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Precocity and a long-term cropping in apple progenies grown on M 9 rootstock

J. Blažek, L. Zelený, J. Křelinová

Research and Breeding Institute of Pomology Holovousy Ltd., Holovousy, Czech Republic

Abstract

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The fruiting of 23 apple progenies, in total 756 genotypes grafted on M 9 rootstock, was evaluated for 11 years (2005–2015). The most precocious was the progeny obtained by the crossing of genotype HL1737 and Pink Lady cultivar, seedlings of which achieved fruiting stage just between the first and second year after planting. The least precocious was the progeny Freedom × Antonovka o.p., in which seedlings started fruiting on average just in the 5th and 6th year after planting. The most productive in the study was the progeny HL782 × Topaz, having a mean rating of 5.33 points on a 1–9 scale. Behind this leader, in decreasing order, were the progenies HL782 × HL665, Resista × Pink Lady, Resista × HL2219 and HL665 × HL782. The progenies Resista × Benet and Idleless × HL665 were distinguished with the highest level of biennial bearing (above 81%). The most valuable for utilisation in breeding is the progeny HL665 × HL782. Other noteworthy donors to be considered for distinctly more regular cropping are the cultivars Pink Lady, Discovery and HL2219.

Keywords: Malus × domestica; cropping; progeny segregation; apple breeding

This study is a continuation of the previous paper which was focused on the heritability of flowering time within progenies of selected apple cultivars (Blažek et al. 2015). The level of yields and regular productivity are among the most important criteria for selection of new cultivars of the apple breeding programme in Holovousy (Blažek 2013; Blažek, Křelinová 2013; Sosna 2014).

A range of large apple breeding programmes are presently being conducted in many countries of the world focused also on the aim to obtain novelties with higher and regular fruit-bearing (Sansavini et al. 2005; Brown, Maloney 2009, 2013; Kumar et al. 2010; Tóth et al. 2012).

Basic findings about possibilities for shortening of the juvenile period within apple seedlings were published already 40 to 50 years ago (Alston, Bates 1979; Visser 1964, 1967).

Within the present apple breeding programmes, the selection for productivity is still one of the most important objectives. The yield capacity of any novelty has to be similar or superior to well-known commercial cultivars (Kellerhals, Meyer 1994).

Productivity or high yield potential are among the most important criteria for selection of new apple cultivars in a range of breeding programmes (Sedov et al. 2014). Positive correlations between the vegetation indices, trunk cross-sectional area (TCSA) and fruit production were observed in a range of breeding programmes (Sedov 2013; Kazlouskaya et al. 2014). Positive correlations between the vegetation indices, trunk cross-sectional

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area (TCSA) and fruit production were observed (González-Talice et al. 2012).

Regular fruiting in apple progenies has a complex character. Biennial bearing seems to be a complex phenomenon influenced by tree age and year as well as genetic effects (Guitton et al. 2012). At present in apple production, a regular bearing is very important and, therefore, chemical thinning agents are applied to control total fruit load. The effects of the treatments are however influenced by several factors and, therefore, the final fruit set is frequently not an optimal one. Therefore, there is a demand for the development of new apple cultivars with self-thinning properties (Celton et al. 2014).

The biennial behaviour of cropping is closely linked to floral induction than to pollination, fruit set and fruit drop. This is consistent with the assumption that gibberellins synthesized by the developing fruits and/or competition for carbohydrates between fruits and shoots could inhibit flower induction (Monselise, Goldschmidt 1982; Bangerth 2009).

The negative relationship between fruit development and flower bud differentiation is one of the most investigated causes of flower set variability in apples (Foster et al. 2003).

Flower set can be strongly inhibited by concurrent fruiting, leading to a pattern of irregular fruiting across consecutive years referred to as biennial bearing. Its level is, however, significantly influenced by the tree architecture (Guitton et al. 2012).

A range of both external factors (photoperiod, temperature and water stress) and internal factors such as the carbon-to-nitrogen ratio and hormones (auxins, cytokinins), abscisic acid, ethylene, and gibberellins, as well as interaction with terminal shoot growth affect flower formation in apples (Hanke et al. 2007; Bangerth 2009).

Several genes are involved in the critical phase of flower development and their effect in flower induction is probably influenced by the level of fruit set (Hattasch et al. 2008).

Recently, hypotheses have been proposed for the control of apple biennial bearing emerging from quantitative trait loci and candidate gene co-locations and to suggest the inolvement of different physiological processes such as the regulation of flowering genes by hormones (Guitton et al. 2012).

Two descriptors were proposed recently for the description of biennial bearing: a new biennial bearing index, based on the deviation around yield trend over years and an autoregressive coefficient, which represents dependency between consecutive yields (Durand et al. 2013).

The aim of the study was to define the heritability pattern of fruiting within selected apple cultivars and recommend the most suitable approach for the selection of the characteristics during the evaluation of apple progenies.

MATERIAL AND METHODS

This study was carried out in the Research and Breeding Institute of Pomology Holovousy. The location is characterised by a mean yearly temperature of 8.4°C, mean rainfall of about 663.5 mm and altitude around 300 m.

The experimental material originated from crossings of selected cultivars and HL genotypes in 1999. The Hl genotypes were selected from the following progenies: HL665 – Spartan × Antonovka o.p.; HL782 – Rubín × Priscilla; HL 1737 – HLIII/1, 5/5 (Mother × James Grieve) × Priscilla; HL2219 – Starkrimson Delicious × Glockenapfel. Stratified seeds were sown in the first week of April 2000 in a foil greenhouse where seedlings were grown for two years without any protection against diseases. There their disease incidence (mainly scab, powdery mildew) was evaluated. The final height of seedlings mostly fluctuated within 1.5–2.7 m. In winter 2002 selected healthy seedlings were grafted on the M.9 rootstock and planted into standard tree nursery. The subsequently grown up 2-year-old trees were planted in the spacing of 4 × 1 m in an experimental orchard located in Holovousy in the spring of 2004. The experimental orchard was located at altitude 320 m a.s.l. on the gentle slope of south exposition. There fruit trees have never been grown there before and soil conditions were uniform.

After establishment, the orchard was maintained with clean herbicide strips under the tree canopies and with mulched grass along the alleyways. Trees were trained in the slender spindle form and canopies were kept in reasonable densities and size using pruning both in the winter and summer time. In some more vigorous genotypes, somewhat greater canopy volume was allowed to develop during the last years if necessary. Fertilising and spraying (based on integrated apple orchard protection guidelines) consisted of normal commercial practices with the exception of the first three years after orchard establishment when fungicide treatments

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were not applied due to the evaluation of cultivars regarding their susceptibility to common diseases.

Since 2005 onwards, fruit sets of these seedlings were individually rated during the harvest season using a 1 to 9 rating scale. Within this scale the number 1 corresponds to no fruiting at all whereas 9 describes the maximum fruit set possible (over cropping). This evaluation was done by the same experienced rater during all 11 years of the study. The tendency towards biennial bearing of every genotype was calculated upon the greatest fruit set drop from two different successive years.

Standard statistical analyses based on the analysis of variance were performed and mean intervals of significant differences were calculated for the mean values. The standard regression analyses were applied among selected characteristics.

RESULTS

Onset of fruiting in evaluated progenies

The entire survey of the start of fruiting within the 23 evaluated progenies is provided in Table 1. The mean start of the stage among all the progenies was in the third year after planting that is in the fifth year of the tree age. The most precocious was the progeny obtained by a crossing of genotype HL1737 and Pink Lady cultivars, seedlings of which achieved fruiting stage on average between the first and second year after planting. With a minimal difference its precocity was followed by the progeny HL782 × Topaz. Somewhat longer in distance behind them followed the progenies Pink Lady × Discovery and HL782 × HL665.

Table 1. The start of fruiting (precocity) in evaluated progenies

Cross	No. of genotypes	The year of the first fruiting			
		mean	LSD	the earliest	the latest
Braeburn × Angold	19	5.16	1.40	1	9
Freedom × Antonovka o.p.	14	5.50	1.51	2	10
HL1737 × Pink Lady	16	1.56	0.57	1	3
HL665 × HL782	111	2.69	1.08	1	10
HL665 × Pink Lady	38	2.89	1.01	1	9
HL665 × Rosana	25	3.04	1.30	1	11
HL782 × HL665	26	2.19	0.69	1	4
HL782 × Pink Lady	36	2.50	1.00	1	8
HL782 × Topaz	13	1.62	0.46	1	3
Idleless × HL665	16	3.00	0.63	2	5
Pink Lady × Discovery	19	2.11	0.80	1	5
Resista × Angold	17	3.76	1.84	1	10
Resista × HL2219	32	3.09	1.47	1	9
Resista × HL447	98	2.45	0.91	1	9
Resista × Karmína	44	3.45	0.90	1	9
Resista × McIntosh Wijcik	15	2.60	0.87	1	5
Resista × Pidi	39	3.44	1.22	1	11
Resista × Pink Lady	26	4.19	1.91	1	11
Resista × Rubinola	20	3.30	0.46	3	5
Resista × Topaz	19	3.16	0.35	2	4
Resista × Benet	14	4.64	1.39	1	9
Resista × Rucla	32	2.69	1.10	1	9
Rucla × HL665	36	3.42	1.40	1	10
Total	726	3.01	1.27	1	11

LSD – least significant difference ($P < 0.05$)

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On the contrary, the least precocious was the progeny Freedom × Antonovka o.p., seedlings of which started fruiting on average between the 5th and 6th year after planting in the orchard. In decreasing order, it was followed by progenies Braeburn × Angold and Resista × Benet. It is obvious from these data that Antonovka and its offspring (Angold) are donors of a longer juvenile period in their progenies.

The segregation according to the first year of fruiting in the largest progeny HL665 × HL782 is illustrated by Fig. 1. More than three quarters of these seedlings started fruiting up until the third year after planting, but the third year was the top (40%). Only one or two of them set their first fruiting at the age of the 7th through the 10th year.

Total course of fruiting in evaluated progenies

The complete overview of fruiting from all years of the study within all the progenies is presented in Table 2. The most productive in the study was the progeny HL782 × Topaz, with a mean rating at the level of 5.33 points. Behind this leader in decreasing order followed the progenies HL782 × HL665, Resista × Pink Lady, Resista × HL2219 and HL665 × HL782. On the other hand, the least productive was the progeny Resista × Benet, having a mean rating only at the level of 3.79 points. With minimal differences, it was preceded by the progenies HL665 × Rosana, Resista × Rubinola and Idleless × HL665.

The progeny HL1737 × Pink Lady previously classified as the most precocious in fruiting was evalu-

Table 2. Fruit set level (productivity) from all years of fruiting

Cross	No. of genotypes	Fruit set (1–9)				
		mean	LSD	min. of the progeny from all years	max. of the progeny from all years	max. of the one genotype
Braeburn × Angold	19	4.87	0.83	2.13	7.50	8
Freedom × Antonovka o.p.	14	4.82	0.66	3.00	6.90	9
HL1737 × Pink Lady	16	4.78	0.53	3.00	6.11	9
HL665 × HL782	111	5.04	0.55	2.44	7.20	9
HL665 × Pink Lady	38	4.24	0.59	1.90	6.00	9
HL665 × Rosana	25	3.84	0.70	1.56	6.00	9
HL782 × HL665	26	5.24	0.50	3.00	6.72	8
HL782 × Pink Lady	36	4.99	0.80	1.80	8.31	9
HL782 × Topaz	13	5.33	0.38	3.64	6.20	8
Idleless × HL665	16	4.04	0.48	2.38	5.80	8
Pink Lady × Discovery	19	4.68	0.49	2.75	6.30	9
Resista × Angold	17	4.25	0.37	2.71	5.56	8
Resista × HL2219	32	5.10	0.58	2.70	6.60	9
Resista × HL447	98	4.88	0.57	2.00	7.80	9
Resista × Karmína	44	5.03	0.72	2.00	7.92	9
Resista × McIntosh Wijcik	15	4.16	0.61	1.75	5.45	8
Resista × Pidi	39	4.46	0.76	2.25	7.60	9
Resista × Pink Lady	26	5.20	0.71	2.50	6.90	8
Resista × Rubinola	20	3.90	0.54	2.13	5.76	8
Resista × Topaz	19	4.64	0.57	2.44	6.48	8
Resista × Benet	14	3.79	0.48	2.33	5.10	9
Resista × Rucla	32	4.73	0.54	1.91	6.48	9
Rucla × HL665	36	4.23	0.58	1.88	6.00	9
Total	726	4.71	0.67	1.56	8.31	9

LSD – least significant difference ($P < 0.05$)

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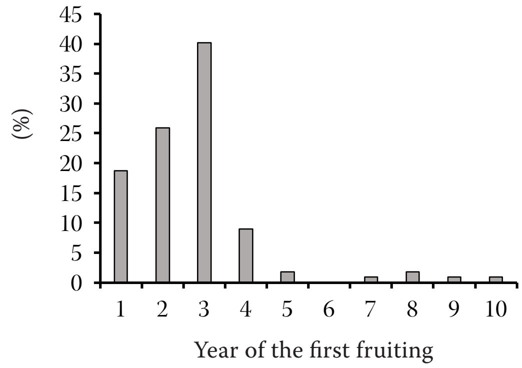

Fig. 1. Distribution of the progeny from the HL665 × HL782 cross according of the year of the first fruiting

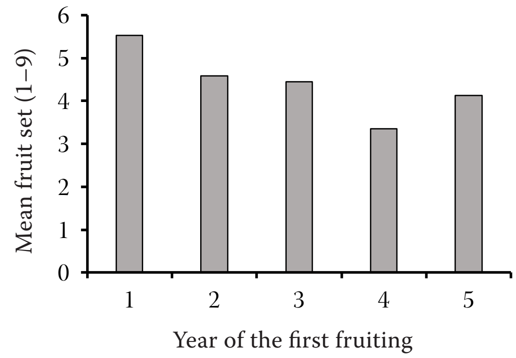

Fig. 2. Mean fruit set level according to year of the first fruiting in the progeny of the HL665 × HL782 cross (correlation $r = -0.55$)

ated according to productivity in the 10th position among all 23 classified progenies.

Concerning the maximum fruit set level from all the years, the top one was the progeny HL782 × Pink Lady with a mean scoring at the level 8.31. It was followed with small decreases of value by the progenies of Resista × Karmína, Resista × HL447 and Resista × Pidi. On the contrary, the lowest value of the parameter was found in the progeny Resista × Benet (5.1), which was preceded by Resista × McIntosh Wijcik, Resista × Angold and Resista × Rubinola.

The smallest values of minimum fruit set from all years were found in the progenies HL665 × Rosana, Resista × McIntosh Wijcik, HL782 × Pink Lady, Rucla × HL665 and HL665 × Pink Lady.

The correlation between the year of the first fruiting and the mean level of productivity was detected in the most numerous progeny HL665 × HL782 (Fig. 2). The highest yield was found in the seedlings, which started fruiting in the first year.

Survey of tendency for biennial bearing in evaluated progenies

The basic parameters of the phenomenon are presented in Table 3. The following progenies were distinguished with the highest mean level of biennial bearing (above 81 %): Resista × Benet and Idleless × HL665. In slightly decreasing order, they were followed by the progenies Resista × Rubinola, Freedom × Antonovka o.p. and Resista × Topaz. On the contrary, the smallest tendency for biennial bearing was found in the Resista × McIntosh Wijcik progeny (only 33.9 %). It was preceded in increasing order by the progenies HL665 × HL782, Resista × Pidi and Pink Lady × Discovery.

The impact of maximum fruit set level on the regularity of fruiting calculated from the data of all progenies is illustrated in Fig. 3, Up to fruit set level 5, the cropping is fully regular. A significant reduction of the regularity, of nearly 2 points in value, begins from fruit set level 6. In the case of the max. fruit set level 9, a drop in regularity is found only to the 3rd grade.

The influence of fruit set level on the percentile decrease of fruiting in the following year, in the case of the progeny HL665 × HL782, is presented by Fig. 4. From this survey, the impact of fruit set level above the value of 5 on the decrease of fruiting in the following year is visible. In the case of the highest fruit set value 9, the fruiting in the following year was decreased on average by 86.5 %.

Choice of progenies as potential donors for apple cropping improvement

Regarding the start of fruiting, unambiguously the most valuable progeny is that of HL1737 × Pink Lady. Beside both parents, the genotype HL 782 and cvs Topaz and Discovery might also be suitable donors of this characteristic.

The progeny HL782 × Topaz was distinguished by the highest level of fruit set among all the years of fruiting. It was followed in this characteristic by the progenies HL782 × HL665, Resista × Pink Lady, Resista × HL2219 and HL665 × HL782.

Regarding biennial bearing, the smallest was found in the progeny Resista × McIntosh Wijcik. Unfortunately, the cropping potential of the cross was con-

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Table 3. The influence of the highest fruit set on the alternative bearing in the fruiting stage

Cross	No. of genotypes	Alternative bearing (%)			
		mean	LSD	min.	max.
Braeburn × Angold	19	61.4	6.95	12.5	87.5
Freedom × Antonovka o.p.	14	72.6	7.40	25.0	100.0
HL1737 × Pink Lady	16	54.1	6.06	12.5	85.7
HL665 × HL782	111	44.3	7.73	11.1	100.0
HL665 × Pink Lady	38	52.3	8.64	11.1	100.0
HL665 × Rosana	25	54.1	6.99	11.1	100.0
HL782 × HL665	26	58.3	6.53	12.5	87.5
HL782 × Pink Lady	36	53.8	6.77	14.3	87.5
HL782 × Topaz	13	60.3	8.10	12.5	87.5
Idleless × HL665	16	81.5	4.26	57.1	100.0
Pink Lady × Discovery	19	50.0	6.47	11.1	100.0
Resista × Angold	17	68.4	7.17	25.0	100.0
Resista × HL2219	32	51.8	6.77	11.1	100.0
Resista × HL447	98	67.1	5.81	12.5	100.0
Resista × Karmína	44	64.7	7.21	0	100.0
Resista × McIntosh Wijcik	15	33.9	6.05	12.5	66.7
Resista × Pidi	39	48.5	9.00	11.1	100.0
Resista × Pink Lady	26	65.7	6.09	14.3	100.0
Resista × Rubinola	20	73.0	4.11	50.0	100.0
Resista × Topaz	19	71.4	5.02	37.5	100.0
Resista × Benet	14	81.7	7.06	33.3	100.0
Resista × Rucla	32	70.0	6.67	14.3	100.0
Rucla × HL665	36	57.0	8.13	11.1	100.0
Total	726	58.2	7.67	0	100.0

LSD – least significant difference ($P < 0.05$)

siderably below average. Therefore, the most useful for utilisation in breeding is the progeny HL665 × HL782. Aside from these genotypes, the following cultivars should also be considered as valuable donors of distinctly more regular cropping: Pink Lady and Discovery as well as the genotype HL2219.

Fig. 3. Influence of max. fruit set level on fruiting regularity in 1–9 rating scale (correlation $r = -0.63$)

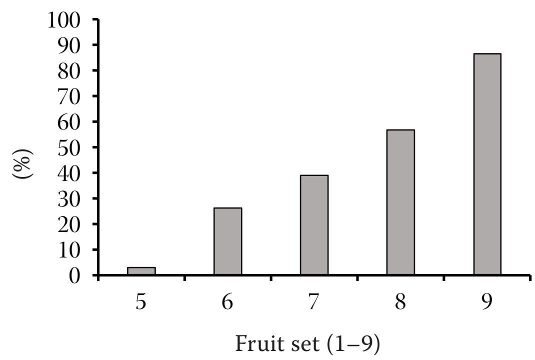

Fig. 4. Influence of maximal fruit set level on the percentile decrease of fruit set in the following year in the progeny of the HL665 × HL782 cross (correlation $r = -0.679$)

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DISCUSSION

Our findings concerning the onset of fruiting within the evaluated progenies is considerably different from Ryugo (1988) who stated that the length of the juvenile period within apple seedlings ranges from seven to ten years. In our case, seedlings were grafted on the M 9 rootstock and the first of them started fruiting already in the third year after planting. It might be an effect of using M 9 rootstock, nevertheless several seedlings first fruited 10 years later. Otherwise, our results concerning the start of fruiting are in agreement with data published by Visser (1964, 1967).

Our results concerning the mean level of yields within the studied progenies are more or less in agreement with currently published data (Kellerhals, Meyer 1994; Brown, Maloney 2009; Kumar et al. 2010; Durand et all, 2013).

Our results concerning the effect of high and extremely high fruit set on biennial bearing occurrence are also in agreement with data in existing literature (Guitton et al. 2012; Durand et al. 2013; Celton et al. 2014).

The results of the study further indicate that by the selection of suitable parents, it might be possible in new progenies to substantially decrease the risk of biennial bearing occurrence. In this direction the subsequent research should be focused on as well.

According to our earlier nonpublished findings, it is not a significant influence of scab infection level of apple seedlings on their precocity. On the other hand, long-term severe infestation of the seedlings by powdery mildew considerably delay start and level of their fruiting.

References

Alston F.H., Bates J.W. (1979): Selection of yield in apple progenies. In: Proceedings of Eucarpia Fruit Section Symposium. Tree Fruit Breeding. September 3–7, 1979, Angers: 15–27.

Bangerth F. (2009): Floral induction in mature, perennial angiosperm fruit trees: similarities and discrepancies with annual/biennial plants and the involvement of plant hormones. Scientia Horticulturae, 122: 153–163.

Blažek J. (2013): Comparative study of apple cultivars bred in Holovousy, Czech Republic. Journal of Plant Studies, 2: 113–121.

Blažek J., Křelinová J. (2013): Tree vigour and productivity within a set of progenies evaluated during an apple breeding program. Scientific Papers of Pomology, 23: 165–178.

Blažek J., Paprštein F., Křelinová J. (2015): Heritability of flowering time within apple progenies. Czech Journal of Genetics and Plant Breeding, 51: 23–28.

Brown S.K., Maloney K.E. (2009): Making sense of new apple varieties, trademarks and clubs: Current Status. New York Fruit Quarterly, 17: 9–12.

Brown S.K., Maloney K.E. (2013): An update on apple cultivars, brands and club-marketing. New York Fruit Quarterly, 21: 3–10.

Celton J.M., Kelner J.J., Martinez S., Bechti A., Touhami A.K., James M.A., Durel C.E., Laurens F., Costes E. (2014): Fruit self-thinning: A trait to consider for genetic improvement of apple tree. PLoS ONE, 9: e91016.

Durand J.B., Guitton B., Peyhardi J., Holtz Y., Guédon Y., Trottier C., Costes E. (2013): New insights for estimating the genetic value of segregating apple progenies for irregular bearing during the first years of tree production. Journal of Experimental Botany, 64: 5099–5113.

Foster T., Johnson R., Selzynova A. (2003): Morphological and quantitative characterization of early floral development in apple (*Malus domestica* Borkh.). Annals of Botany, 92: 199–206.

González-Talice J, Yuri JA, Lepe V, Hirzel J, del Pozo A. (2012): Water use in three apple cultivars from the second season to sixth season in a drainage lysimeter. Scientia Horticulturae, 146: 131–136.

Guitton B., Kelner J.J., Velasco R., Gardiner S.E., Chagné D., Costes E. (2012): Genetic control of biennial bearing in apple. Journal of Experimental Botany, 63: 131–149.

Hanke M.V., Flachowski H., Peil A., Hatlasch C. (2007): No flower no fruit – genetic potential to higher flowering in fruit trees. Genes, 1: 1–20.

Hattasch C., Flachowsky H., Kapturska D., Hanke M.V. (2008): Isolation of flowering genes and seasonal changes in their transcript levels related to flower induction and initiation in apple (*Malus domestica*). Tree Physiology, 28: 1459–1466.

Kellerhals M., Meyer M. (1994): Aims of the apple breeding programme at Wädenswil. Progress in temperate fruit breeding. Developments in Plant, 1: 117–121.

Kazlouskaya Z.A., Yakimovich V., Hashenka T., Vaseha V. (2014): Target character's collections of apple-tree and pear-tree in Belarus. Fruit Growing Research, 30: 31–34.

Kumar S., Volz R.K., Alspach P.A., Bus V.G. (2010): Development of a recurrent apple breeding programme in New Zealand: a synthesis of results, and a proposed revised breeding strategy. Euphytica, 173: 207.

Monselise S.P., Goldschmidt E.E. (1982): Alternate bearing in fruit trees. Horticultural Reviews, 4: 128–173.

Ryugo K. (1988): Fruit Culture. New York, John Wiley & Sons.

doi: 10.17221/268/2015-HORTSCI

Sansavini S., Belfanti E., Costa F., Donati F. (2005): European apple breeding programs turn to biotechnology. Chronica Horticulturae, 45: 16–19.

Sedov E.N. (2013): Results and prospects in apple breeding. Universal Journal of Plant Science, 1: 55–65.

Sosna I. (2014): Estimation of productive value of Czech origin scab-resistant apple cultivars on different rootstocks. Journal of Horticultural Research, 22: 115–121.

Tóth M., Ficzek G., Király I., Kovács S., Hevesi M., Halász J., Szani S. (2012): 'Artemisz', 'Cordelia', 'Hesztia', and 'Rosmerta': New Hungarian multi-resistant apple cultivars. HortScience, 47: 1795–1800.

Visser T. (1964): Juvenile phase and growth of apple and pear seedlings. Euphytica, 13: 119–129.

Visser T. (1967): Juvenile period and precocity of apple and pear seedlings. Euphytica, 16: 319–320.

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Corresponding author:

Ing. Jan Blažek, CSc, Research and Breeding Institute of Pomology Holovousy, Holovousy 121, 508 01 Hořice v Podkrkonoší, Czech Republic; e-mail: blazek@vsuo.cz