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THE QUALITY OF APPLE NURSERY TREES OF *KNIP-BOOM* TYPE AS AFFECTED BY THE METHODS OF PROPAGATION

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Abstract. One of the requirements for early and profitable fruit cropping is the quality of trees used for orchard establishment. Nursery tree quality is influenced by many factors, among which the method of tree propagation plays an important role. In these experiments, the *knip-boom* (KB) trees produced in the 3-year cycle, from either sleeping buds (B) or bench-grafts (G), were compared in terms of tree quality parameters. B-trees outperformed G-trees in trunk diameter, total shoot extension, and in the number of shoots > 10 cm. No significant differences were found in such features as tree height, apical dominance and the percent of the number of shoots suitable for tree training. Studies on spatial configuration of lateral shoots and their length did not show any essential differences in the shape of canopy between both tree types. However, lateral shoots of B-trees were significantly longer than those of G-trees. Linear correlations between different quality characteristics in both types of trees demonstrated greater strength of either positive or negative correlations in G-compared with B-trees. We have not found any essential differences between B- and G-trees in nursery tree performance; therefore for a full evaluation of the trees produced by either method of propagation should be based on the analysis of nursery production economics and orchard performance of the trees (B and G) used.

Key words: bench-grafting, growth correlations, shoot spatial position, sleeping bud

INTRODUCTION

The quality of plant material is one of the most important factors influencing fruit cropping. Up to the recent years, the requirements for precocious and efficient fruit production were fulfilled by using high quality branched maiden trees for establishing intensive orchards [Poniedziałek et al. 1996, Elfving and Visser 2005].

Developed in the eighties of 20^{th} century in the Netherlands the concept of "knip-boom" tree has totally revolutionized the methods of establishment and management of

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high density plantings. This concept was based on the introduction of completely new methods of nursery tree production suited for such type of orchards. A "knip-boom" (KB) tree is produced in the 3-year cycle. Such tree consists of 3-y-old root system, 2-y-old tree trunk, and 1-y-old feathered crown that is able to bear fruit often in the first year after transplanting [Nicolai and Nicolai 1998]. The KB-trees usually outperform other tree types in cropping [Berg 2003]. The results of numerous experiments confirmed high suitability of KB-trees for improved fruit production [Nicolai and Nicolai 1998, Berg 2003, Bielicki et al. 2004, Gudarowska and Szewczuk 2006].

The KB-trees can be produced by either cutting back a maiden tree *in situ* at 60 cm above the soil line [Czarnecki 1998] and eventually raising trees for another year in the nursery, or KB-trees can be grown by more sophisticated methods, i.e. bench-grafting in winter or "sleeping bud" in summer, and then transplanting grafted and/or budded plants into the nursery. These propagation techniques have been described by Sadowski et al. [2006].

There is a *consensus* that KB-trees produced by bench-grafting and/or "sleeping bud" are more compact and better suited for dense or super dense plantings in comparison with their counterparts grown directly from headed maiden trees.

Bench-grafting in relation to budding seldom produces maiden trees of acceptable quality [Rejman and Makosz 1994, Jacyna – unpublished data]. An extensive review of many experiments on propagation of temperate fruit trees showed that chip budding significantly outperformed other propagation methods in terms of ease of application, rapid bud union formation, high bud take, tree uniformity and quality, and low labor input [Ananda and Negi 1998]. Bench-grafting may be an alternative method to "sleeping bud" technique in production of BK-trees in terms of reasonable use of professional labor in winter time. However, neither scientific data on the quality characteristics of KB-trees produced by both techniques nor on the production economics were published so far.

The objective of these studies was to compare basic quality characteristics of knip-boom trees produced by "sleeping bud" and bench-grafting techniques while using commercially important apple cultivar 'Golden Delicious Reinders'.

MATERIAL AND METHODS

The experiments were performed in the period of 2008–2010 in a commercial nursery in Lublin area (22º34'E, 51º14'N) Poland. Apple rootstocks M.9 (T337) and apple scions of 'Golden Delicious Reinders' used for budding and bench-grafting were provided by A. Verbeek Nursery, the Netherlands. The rootstocks (M.9 ISK) used in the third year of the experimentation were produced by own stoolbeds. At planting time, all used rootstock liners were characterized by stems of approx. 7–8 mm in diameter. In the course of the experiment one part of the liners were budded in the field in August, whereas the remaining liners were left intact in the field. In autumn both groups of liners were lifted and stored in the nursery facilities.

Nursery production protocols. Detailed nursery production protocols are given in table 1. During all vegetative seasons the experimental trees were given the same regime of fertilization, soil management and plant protection. Neither chemical branching practices nor irrigation/fertigation procedures were applied.

Table 1. Proprietary nursery protocols applied in the production of KB (knip-boom) trees in experimental treatments (2008–2010)

Operations	Methods of tree propagation		Annual production cycle	Time of operations
	bench-grafting	budding		
Planting rootstock liners (field)[1]	+	+	1st (initial stage)	April
Budding planted liners (A)[2]		+		August
No budding planted liners (B)	+			
Lifting liners (A and B)	+	+		October
Bench-grafting of liners[2]	+			February
Liners in cold room [3]	+	+		October to April (mid stage)
Transplanting liners (A and B) to field[4]	+	+	2nd (mid stage)	April
Field growing	+	+		All season
Heading liners (A and B)[5]	+	+	3rd (final stage)	April
Field growing	+	+		All season
Lifting bench-grafted and budded KB-trees	+	+		October

[1] planting spacing: 5 × 90 (cm)
[2] height of bench-grafting and budding was performed at 30 cm above collar root or above soil line, respectively
[3] temperature in cold room was between + 2.0 and + 2.5°C during all storage season (October–April)
[4] planting spacing: (25–30) cm × 90 cm
[5] parent shoot was headed at 60 cm above the soil line

The experimental design. The experiment was conducted for three consecutive years in repeating annual series. The experiment was established using a completely randomized design with 30 or 36 single-tree replications for each method of propagation (budding or bench-grafting) in 2008 and 2009, and in 2010, respectively.

Data recording and statistics. The measurements of each series of experiments were performed in the spring after heading back the parent shoot at 60 cm from either bud or graft union [Czarnecki 1998, Bielicki et al. 2004], and in the fall when a whole canopy of a tree was completed. The spring measurements (except for 2010) were: trunk diameter taken below and above the bud and/or graft union, and a trunk diameter measured at the heading point (60 cm). The autumn measurements were following: tree trunk diameter taken below and above the bud and/or graft union, height of tree measured from the soil line, and the number and length of feathers (laterals) > 10cm. Additionally, a detailed study on the spatial structure of nursery trees comprising lateral shoot distribution (position of lateral shoots on parent shoot relative to soil line), and corresponding shoot lengths with mean number of lateral(s) per node were carried out in each of the annual experiment series.

The data were subjected to analysis of variance, and a Duncan's multiple range test at $P < 0.05$ was used for mean separation. Mutual relations between some quality characteristics were evaluated by Pearson's product moment correlations at $P < 0.05$.

RESULTS AND DISCUSSION

Examination of the diameters of rootstock/scion unions in either bud or graft showed that the only consistent results in these measurements were those noted below the union. In both years the diameter of the rootstock of budded (B) trees was significantly larger than that of bench-grafted (G) trees. The remaining measurements of the tree trunk (parent shoot) diameters, i.e. above the union and at the distance of 60 cm from the union, were inconsistent during 2-year period (tab. 2). It is well known that scion may influence rootstock and/or interstock behavior [Hartmann et al. 2011]. It is also well documented that a method of propagation may affect the growth of tree components [Czynczyk 1996, Poniedziałek et al. 1996]. In spite of different responses in the measurements taken below or above the bud and/or graft union, and at 60 cm of parent shoot (scion) height, all correlations between these parameters ranged from medium positive ($r = 0.62$) to highly positive ($r = 0.82$) – table 2. The r – values in 2008 were somewhat lower than those in 2009 (tab. 2). It supposedly might have been associated with tree growth differences between both years.

Table 2. Effects of the methods of tree propagation on some vegetative growth parameters of 'Golden Delicious Reinders' apple KB-trees measured at the end of the mid stage of nursery production cycle

Growth parameters	Experimental series of:			
	2008		2009	
Coefficient of correlation (r)	methods of tree propagation			
	bench-grafting	budding	bench-grafting	budding
Diameter below [TD_b][1] (mm)	15.0 a[5]	15.9 b	12.4 a	16.4 b
Diameter above [TD][2] (mm)	12.4 a	12.0 a	9.7 a	12.1 b
Diameter at 60 cm [TD_{60}][3] (mm)	8.1 a	8.8 a	7.4 a	8.4 b
$TD_b \times TD$[4]	0.73	0.65	0.81	0.71
$TD_b \times TD_{60}$[4]	0.78	0.62	0.81	0.70
$TD \times TD_{60}$[4]	0.75	0.82	0.81	0.78

[1] TD_b tree trunk(rootstock) diameter measured below either graft or bud union
[2] TD tree trunk (parent shoot) diameter measured above either graft or bud union
[3] TD_{60} tree trunk (parent shoot) measured at heading point (60 cm)
[4] all r are significant at $P < 0.01$
[5] means followed by the same letter are not significantly different at $P < 0.05$; comparisons are valid within the same year

The results obtained in autumn measurements, when tree growth was completed indicated that B-trees outperformed G-trees in the basic quality parameters such as trunk diameter, total shoot extension and the number of lateral shoots >10 cm (tab. 3). No significant differences were noted between both tree types in height, percent of apical dominance, mean shoot length, and the percent of the number of shoots suitable for canopy formation (> 20 cm). We have not found any significant interactions between the propagation methods and the years of performing these studies in tested tree quality characteristics, except in total shoot extension ($P = 0.0341$) – tab. 3. Budding is usually performed in natural environment conditions, whereas bench-grafting takes place in somewhat artificial conditions. Fluctuation in temperature relative to the length of storing period (callusing), moisture of air and/or storing media, oxygen level and inhibiting influence of light may significantly contribute to failure or success of graft healing period [Hartmann et al. 2011]. Therefore, it appears that budded trees after transplanting resume vegetative growth more quickly than bench-grafts. Thus it is likely that in these circumstances the B-trees may have developed better standards for some quality characteristics than G-trees; it may be then regarded as a direct effect of tree propagation method.

Table 3. The mean values of basic apple KB-tree characteristics of 'Golden Delicious Reinders' as influenced by the methods of tree propagation (2008–2010)

Tree characteristics	Methods of tree propagation (MP)		*P* for interaction MP × year
	bench-grafting	budding	
Trunk diameter (mm)	14.8 a	15.8 b	ns
Tree height (cm)	174.1 a	169.6 a	ns
Total shoot extension ($cm \cdot tree^{-1}$)	236.1 a	287.2 b	0.0341
Apical dominance (%)[1)]	39.0 a	46.9 a	ns
No. shoots > 10 cm	7.1 a	8.4 b	ns
% shoots suitable for tree training [2), 3)]	86.1 a	89.5 a	ns
Mean shoot length (cm)	34.5 a	32.7 a	ns

[1)] Parent shoot (tree leader) length expressed as percent of total tree extension length (tree height + total shoot extension) according to the formula of Lee and Looney [1977]
[2)] Anova was performed using transformed values by Bliss formula, data presented herein are given in back-transformed values
[3)] shoots > 20 cm; ns – not significant

Particularly advantages from using B-trees were evident in 2009 when the nursery experimental field was partly flooded due to heavy rains in summer. Losses in B-trees caused by flooding were approx. 9.1%, whereas in G-trees reached up to 13.8% (data not shown). We have noticed that during winter 2009/2010 some frost injuries in callus tissues occurred at the union place of G-trees but did not in B-trees.

The results of detailed studies on tree canopy spatial structure and shape revealed no essential differences between the trees propagated by either method (fig. 1). In spite of similar shape of canopies of both types of trees (B *vs.* G), B-trees were characterized by significantly longer lateral shoots than G-trees except the shoots in the nodes 4 and 7 (tab. 4, fig. 1). Application of the *SLI* (shoot length index) in analysis of variance allowed to reduce the number of insignificant differences from two to one (node nr 7) – tab. 4. There were no differences in shoot length and the corresponding *SLI*-s in three uppermost nodes of the B- and G-trees. There were some significant interactions between the methods of propagation and the years of studies, namely in the mean shoot length (4 out of 13) and in the *SLI*-s (6 out of 13) – tab. 4.

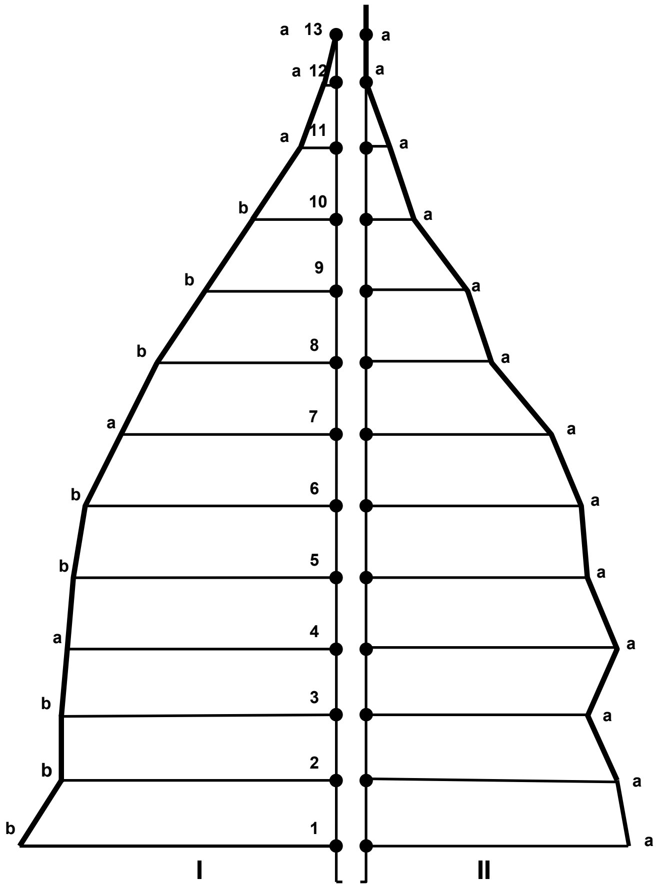

Fig. 1. Schematic pattern of the shape of the canopy of 'Golden Delicious Reinders' apple BK-trees propagated by budding (I) and bench-grafting (II). Each horizontal line indicates the mean length of a relative lateral shoot located at a given node (·). The lines at the same level followed by the same letter are not significantly different at $P < 0.05$ (for mean shoot length see tab. 4)

Table 4. Distribution of length of the lateral shoots on parent shoots of the KB-trees of 'Golden Delicious Reinders' as influenced by the methods of tree propagation (means 2008––2010) assessed at the final stage of tree production

Lateral shoot position on parent shoot (node nr)	Methods of tree propagation (MP)				Interaction (MP × year) for	
	bench-grafting		budding		mean shoot length	$SLI_{G/B}$
	mean shoot length (cm) [3]	SLI_G [1]	mean shoot length (cm)	SLI_B [2]	*P*	*P*
1 (soil level)	32.9 a [4]	33.9 a [5]	40.2 b [4]	40.2 b[5]	ns	ns
2	31.1 a	31.1 a	35.3 b	35.3 b	ns	ns
3	28.2 a	28.2 a	34.7 b	34.6 b	ns	ns
4	31.7 a	28.2 a	33.6 a	32.9 b	ns	ns
5	28.2 a	28.2 a	33.3 b	33.3 b	0.0068	0.0068
6	27.3 a	27.3 a	32.2 b	32.2 b	ns	ns
7	23.5 a	23.3 a	27.1 a	27.1 a	0.0173	0.0155
8	15.7 a	15.4 a	23.0 b	23.3 b	0.0379	0.0379
9	11.9 a	11.7 a	17.3 b	17.3 b	0.0166	0.0141
10	5.6 a	5.6 a	11.1 b	11.1 b	ns	ns
11	3.1 a	3.1 a	4.8 a	3.8 a	ns	0.0303
12	0.5 a	3.1 a	1.9 a	3.8 a	ns	0.0303
13 (tree top)	0.1 a	0.0 a	0.2 a	0.2 a	ns	ns

[1,2] $SLI_{G/B}$ – Shoot Length Index (shoot number per node *x* node shoot length) for: grafted (G) or budded trees (B); [3] mean shoot length was based on the actual number of trees in each treatment in a given year. Comparisons are valid between the columns with the same denotation ([4, 5]). Means followed by the same letter are not significantly different at $P < 0.05$

Table 5. The coefficients of linear correlation for mean values of basic characteristics of 'Golden Delicious Reinders' apple KB-trees as influenced by the methods of tree propagation (2008–2010)

Correlations	Methods of tree propagation			
	bench-grafting		budding	
	r	*P*	*r*	*P*
TD [1] × TNS [2]	0.63	0.0000	0.55	0.0000
TD × TSE [3]	0.70	0.0000	0.69	0.0000
TD × TH [4]	0.42	0.0000	0.20	ns.
TD × MSL[5]	0.41	0.0000	0.38	0.0003
TH × TNS	0.39	0.0001	0.11	ns.
TH × TSE	0.44	0.0000	0.11	ns.
TH × MSL	0.35	0.0006	0.06	ns.
MSL × TNS	0.19	ns.	- 0.07	ns.
MSL × TSE	0.53	0.0000	0.45	0.0000
TNS × TSE	0.90	0.0000	0.82	0.0000
AD [6] × TNS	- 0.90	0.0000	- 0.79	0.0000
AD × TD	- 0.64	0.0000	- 0.58	0.0000
AD × MSL	- 0.49	0.0000	- 0.34	0.0013
AD × TSE	- 0.93	0.0000	- 0.90	0.0000

[1] TD – tree trunk diameter measured above graft and/or bud union
[2] TNS – total number of lateral shoots
[3] TSE – total shoot extension length
[4] TH – tree height
[5] MSL – mean shoot length
[6] AD – apical dominance

G-trees exhibited stronger linear correlations than B-trees in each of the studied pairs of the growth characteristics. In G-trees 1 pair of correlation out of 14 appeared to be insignificant, whereas in B-trees it reached 5 out of 14 pairs (tab. 5). The strength of correlation may depend on tree age, species, cultivar, rootstock/interstock, type of characteristics studied, stage of plant development, etc. [Ostrowska and Chełpiński 1997, Lipecki and Janisz 1999, Jacyna 2007]. All correlations were positive, except those where apical dominance (AD) was involved. Irrespective of the tree propagation method, the correlations where trunk diameter was included were characterized by higher *r* – values than those with the inclusion of tree height. This relationship was very typical for young apple, sweet cherry, pear and plum trees and was previously reported by Lipecki and Janisz [1999], Kowalik [2001] and Łanczont [2004] The highest positive *r* – values for total number of shoots (TNS) *x* total shoot extension (TSE) were $r = 0.90$ and 0.82 for G- and B-trees, respectively. The highest negative *r* – values were shown by AD × TSE ($r = -0.93$ and - 0.90 for G- and B-trees, respectively) – tab. 5.

CONCLUSIONS

1. Knip-boom trees (KB) propagated by budding (sleeping bud method – B) were characterized by significantly higher values of trunk diameter, total shoot extension and the number of shoots > 10 cm than the trees propagated by grafting (bench grafting method – G).
2. There were no essential differences in the canopy spatial structure and shape between the trees propagated by either methods but the lateral shoots produced by B-trees were significantly longer in the zone from the 1st (above the soil line) up to the 10th node than the shoots produced by G-trees.
3. Strength of linear correlations between basic growth characteristics was greater in G- than B-trees.
4. It is recommended that for a whole evaluation of both types of KB-trees the economics of nursery tree production combined with orchard tree performance ought to be carefully analyzed.

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WPŁYW METOD ROZMNAŻANIA NA JAKOŚĆ DRZEWEK JABŁONI TYPU *KNIP-BOOM*

Streszczenie. Jakość materiału szkółkarskiego użytego do zakładania sadów decyduje w dużej mierze o porze wejścia drzew w okres owocowania i wielkości plonów owoców. Na jakość drzewek wpływają różne czynniki, wśród których metody ich rozmnażania odgrywają ważną rolę. Testowane w tych badaniach drzewka typu „knip-boom" produkowano w 3-letnim cyklu produkcyjnym ze śpiącego pąka (*B* – sleeping bud) oraz ze szczepienia w ręku (*G* – bench grafting). Oba rodzaje drzewek (*B* vs. *G*) porównywano pod względem parametrów jakości. Drzewka *B* w porównaniu z drzewkami *G* charakteryzowały się większymi wartościami takich cech jak średnica pnia, sumaryczna długość pędów oraz liczba pędów syleptycznych > 10 cm. Porównanie wartości wysokości drzewa, dominacji wierzchołkowej i procentowej liczby pędów przydatnych do formowania korony nie wykazało istotnych różnic między oboma rodzajami drzewek (*B* vs. *G*). Nie stwierdzono zasadniczych różnic między kształtem koron drzew *B* i *G* ocenianych przestrzennym położeniem pędów w koronach i ich długością. Jednakże porównanie długości pędów na analogicznych poziomach korony wykazało, że pędy drzew *B* były istotnie dłuższe niż drzew *G*. Drzewa *G* w porównaniu z *B* charakteryzowały się silniejszymi związkami między badanymi cechami, które oceniono za pomocą korelacji liniowych (pozytywne i negatywne). Przeprowadzone badania nie wykazały zasadniczych różnic produkcyjnych między drzewkami *B* i *G*. Całkowita ocena drzewek *B* i *G* powinna być oparta na analizie ekonomicznej produkcji szkółkarskiej i zdolności produkcyjnych drzewek po posadzeniu w sadzie.

Słowa kluczowe: korelacje wzrostowe, przestrzenna pozycja pędu, pąk (oczko) śpiący, szczepienie w ręku

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