Baltic fruit rootstock studies: evaluation of 12 apple rootstocks in North-East Europe

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Abstract

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In the frame of 'Baltic fruit rootstock studies' apple rootstocks B.9, B.146, B.396, B.491, P 2, P 22, P 60, M.9, M.26, Jork 9, Bulboga and Pure 1 were tested in Estonia, Latvia and Lithuania. More vigorous tree growth was recorded following North-South direction being the weakest in Estonia and the strongest in Lithuania. Apple rootstocks can be grouped, according to the induced tree vigour, in the following way: less vigorous than M.9: P 22, the same as M.9: Pure 1, B.396, Jork 9, P 60, B.9 and P 2, between M.9 and M.26: B.491, more vigorous than M.26: Bulboga and B.146. Rootstock effect on cumulative yield and cumulative yield efficiency index was determined by location. The highest productivity, considering cumulative yield and efficiency index, was obtained on M.9 rootstock in Lithuania, on Bulboga, B.146, M.26 and B.491 rootstocks in Estonia and on Pure 1, P 60 and B.9 rootstocks in Latvia. Rootstock effect on fruit weight was not clear and differed among locations. Interactions between rootstock and location indicate at the importance of multi-site rootstock evaluation.

Keywords: *Malus domestica*; growth; yield; fruit quality; efficiency index; geographical location

The choice of rootstocks depends mostly on climatic conditions, which are usually unsatisfactory in northern countries. The vegetation period is shorter, and sum of active temperatures is lower in the Northern Europe than in other European countries. The winters could also be a limiting factor for rootstock performance. Since rootstock effect on apple tree growth and productivity depends on many factors, series of multi-site rootstock trials were established around the world (Maas, Wertheim 2004; Robinson et al. 2004; Autio et al. 2008).

The cooperative fruit tree rootstock project 'Baltic fruit rootstock studies' was started in 1998. The first orchard trials were established in 2001 in Latvia, Lithuania, Estonia and Belarus (Bite et al. 2004) and the latest rootstock trial included Poland as well. Some results on performance of apple and pear rootstocks in the young orchard were already published (Haak et al. 2006; Kviklys et al. 2006; Univer et al. 2010). Current research summarizes the effect of different rootstocks on apple trees in full bearing. The rootstocks for the trials were chosen taking into account their low vigour and apparently higher winter hardiness. Some of these rootstocks were never tested before in the Baltic region or in the rest of Europe. Pure 1 is a seedling of B.9 from open pollination, selected in Latvia as a very productive rootstock with good propagation ability (Lepsis 2006). Bulboga rootstock was bred in Moldova and is recommended as a productive semi-dwarfing rootstock of the vigour range of M.26. Jork 9 (J.9) is a seedling of M.9 from open pollination, selected in Germany. The main feature of J.9 rootstock is a higher winter hardiness (Webster, Wertheim 2003) and good productivity (Kosina 2010).

The objective of the research was to assess the effect of the studied rootstocks on growth and productivity of apple trees grown at different geographical locations and environmental conditions in North-East Europe.

MATERIAL AND METHODS

The trials were carried out at the Institute of Horticulture in Lithuania (LT) (55°60'N, 23°48'E), Pure Horticultural Research Centre in Latvia (LV) (57°02'N, 22°52'E) and at the Polli Horticultural Research Centre in Estonia (EST) (58°67'N, 25°33'E) in the years 2001–2008.

Twelve vegetatively propagated apple rootstocks M.26, M.9, Jork 9, B.9, B.396 (original name 62-396), B.146 (original name 57-146), B.491 (original name 57-491), P 60, P 22, P 2, Bulboga (Moldavian selection) and Pure 1 (Latvian selection) were tested with the Auksis cultivar. Planting material was produced in the nursery of the Pure Horticultural Research Centre. The orchards were planted in spring 2001 under a uniform scheme. Planting distance was 4 × 1.5 m. Trees were trained as slender spindle. Weed-free strips (1.5 m wide) were maintained along the tree rows, with herbicide applications. The grassed alleyways were mowed. Pest and disease management was carried out according to the rules of integrated plant protection.

The trials were arranged in randomized block design, with four replicates and 3 trees per plot. Replicates were randomised.

The present paper deals wit the results obtained in a period of full bearing, in the years 2005–2006. Tree growth was evaluated by trunk diameter, 30 cm above soil surface, converted to trunk cross sectional area (TCSA), expressed in cm^2. Fruit yield from each tree was recorded and the average yield per tree of a replicate (in kg) was calculated. Cumulative yield efficiency index was calculated as a ratio of yield per tree to TCSA and expressed in kg/cm^2. Mean fruit weight (g) was determined from every tree and the average for each replicate was derived. The relative tree size, yield, productivity and fruit size were calculated as percentages of the respective parameters of the trees on M.9 rootstock – considered as standard (100%).

Additional investigations of internal and external fruit quality parameters were performed in Lithuania at harvest time. Fruit blush (surface red colour) was estimated by visual evaluation and expressed as percentage of skin covered with red blush. Firmness was measured with a penetrometer (FT-327, TR Turoni, Forli, Italy) with 11 mm diameter probe and expressed in kg/cm^2. Soluble solids content (SSC) was measured with a digital refractometer (ATAGO 101, Atago Co., Ltd., Tokyo, Japan) and expressed as percentage of fresh weight. The starch index was determined using a 0.1N iodine and potassium iodine solution (scale 1–10). Maturity index was calculated as:

$$F/RS$$

where:

F – firmness

R – concentration of soluble solids

S – starch conversion

Apple yield and mean fruit weight was not evaluated in Latvia in 2007 due to spring frost damage. High yield losses for the same reason were recorded in 2006, too.

Data on main traits were elaborated by the analysis of variance. Significance of differences between treatment (rootstock) means was evaluated using the Duncan's multiple range test at $P < 0.05$. Because of the inherent differences in variance among locations rootstock effects were analyzed for each location separately.

RESULTS AND DISCUSSIONS

Tree growth

Eight years after planting, in general, the smallest were the trees grown in the Estonian trial (EST) and the largest were those grown in Lithuania (LT) (Table 1). The tendency to a lower tree vigour moving from South to North was apparently due to a shorter vegetation period with increasing geographical latitude – from Lithuania, through Latvia, to Estonia.

Table 1. Rootstock effect on treee size of apple trees in 2008 (expressed as the TCSA [cm^2])

Rootstock	LV	Relative size (%)[1]	LT	Relative size (%)[1]	EST	Relative size (%)[1]
M.9	22.6$^{cd/2}$	100	31.9^{c}	100	18.1^{d}	100
M.26	34.1^{a}	151	44.2^{b}	138	27.3^{c}	151
Jork 9	–	–	26.7^{c}	84	15.2^{de}	84
B.9	19.5^{cd}	86	29.2^{c}	92	18.1^{d}	100
B.146	35.9^{a}	159	51.1^{ab}	160	40.7^{ab}	225
B.396	18.6^{cd}	82	25.8^{cd}	81	20.4^{d}	113
B.491	23.3^{c}	103	32.2^{c}	101	34.2^{b}	189
Bulboga	32.0^{ab}	141	58.1^{a}	182	43.0^{a}	237
P 2	20.8^{cd}	92	23.7^{cd}	74	–	–
P 22	13.5^{d}	60	21.5^{d}	67	10.7^{e}	59
P 60	25.1^{bc}	111	25.5^{cd}	80	16.6^{d}	92
Pure 1	19.8^{cd}	88	29.2^{c}	92	15.9^{de}	88
Mean	23.7		32.5		19.0	

LV – Latvia; LT – Lithuania; EST – Estonia; TCSA – trunk cross sectional area; [1]TCSA of trees on M.9 rootstock was considered as 100%; [2]means followed by the same letter in each column are not significantly different at $P \leq 0.05$ by the Duncan's multiple range test

On the average, all tested rootstocks could be grouped, according to the tree vigour induced by them, in the following way. The vigour lower than on M.9 showed the trees on P 22; the same as on M.9: on Pure 1, B.396, Jork 9, P 60, B.9 or on P 2; between M.9 and M.26: on B.491; more vigorous than on M.26: on Bulboga or on B.146. Such rootstock vigour range mainly corresponds to the results reported elsewhere (Hirst et al. 2001; Autio et al. 2008; Marini et al. 2009), though in some cases it contradicts to results obtained in other trials, especially concerning Budagovski rootstocks. In the Netherlands, B.146 and B.491 were recorded as inducing a lower vigour than M.9 (Maas, Wertheim 2004). In Great Britain, B.146 produced more dwarfed trees than M.27 EMLA. In the USA, B.491 proved to be equal in vigour to P 22 and M.27 EMLA (Hirst 2001). The relative tree size determined by a rootstock in this study (eight years after planting) was the same as revealed in the young orchard (Kviklys et al. 2006). This seems to indicate that the period of evaluation of rootstock effect on tree vigour may be significantly shortened.

Yield and yield efficiency

The highest cumulative (2005–2008) yield per tree was obtained in LT followed by EST and LV (Table 2). A rather poor bearing in LV could be explained by severe spring frosts in 2006 and 2007. No rootstock performed better than M.9 in Lithuania. Opposite results were in EST; there, only trees on P 22 gave the significantly lower yield than those on M.9. Rootstock M.9 is known as a rootstock with low winter hardiness. Colder winters in EST could affect the yield, though higher tree mortality on M.9 was not recorded, in contrast to some trials in North America (Autio et al. 2008).

Since apple trees were less vigorous in EST and not all of them filled the assigned space in the row, the vigorous rootstocks had a clear advantage in the Estonian trial. Yields per tree tended to be closely related to tree size; therefore rootstocks inducing the largest trees induced also the highest yield. Cumulative apple yield on Bulboga, B.146, M.26 and B.491 rootstocks overcame the yield on M.9 by 70 to 128% (Table 2). In Latvia, the highest cumulative yields were obtained from the trees on Pure 1 and P 60, albeit those rootstocks were not distinguished in the other locations. Rootstock effect on apple yield was clearly modified by the effect of location. Location had also a much larger effect than rootstock on tree performance in a study carried out at 24 sites in North America (Hirst 2001). Marini et al. (2006) also found that rootstock performance differed greatly from one location to another in the NC-140 trial with 18 rootstocks at 25 locations.

Trees on Pure 1 rootstock, followed by those on P 60 and B.9 gave the highest yield after the first

Table 2. Rootstock effect on cumulative yield in the years 2005–2008 (kg/tree) depending on geographical location

Rootstock	LV	Relative yield (%)	LT	Relative yield (%)[1]	EST	Relative yield (%)[1]
M.9	10.6[bc/2]	100	77.9[a]	100	31.2[c]	100
M.26	15.2[ab]	138	51.4[e]	66	54.6[b]	175
Jork 9	–	–	67.9[bc]	87	38.8[c]	124
B.9	15.4[ab]	140	56.9[de]	73	30.5[cd]	98
B.146	16.0[ab]	146	60.4[cd]	78	58.3[b]	187
B.396	9.2[bc]	84	56.9[de]	73	40.6[c]	130
B.491	10.2[b]	93	50.5[e]	65	52.9[b]	170
Bulboga	12.6[b]	115	73.5[ab]	94	71.1[a]	228
P 2	8.1[bc]	74	41.6[f]	53	–	–
P 22	7.3[c]	66	53.1[de]	68	20.5[d]	66
P 60	18.8[a]	171	60.9[cd]	78	32.5[c]	104
Pure 1	19.0[a]	173	68.5[bc]	88	36.6[c]	117
Mean	13.0		60.0		42.5	

LV, LT, EST – see Table 1; [1]yield of trees on M.9 rootstock was considered as 100%; [2]means followed by the same letter in each column are not significantly different at $P \leq 0.05$ by the Duncan's multiple range test

five years, i.e. in the young orchard (Kviklys et al. 2006). The other tendency appeared, however, in the full bearing stage; this confirms a necessity of long-term rootstock trials, in order to evaluate properly the aspects of productivity.

On the average, the cumulative yield efficiency index was the same in LT and EST, while it was threefold lower in LV – due to lower yields in Latvia (Table 3). Trees on Pure 1 were the most efficient in LV; they showed also a high efficiency index in LT and EST. In addition to the trees on Pure 1, a high yield efficiency was also presented by trees on B.9 and P 60 in LV, on Jork 9 in EST and on M.9 in LT. High efficiency index of trees on B.9, Jork 9 and M.9 was reported in different trials (Hirst et al. 2001; Autio et al. 2008; Kosina 2010).

Table 3. Rootstock effect on cumulative yield efficiency index (kg/cm^2), depending on geographical location (2005–2008)

Rootstock	LV	Relative efficiency (%)[1]	LT	Relative efficiency (%)[1]	EST	Relative efficiency (%)[1]
M.9	0.73[cd/2]	100	3.78[a]	100	2.75[cd]	100
M.26	0.64[d]	88	1.84[e]	49	2.88[bc]	105
Jork 9	–	–	3.34[ab]	88	3.67[a]	133
B.9	1.10[ab]	151	2.64[d]	70	2.52[d]	92
B.146	0.58[d]	79	1.70	45	2.08[e]	76
B.396	0.71[cd]	97	3.26[bc]	86	2.81[cd]	102
B.491	0.72[cd]	98	2.47[d]	65	2.52[d]	92
Bulboga	0.53[d]	72	1.67[e]	44	2.45[de]	89
P 2	0.51[d]	70	2.59[d]	69	–	–
P 22	0.76[cd]	105	3.43[ab]	91	2.89[bc]	105
P 60	1.07[bc]	146	2.95[cd]	78	3.09[bc]	112
Pure 1	1.35[a]	184	3.79[a]	100	3.25[ab]	118
Mean	0.79		2.79		2.81	

LV, LT, EST – see Table 1; [1]cumulative yield efficiency index of trees on M.9 rootstock was considered as 100%; [2]means followed by the same letter in each column are not significantly different at $P \leq 0.05$ by the Duncan's multiple range test

Table 4. Rootstock effect on mean fruit mass (g) (average of the years 2005–2008)

Rootstock	LV	Relative mass (%)[1]	LT	Relative mass (%)	EST	Relative mass (%)
M.9	114[bc/2]	100	171[ab]	100	117[ab]	100
M.26	127[ab]	111	174[ab]	102	121[a]	103
Jork 9	–	–	172[ab]	101	115[ab]	98
B.9	133[a]	117	168[bc]	98	121[a]	103
B.146	113[bc]	99	171[ab]	100	113[ab]	97
B.396	111[c]	97	159[cd]	93	116[ab]	99
B.491	128[ab]	112	186[a]	109	113[ab]	97
Bulboga	118[bc]	104	180[a]	105	112[ab]	96
P 2	108[c]	95	177[ab]	103	–	–
P 22	110[c]	96	170[b]	96	103[c]	88
P 60	117[bc]	103	177[ab]	103	119[ab]	102
Pure 1	115[bc]	101	147[d]	86	109[bc]	93
Mean	118		171		115	

LV, LT, EST – see Table 1; [1]mean fruit mass of trees on M.9 rootstock was considered as 100%; [2]means followed by the same letter in each column are not significantly different at $P \leq 0.05$ by the Duncan's multiple range test

Trees on B.146 were the least efficient in EST and LT, and showed also a low efficiency index in LV. A low efficiency index was recorded for the trees on Bulboga rootstock in LV and LT, on P 2 in LV and on M.26 in LT. In general, a negative relationship between tree size and cumulative efficiency index was evident at all trials; albeit it differed in pattern among locations. Similar tendencies were reported from the NC 140 trials (Hirst et al. 2001).

Fruit quality and maturity

Mean fruit mass depended on location and on tree vigour and was the highest in LT (Table 4). Rootstock effect on fruit mass was not clear and differed among locations. Results of many studies do not confirm any consistent and durable rootstock effect on mean apple mass (Barden, Marini 2001; Al-Hinai et al. 2004; Wrona, Sadowski 2006;

Table 5. Rootstock effect on fruit quality and maturity at harvest in Lithuania (2005–2008)

Rootstock	Blush (% surface covered)	Firmness (kg/cm^2)	Starch conversion (points)	SSC (%)	Maturity index
M.9	53[bc/1]	8.5[ab]	4.5[d]	12.9[ab]	0.15[b]
M.26	45[c]	8.3[b]	4.7[d]	12.3[c]	0.14[bc]
Jork 9	59[ab]	8.4[ab]	4.5[d]	12.9[ab]	0.14[bc]
B.9	52[bc]	8.6[a]	5.1[bc]	12.7[bc]	0.13[cd]
B.146	48[bc]	8.4[ab]	4.8[cd]	12.7[bc]	0.14[bc]
B.396	53[bc]	8.4[ab]	5.4[b]	12.8[ab]	0.12[de]
B.491	49[bc]	8.5[ab]	5.4[b]	12.3[c]	0.13[cd]
Bulboga	50[bc]	8.5[ab]	3.9[e]	12.5[bc]	0.17[a]
P 2	52[bc]	8.0[c]	5.1[bc]	13.2[a]	0.12[de]
P 22	65[a]	8.4[ab]	5.3[bc]	12.6[bc]	0.13[cd]
P 60	56[ab]	8.4[ab]	4.9[bcd]	12.9[ab]	0.13[cd]
Pure 1	66[a]	8.3[b]	6.0[a]	12.3[c]	0.11[e]

SSC – soluble solids content; [1]means followed by the same letter in each column are not significantly different at $P \leq 0.05$ by the Duncan's multiple range test

Marini et al. 2008). In some trials where more contrasting effects of rootstocks upon tree growth were noted, superdwarfing rootstocks usually reduced the mean fruit mass (Kviklys et al. 2006; Tomala et al. 2008). Similar results were recorded in our trial too. On the average, the lowest mean mass was recorded in case of fruits from trees on Pure 1 rootstock in LT, on P 22 and Pure 1 in EST, and on P 22, P 2 and B.396 in LV. However, the differences due to rootstock were often not significant or were not very consistent from year to year.

Rootstock usually had a conditional effect on fruit colouring. Such tendencies were also noted in other rootstock studies, where red coloration was variable and it was impossible to draw general conclusions (Barden, Marini 2001). Effect on fruit coloration was apparently related to the effect of rootstock on crop load as well as on tree vigour or on fruit size. Fruits from dwarf and high yielding trees on Pure 1 and P 22 showed the highest percentage of fruit surface covered by red colour (Table 5). Better coloration of apples on P 22 rootstock was recorded also in the Netherlands (Maas, Wertheim 2004). A positive effect of M.9 rootstock on fruit colour reported in many trials was not established in our investigation. A tendency to poorer coloration was noted with increasing rootstock vigour. The use of a semi-dwarfing M.26 rootstock resulted in the poorest colouring of apples.

A higher content of soluble solids was recorded in apples from trees grown on rootstocks P 2, P 60, M.9, Jork 9 or B.396 (Table 5). Rootstocks M.26, Pure 1 and B.491 induced a significantly lower SSC. Relationship between rootstock vigour and content of soluble solids was not noted in this study. Our earlier trials (Kviklys, Kviklienė 2002) showed that fruits from trees on low-vigour rootstocks, such as P 22, M.9 or P 2, contained much more soluble solids than fruits from trees grown on more vigorous, M.26 or P 60 rootstocks.

Differences in fruit flesh firmness due to rootstock were not significant, except for the effect of P 2 rootstock (Table 5). The maturity index indicated that the apples from trees on Pure 1 rootstock were slightly more mature at harvest, though they were not significantly different in that respect from apples from trees on P 22 or P 2. At harvest, fruits from trees on Pure 1 had a very high starch conversion rate; so the effect of this rootstock on the earlier fruit maturation was established. An opposite phenomenon was recorded in fruits from trees on Bulboga rootstock; a significantly lower starch conversion rate indicated at a later maturity of fruits from trees on this rootstock.

CONCLUSION

The relative differences in rootstock effects on tree growth were similar at different locations. The range of rootstock vigour – from the weakest to the strongest is the following: P 22, Jork 9, Pure 1, B.396, B.9, P 60, P 2, M.9, B.491, M.26, B.146 and Bulboga.

Rootstock effect on apple yield and on cumulative yield efficiency index was clearly determined by location. The greatest cumulative yield per tree and the highest efficiency index were obtained on M.9 rootstock in Lithuania. Rootstocks inducing the strongest growth, Bulboga, B.146, M.26 and B.491, induced the highest yield per tree in Estonia, though the yield efficiency index (calculated in relation to TCSA) was higher for less vigorous rootstocks. In addition to the trees on more vigorous rootstocks, M.26 and B.146, trees on Pure 1, P 60 and B.9 rootstocks produced the highest yields in Latvia and showed the highest efficiency index.

Rootstock effect on fruit mass was not clear and differed among locations, though a tendency to the negative effect of superdwarfing rootstocks on fruit mass was established.

Rootstock effects on fruit quality parameters were not significant in most cases. Pure 1 rootstock determines a better coloration, earlier ripening and smaller fruits. Bulboga rootstock induces late ripening of apples. P 2 rootstock induces a higher content of soluble solids and lower firmness of fruit flesh.

References

Al-Hinai Y.K., Roper T.R., 2004. Rootstock effects on growth and quality of 'Gala' apples. HortScience, *39*: 1231–1233.

Autio W., Robinson T., Cowgill W., Hampson C., Kushad M., Masabni J., Quezada P.R., Perry R., Rom C., 2008. Performance of 'Gala' apple trees on Supporter 4, P.14, and different strains of B.9, M.9 and M.26 rootstocks: A five-year report on the 2002 NC-140 Apple Rootstock Trial. Journal of the American Pomological Society, *62*: 119–128.

Barden J.A., Marini R.P, 2001. Yield, fruit size, red color, and estimated crop value in the NC-40 1990 cultivar/rootstock trial in Virginia. Journal of the American Pomological Society, *55*: 154–158.

Bite A., Kviklys D., Univer T., Lukut T., 2004. The beginning of the project "Baltic fruit rootstock studies". Acta Horticulturae, *658*: 437–440.

Haak E., Kviklys D., Lepsis J., 2006. Comparison of *Cydonia* and *Pyrus* rootstocks in Estonia, Latvia and Lithuania. Sodininkystė ir Daržininkystė, *25*: 322–326.

Hirst P.M., 2001. Early performance of 'Gala' on 18 dwarf and 4 semi-dwarf rootstocks growing at 24 sites in North America. Acta Horticulturae, *557*: 199–208

Hirst P.M., Autio W.R., Barden J.A., Brown G.R., Crassweller R.M., Domoto P.A., Schupp J.R., 2001. Performance of trees in the 1990 NC-140 apple cultivar/rootstock planting: Additional cultivars and rootstocks. Journal of the American Pomological Society, *55*: 178–184.

Kosina J., 2010. Effect of dwarfing and semi dwarfing apple rootstocks on growth and productivity of selected apple cultivars. Horticultural Science (Prague), *37*: 121–126.

Kviklys D., Kviklienė N., 2002. Effect of rootstock on apple quality and storability. Folia Horticulture, *14*: 227–233.

Kviklys D., Kviklienė N., Bite A., Lepsis J., Lukut T., Haak E., 2006. Baltic fruit rootstock studies: evaluation of 12 rootstocks for apple cultivar 'Auksis'. Sodininkystė ir Daržininkystė, *25*: 334–341.

Lepsis J., 2006. Evaluation of apple rootstock Pure 1. Latvian Journal of Agronomy, *9*: 75–79.

Maas F.M., Wertheim S.J., 2004. A multi-site rootstock trial with the apple cultivars 'Cox's Orange Pippin' and 'Jonagold'. Acta Horticulturae, *658*: 177–184.

Marini R.P., Anderson J.L., Autio W.R., Barritt B.H., Cline J.A., Cowgill W.P., Crassweller R.M., Domoto P.A., Ferree D.C., Garner J., Gaus A., Greene G.M., Hampson C., Hirst P., Kushad M.M., Mielke E., Mullins C.A., Parker M., Perry R.L., Prive J.P., Reighard G.L., Robinson T., Rom C.R., Roper T.R, Schupp J.R., Stover E., Unrath R., 2006. Performance of Gala apple on 18 dwarf rootstocks:Ten-year summary of the 1994 NC-140 dwarf rootstock trial. Journal of the American Pomological Society, *60*: 69–83.

Marini R.P., Moran R., Hampson C., Kushad M., Perry R.L., Robinson T.L., 2008. Effect of dwarf apple rootstocks on average 'Gala' fruit weight at six locations over three seasons. Journal of the American Pomological Society, *62*: 129–136.

Marini R.P., Black B., Crassweller R.M., Domoto P.A., Hampson C., Johnson S., Kosola K., Mcartney S., Masabni J., Moran R., Quezada R.P., Robinson T., Rom C.R., 2009. Performance of 'Golden Delicious' apple on 23 rootstocks at 12 locations: A five-year summary of the 2003 NC-140 dwarf rootstock trial. Journal of the American Pomological Society, *63*: 115–127.

Robinson T.L., Anderson L., Azarenko A., Barritt B.H., Brown G., Cline J., Crassweller R., Domoto P., Embree C., Fennell A., Ferree D., Garcia E., Gaus A., Greene G., Hampson C., Hirst P., Hoover E., Johnson S., Kushad M., Marini R.E., 2004. Performance of Cornell-Geneva rootstocks across North America in multi-location NC-140 rootstock trials. Acta Horticulturae, *658*: 241–245.

Tomala K., Andziak J., Jeziorek K., Dziuban R., 2008. Influence of rootstock on the quality of 'Jonagold' apples at harvest and after storage. Journal of Fruit and Ornamental Plant Research, *16*: 31–38.

Univer T., Kviklys D., Lepsis J., Univer N., 2010. Early performance of 'Auksis' apple trees on dwarfing rootstocks in Baltic region. Agronomy Research, *8*: 753–748.

Webster A.D., Wertheim S.J., 2003. Apple rootstocks. In: Ferree D.C., Warrington I.J. (eds), Apples: Botany, Production and Uses. CAB International, Cambridge: 91–124.

Wrona D., Sadowski A., 2006. Comparison of 18 apple rootstocks for apple tree cv. 'Elisa' in V planting system. Sodininkystė ir Daržininkystė, *25*: 144–150.

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