.6^{a*}	30	46^{a}	5.4^{e}
P 22	9.5^{a}	33	48^{a}	5.0^{de}
P 16	12.0^{ab}	42	73^{a}	6.3^{f}
B 146	17.2^{ab}	60	75^{a}	4.5^{cd}
B 9	21.8^{bc}	76	116^{b}	5.4^{e}
M.9 EMLA	28.9^{cd}	100	128^{bc}	4.5^{cd}
No. 47	29.7^{cd}	103	125^{bc}	4.2^{bc}
P 60	30.1^{cd}	104	155^{bc}	5.1^{de}
M.9 984	31.9^{cd}	110	143^{bc}	4.6^{cd}
M.9 T339	36.9^{de}	128	160^{c}	4.4^{bcd}
M.9 T337	39.0^{de}	135	149^{bc}	3.9^{ab}
M.26	44.2^{e}	153	151^{bc}	3.5^{a}
M.7	55.5^{f}	192	221^{d}	4.2^{bc}

for explanations see Table 2

on B 9, No. 47, M.9 EMLA, M.9 984, M.9 T337, M.26 and P 60 bore significantly higher yields.

Cv. ‘Holiday’ yields were lowest on M.27 and P 22, and significantly higher on P 60 and No. 47, followed by all M.9 subclones and M.26 (Table 4). Both ‘Fiesta’ and ‘Holiday’ yields were highest on M.7 rootstock.

The lowest yield of ‘Elise’ was on PB-4, and the highest yields were on P 14, B 396 and M.26 (Table 5). Cv. ‘Elise’ in ‘V’ planting system cropped least on PB-4 and M.27, and more than three times higher on M.9 751, M.26, P 60, B 396 and P 14 (Table 6).

The cropping efficiency coefficient (CEC) of ‘Jonagold’ trees was lowest on M.7 (Table 2). The CEC was highest on B 146 and P 22. The CEC of ‘Fiesta’ was lowest on M.26 and M.9 T337, and highest on P 16 (Table 3).

Cv. ‘Holiday’ showed its lowest CEC on No. 47, M.26 and M.7 (Table 4). On the other hand, the highest CEC was exhibited by trees on P 16, which was not significantly different from those on M.9 984, M.27 or M.9 T337. The CEC of ‘Elise’ was lowest on P 14 and M.7 (Table 5). The highest CEC was on P 59, which was not significantly different from P 16, M.9 Pajam 2 and M.9 T339. ‘Elise’ in ‘V’ planting system exhibited the lowest CEC on P 14, and highest on P 59 (Table 6).

Table 4. Tree size and yield of ‘Holiday’ apples depending on rootstock

Rootstock	TCSA (autumn 2004)		Cumulative yield 1996–2005 (kg/tree)	CEC (kg/cm^2)	Fruit mass (g)
	(cm^2)	(%)**			
M.27	7.8^{a*}	26	31^{a}	4.1^{bc}	163^{a}
P 16	10.1^{a}	34	46^{b}	4.6^{c}	160^{a}
P 22	10.6^{a}	36	36^{ab}	3.4^{b}	153^{a}
P 60	24.0^{b}	81	61^{c}	3.4^{b}	190^{bc}
M.9 984	24.9^{b}	84	93de	3.8^{bc}	182^{b}
M.9 T337	28.6^{b}	96	93de	4.2^{bc}	186^{bc}
M.9 EMLA	29.7^{b}	100	104^{e}	3.5^{b}	186^{bc}
M.9 T339	29.8^{b}	100	100^{e}	3.4^{b}	184^{b}
No. 47	35.8^{bc}	120	61^{c}	1.8^{a}	202^{c}
M.26	42.1^{cd}	142	99^{e}	2.4^{a}	191^{bc}
M.7	50.3^{d}	170	119^{f}	2.4^{a}	190^{bc}

for explanations see Table 2

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Table 5. Tree size and yield of 'Elise' apples depending on rootstock

Rootstock	TCSA (autumn 2010)		Cumulative yield 1998–2010 (kg/tree)	CEC (kg/cm^2)	Fruit mass (g)
	(cm^2)	(%)**			
P 59	23.9^{a*}	35	122^{b}	5.4^{h}	191^{a}
P^{B}-4	28.3^{ab}	41	77^{a}	3.2^{bcd}	190^{a}
P 22	29.3^{ab}	43	111^{b}	3.8^{cde}	206^{b-e}
M.27	35.1^{abc}	51	132^{b}	3.8^{cde}	201^{a-d}
P 16	41.8^{bcd}	61	185^{c}	4.6^{e-h}	206^{b-e}
M.9 Pajam 2	46.9^{cde}	69	220de	4.8^{fgh}	191^{a}
M.9 Pajam 1	49.4^{cde}	72	216^{d}	4.5^{efg}	201^{a-d}
M.9 T339	51.6^{de}	76	249^{ef}	4.9^{gh}	207^{b-e}
M.9 RN29	56.3^{def}	82	218^{d}	3.9^{def}	198^{abc}
M.9 T337	57.9^{efg}	85	231de	4.0^{d-g}	191^{a}
B 9	59.9^{efg}	88	226de	3.8^{cde}	199^{abc}
M.9 984	61.8^{efg}	90	238de	3.9^{c-f}	198^{ab}
P 2	66.7^{fgh}	98	288^{gh}	4.4^{efg}	215de
M.9 EMLA	67.9^{fgh}	100	249^{ef}	3.7^{b-e}	196^{ab}
P 60	71.5^{ghi}	105	313^{hi}	4.4^{efg}	197^{ab}
B 396	76.9^{hi}	113	347^{j}	4.5^{efg}	206^{b-e}
No. 47	78.3^{hi}	115	307^{h}	4.0^{d-g}	216^{e}
M.9 751	83.6^{i}	123	272^{fg}	3.3^{bcd}	203^{a-e}
M.7	106.9^{j}	157	306^{h}	2.9^{ab}	193^{ab}
M.26	116.8^{j}	171	353^{j}	3.0^{bc}	200^{abc}
P 14	163.7^{k}	240	343^{ij}	2.1^{a}	213^{cde}

for explanations see Table 2

Cv. 'Jonagold' fruits were smallest from trees on P 22, and largest on P 60, M.7, B 396, B 9 and M.9 subclones (Table 2). Fruits of 'Holiday' on P 22, P 16 and M.27 were significantly smaller than on M.9 subclones, P 60, M.7, M.26 and No. 47 (Table 4). The fruit mass of 'Elise' was lowest from trees on PB-4, M.9 T337, M.9 Pajam 2 and P 59, and significantly higher on P 22, B 396, P 16, M.9 339, P 14, P 2 and No. 47 (Table 5). Fruits of 'Elise' in 'V' planting system were smaller from trees on PB-4, M.27 and P 16 than on the other rootstocks (Table 6).

DISCUSSION AND CONCLUSIONS

Many studies, including those carried out in Poland, have focused on searching for improved apple rootstocks that also have superior frost resistance. The assertion that trees on M.9 exhibit only low levels of winter hardiness is somewhat controversial in the light of data accumulated through the years. Polish studies indicated rather high frost sensitivity of M.9 rootstock (Zagaja 1977, Czynczyk 1979). However, Robinson et al. (2006) noted that the survival rate of 'Honeycrisp' and 'McIntosh' apple trees on M.9 subclones T337 or RN29 was quite high after the severe winter of 2004 in New York State and, in fact, similar to that on B 9 or M.26 rootstock.

In Poland, in recent years, M.9 and its subclones have become the most important apple rootstock (Czynczyk, Jakubowski 2007), and Polish growers have increasingly planted trees on M.9. Concerns about the low frost resistance of this rootstock have not been confirmed in Polish commercial apple growing, especially since the last severe winter in Poland which occurred almost 30 years ago (1986/1987).

Trees on M.9 are recognised worldwide as optimal in size, yield and fruit quality according to the requirements of modern intensive apple production (Fazio et al. 2015). More than 40 years ago,

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Table 6. Tree size and yield of 'Elise' apples in 'V' planting system depending on rootstock

Rootstock	TCSA (autumn 2010)		Cumulative yield 2001–2010 (kg/tree)	CEC (kg/cm^2)	Fruit mass (g)
	(cm^2)	(%)**			
PB-4	9.6^{a*}	31	39^{a}	4.0^{bcd}	169^{a}
P 59	10.9^{a}	36	73^{bc}	6.7^{e}	198^{b}
M.27	16.0^{b}	52	57^{ab}	3.6^{b}	178^{a}
P 16	16.4^{b}	53	83^{cd}	5.1^{cd}	181^{a}
B 146	22.5^{c}	73	102de	4.5^{bcd}	212^{bc}
M.9 RN29	24.3^{cd}	79	113^{ef}	4.6^{bcd}	212^{bc}
M.9 T339	24.7^{cd}	80	127^{efg}	5.2^{d}	211^{bc}
M.9 Pajam 1	25.2^{cde}	82	130^{efg}	5.2^{cd}	215^{bc}
B 9	27.2^{cde}	89	117^{ef}	4.3^{bcd}	210^{bc}
P 2	28.4^{cde}	93	121^{efg}	4.3^{bcd}	217^{c}
M.9 984	28.7^{cde}	93	128^{efg}	4.5^{bcd}	212^{bc}
M.9 751	29.6^{def}	96	144^{fgh}	4.8^{bcd}	221^{c}
M.9 EMLA	30.7^{def}	100	135^{efg}	4.4^{bcd}	212^{bc}
M.9 Pajam 2	31.2^{ef}	102	132^{efg}	4.3^{bcd}	220^{c}
B 396	35.2^{fg}	115	166^{h}	4.7^{bcd}	218^{c}
P 60	35.3^{fg}	115	152^{gh}	4.3^{bcd}	211^{bc}
M.26	39.3^{g}	128	147^{fgh}	3.8^{bc}	212^{bc}
P 14	67.4^{h}	220	172^{h}	2.6^{a}	213^{bc}

for explanations see Table 2

Cummins and Aldwinckle (1974) accurately stated that trees on M.9 rootstock are "very efficient convertors of solar energy into fruit", as represented by the high cropping efficiency (productivity) of cultivars budded or grafted onto it.

In the five experiments described in this article, only a few rootstocks performed better than M.9 in terms of productivity or yield, and at vigour levels similar to that on M.9 EMLA. Trees of 'Jonagold' on B 146, 'Fiesta' on B 9, 'Elise' on M.9 subclones T339 and Pajam 2, and on P 59 in the 'V' planting system were more productive than on M.9 EMLA. Moreover, trees of 'Elise', both in a row system on B 396, P 60, P 2 or No. 47 and in a 'V' planting system on B 396, were similar in size to those on M.9 EMLA, but yielded higher. None of the rootstocks onto which cultivar 'Holiday' was grafted showed a cropping efficiency or yield that was significantly superior over M.9 EMLA.

The results show that many of the tested rootstocks were similar in orchard performance to the standard M.9 EMLA clone and therefore cannot currently compete with M.9. It appears that only a few rootstocks can be considered as alternatives to M.9, and even then only for certain cultivars. B 9 with its hybrid derivatives probably exhibits the greatest potential as demonstrated by good test results under Polish conditions (Ugolik, Kantorowicz-Bąk 1992; Czynczyk et al. 2001).

It can be argued that the results presented in these studies might not be enough to adequately demonstrate the differences between rootstocks, as the yield potential of the test cultivars has been adequately high. It should be noted that in the same locality, Piestrzeniewicz et al. (2013) noted the extreme differences between rootstocks were similar with the cultivar 'Rubin', which was characterised by low yield potential coupled with very strong tree growth. The authors found that TCSA of trees on some rootstocks was almost half that of those on M.9 EMLA, but with virtually the same cumulative yields.

New apple rootstocks need to induce a yield efficiency similar to that of M.9 in scion cultivars, but might also have other improved properties. Of course, accumulation of all favourable features in a single plant is impossible, but one can always select rootstocks better than those currently grown. A good example of the significant progress that has been made was achieved in the framework of the

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North American breeding program conducted for several decades at NYSAES in Geneva. Rootstocks developed there were characterised by differing degrees of vigour, but were always characterised by high yield potential and, what is especially important, resistance or tolerance to particularly dangerous pests and diseases (Fazio et al. 2015).

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