Original scientific paper
Originalan naučni rad
UDK: 634.22-152.75
DOI: 10.7251/AGREN1501005M

University of Banjaluka, Faculty of Agriculture
Agro-knowledge Journal

Yield Potential of Long Bearing Shoots of Ten Plum Cultivars (*Prunus domestica* L.)

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Abstract

The yield potential of ten plum cultivars (‘Čačak's Beauty’, ‘Čačak's Best’, ‘Čačak's Fruitful’, ‘California Blue’, ‘Elena’, ‘Hanita’, ‘Katinka’, ‘Renclode Althan’, ‘Stanley’, and ‘Top’), exhibited through the structure of buds on long bearing shoots, was analyzed under the agro-ecological growing conditions of the Banja Luka region for two fruiting seasons (2012 and 2013). Long bearing shoots with collateral buds were the most productive type of fruiting branches, which is why the structure of buds on these branches is the basis for defining specific cultural measures in order to boost yield potential. Based on the established structure of buds on the nodes along the long bearing shoots and the established yield potential, the plum cultivars evaluated were classified into 4 groups: 1) cultivars with a predisposition to have a high yield potential, without need for specific treatments in fruiting control (‘Čačak's Beauty’ and ‘Top’); 2) cultivars with a predisposition to have a high yield potential with the application of cultivar-specific cultural measures for control of fruiting (‘Čačak's Best’, ‘Elena’, and ‘Stanley’); 3) cultivars that require differentiated cultural measures in the control of yield potential for regular fruiting (‘Čačak's Fruitful’, ‘California Blue’, and ‘Katinka’) and 4) cultivars that require innovative growing systems and specific cultural treatments to control fruiting (‘Hanita’ and ‘Renclode Althan’).

Key words: vegetative buds, aborted flower buds, specific cultural measures

Introduction

In intensive and highly intensive plum growing orchards, long bearing shoots are the main type of fruiting wood that usually is selected during pruning. These shoots are formed as a result of the appropriate positioning of flower and vegetative buds along the shoots (Mićić and Čmelik, 1988; Mićić, 1993; Milatović et al., 2015). The intensity of specific cultural measures has a direct impact on the growth dynamics of shoots and, thus, on the differentiation of buds and the subsequent structure and positioning of buds along these shoots (Mićić and Čmelik, 1983; Đurić et al., 1998; Mićić et al., 2006). Knowing the specific properties of bud structures on the fruiting branches of specific cultivars of plum is an important precondition for the application of cultivar-specific cultural measures which is the basis for achieving projected yields (Mićić et al., 2006). For stone fruit trees, the key factor for ensuring biological yield potential (new flower buds) is to ensure the development of new shoots on which flower buds will differentiate during the vegetation period for fruiting in the following year and also that a sufficient number of vegetative buds are formed for providing the necessary leaf mass. Therefore, the question of the cultivar-specific cultural measures actually comes down to the question of presence and positioning of vegetative and flower buds, as well as aborted flower buds, in specific categories of fruiting wood (Đurić et al., 1998; Mićić et al., 2006; Milošević and Milošević, 2009).

Bud differentiation and the transition of meristems from the vegetative into the generative phase is a part of the general scheme of differentiation of generative organs in flowering plants (Kuperman, 1968), which was later adapted to fruit trees (Isaeva, 1977). The descriptions of individual stages of plum organogenesis have been studied through the growth dynamics of plum shoots (Paunović and Ogašanović, 1972), the completion of shoot growth by tip abortion, the initiation of the third phase of organogenesis, and so on (Mićić and Čmelik, 1983). The study of differentiation of buds on the nodes of long bearing shoots of three plum cultivars (Mićić, 1993) found that each node primarily formed three meristematic apices in a collateral arrangement. The subsequent course of their differentiation was shown to be determined by their position on a node and along the shoot. Namely, the central apex of nodes can differentiate into both vegetative and flower buds in such a way that, on a certain number of nodes, flower buds are formed on nodes at the base of branches, while vegetative buds are formed at upper nodes on branches. The lateral meristematic apices of nodes can only differentiate into flower buds, or atrophy shortly after formation, or abort shortly after entering the generative sequence of differentiation (Mićić and Čmelik, 1988; Mićić, 1992).

The nature of the structure of buds on long bearing shoots of a plum cultivar is basically the factor that determines yield potential of that cultivar in specific agro-ecological growing conditions (Đurić et al., 1998; Mićić, 1994). It is very important, both for the for breeders and producers, to know the growth and development of new plum cultivars in specific local growing conditions. Usually, these research are done through analyses of the growth and yield parameters such as canopy size; trunk cross-sectional area; cumulative yield, fruit mass, and canopy density; and application of winter and summer pruning (Blažek et al., 2004; Blažek and Pištekova, 2012; Čmelik et al., 2007; Dinkova et al., 2007, 2012; Dinkova et al., 2012; Dzintra et al., 2013; Nikolić and Milatović, 2010; Robinson et al., 2010). However, the issues of identifying the dominant type of bearing shoots, i.e. the biological yield potential of new cultivars, is unjustifiably neglected, although it is known that applied cultural measures primarily affect the realization of biological production potential.

Materials and Methods

Orchard sites

The structure of buds on the nodes of long bearing shoots was studied during 2012 and 2013 under the agro-ecological growing conditions of the Banja Luka – Prijedor region on 10 plum cultivars: ‘Čačak's Beauty’, ‘Čačak's Best’, ‘Čačak's Fruitful’, ‘California Blue’, ‘Elena’, ‘Hanita’, ‘Katinka’, ‘Renclode Althan’, ‘Stanley’, and ‘Top’. All cultivars were grafted onto Myrobalan seedling rootstock and each cultivar was represented by three trees. The planting in Bukvalek (44º45′21″N, 17º7′51″E; 419 m asl) was established in the fall of 1997, when one-year-old, unbranched saplings were established, and included the following six standard plum cultivars: ‘Čačak's Beauty’, ‘Čačak's Best’, ‘Čačak's Fruitful’, ‘California Blue’, ‘Renclode Althan’, and ‘Stanley’. The training system was a spindle with a spacing of 5 × 3 m. The planting on the Gradina site (44º51'10"N, 16º54'11"E; 210 m asl), was started in the spring of 2000, by planting two-year-old, branched saplings of the following new introduced plum cultivars: ‘Elena’, ‘Hanita’, ‘Katinka’, and ‘Top’. The training system was a spindle with a spacing of 4.5 × 2.5 m.

Plant material

The study of bud structure was conducted on long bearing shoots, being the most common and most important type of plum fruiting branches. A sample of 30 long bearing shoots were taken for analysis from established trees of each

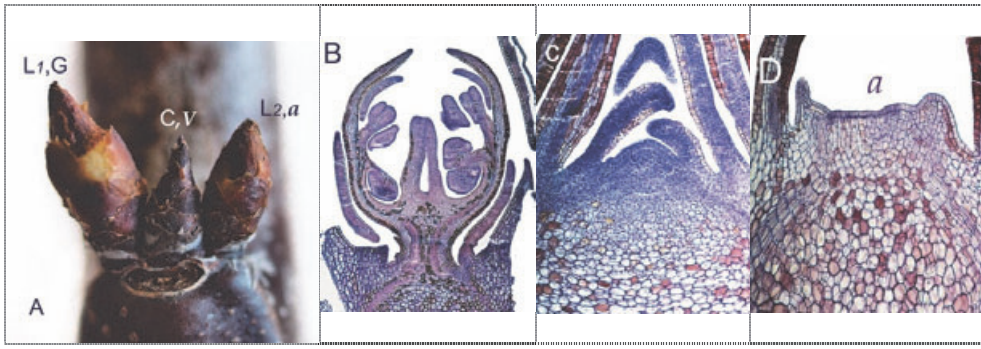


Fig. 1. The morphology and histological cross-section of plum collateral buds on the node: A - bud on the L_1 position is generative (G), bud on the central position (C) is vegetative (V), and bud on the L_2 position is with aborted apex (a); B - histological cross-section of the bud on the L_1 position; C - histological cross-section of the bud on the C position; D - histological cross-section of the bud on L_2 position

Morfološki izgled i histološki presjek kolateralnih pupoljaka na nodusu šljive: A – pupoljak na poziciji L_1 je generativni (G), pupoljak na centralnoj poziciji (C) je vegetativni (V), a pupoljak na poziciji L_2 je sa abortiranim apeksom (a); B – histološki presjek pupoljka na poziciji L_1; C – histološki presjek pupoljka na poziciji C; D – histološki presjek pupoljka na poziciji L_2

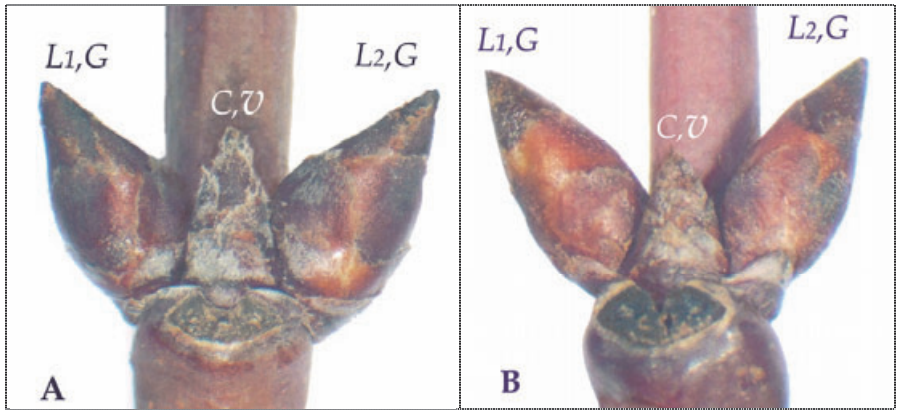


Fig. 2. The colateral buds of plum cultivars Čačak's Beauty (A) and Elena (B): the normal generative buds on lateral position on nodes (L_1,G and L_2,G) with vegetative buds (C,V) on central position on nodes

Kolateralni pupoljci šljive sorti Čačanska lepotica (A) i Elena (B): normalni generativni pupoljci na bočnim pozicijama na nodusima (L_1,G i L_2,G) sa vegetativnim pupoljcima (C,V) na centralnoj poziciji na nodusima

cultivar in both years (2012 and 2013) from the middle zone on all four sides of the crown. The length and number of nodes as well as bud presence and distribution were determined on the analysed branches.

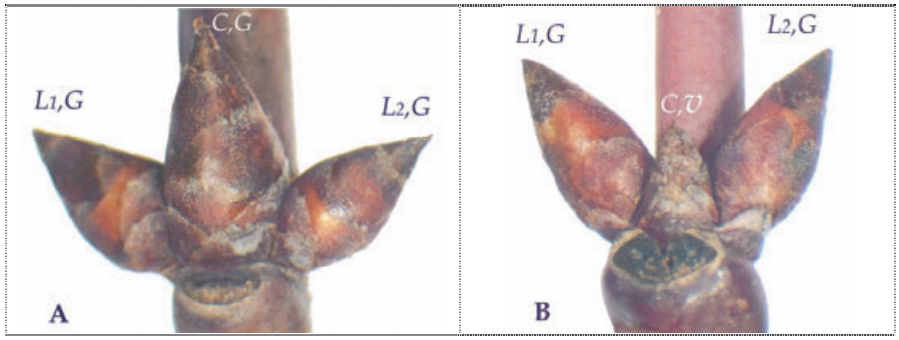


Fig. 3. The colateral buds of plum cultivars Čačak's Best (a) and Elena (b): the normal generative buds on lateral position on nodes (L_1,G and L_2,G) as well as on central position on nodes (C,G)

Kolateralni pupoljci šljive sorti Čačanska najbolja (a) i Elena (b): normalni generativni pupoljci na bočnim pozicijama na nodusima (L_1,G i L_2,G) kao i na centralnoj poziciji na nodusima (C,G)

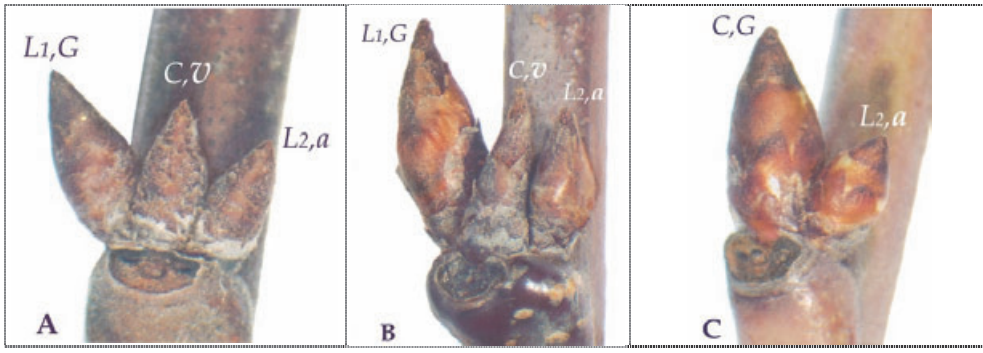


Fig. 4. The colateral buds of plum cultivars Katinka (a), Stanley (b) and Althan's renklode (c): the normal generative buds on lateral position on nodes (L_1,G) as well aborted generative buds (a) on position b_2. The central buds on node are vegetative (V_C) by Katinka and Stanley, and generative by Althan's renklode (G_C)

Kolateralni pupoljci šljive sorti Katinka (a), Stenlej (b) i Altanova renkloda (c): normalni generativni pupoljci na bočnim položajima na nodusima (L_1,G) kao i abortirani generativni pupoljci (a) na poziciji b_2. Centralni pupoljci na nodusu su vegetativni (V_C) kod Katinke i Stenleja, a generativni kod Altanove renklode (G_C)

Bud analysis

The structure of plum buds was established by observing all buds on all fruiting branches under a binocular microscope (Olympus SZH 10), while photographic documentation was conducted using Olympus DP - Soft Image Analysis Software. The following three categories of buds were present at the nodes of long bearing shoots: vegetative, normally differentiated flower buds, and aborted flower buds (buds with an atrophied apex) (Figs. 1, 2, 3 and 4). The bud characteristics were established for all long bearing shoots of each cultivar in both years, including buds in the central position of all nodes, from the base to the top of the long bearing shoots, as well as buds in both lateral positions at nodes with a collateral bud arrangement.

Statistics

The average values with corresponding measures of variability, the variation coefficient and standard error of the mean, were calculated for the length and number of nodes of long bearing shoots. Significant difference was determined by Student's t-test.

Based on the number of normally differentiated flower and vegetative buds on all 30 long bearing shoots from each of the studied cultivars, the relative coefficient of yield potential (CYP) of long bearing shoots was determined and expressed as the number of normal flower buds per vegetative bud.

Using the number of vegetative buds, the number of normally differentiated flower buds and the relative CYP, the cultivars studied were grouped using cluster analysis using SPSS software.

On the basis of the total number of buds in each category at the nodes of fruiting branches, the average relative presence (expressed in %) was calculated for buds in both central and lateral positions for all nodes, from the branch base to top. Based on that presence, graphical presentations of bud structure were developed for each variety.

Results and Discussion

Characteristics of long bearing shoots

The average length of long bearing shoots ranged from 17.71 cm in ‘Čačak's Beauty’ to 27.21 cm in ‘Top’, each in 2013. The average number of nodes on long bearing shoots ranged from 9.46 in ‘Elena’ to 16.15 in ‘California Blue’, also both in 2013 (Table 1).

Tab. 1. Average length and average number of nodes of one-year-old long bearing shoots of ten plum cultivars
Prosječna dužina i prosječan broj nodusa na jednogodišnjim dugim (mješovitim) rodnim grančicama u deset sorti šljive

Cultivars *Sorte*	Year *God.*	Length (cm) *Dužina (cm)*	$t_{2012\text{-}2013}$	Number of nodes *Broj nodusa*	$t_{2012\text{-}2013}^{z}$
California Blue	2012	20.67 ± 1.51	2.123*	13.07 ± 0.76	2.289*
Kalifornijska plava	2013	25.84 ± 1.91		16.15 ± 1.11	
Althan's Renclode	2012	22.53 ± 1.26	1.321^{ns}	12.22 ± 0.49	0.415^{ns}
Altanova renkloda	2013	19.86 ± 1.58		11.49 ± 0.69	
Čačak's Fruitful	2012	23.11 ± 1.62	0.591^{ns}	11.58 ± 0.45	0.631^{ns}
Čačanska rodna	2013	24.42 ± 1,51		12.10 ± 0.69	
Čačak's Beauty	2012	21.16 ± 1.48	1.510^{ns}	12.17 ± 0.50	0.709^{ns}
Čačanska lepotica	2013	17.71 ± 1.74		11.60 ± 0.63	
Čačak's Best	2012	23.43 ± 1.70	0.372^{ns}	11.44 ± 0.58	0.820^{ns}
Čačanska najbolja	2013	24.10 ± 0.60		10.79 ± 0.54	
Stanley	2012	23.77 ± 1.47	0.586^{ns}	11.78 ± 0.37	0.942^{ns}
Stenlej	2013	25.10 ± 1.73		12.42 ± 0.57	
Katinka	2012	22.08 ± 1.81	1.440^{ns}	14.09 ± 0.77	0.231^{ns}
	2013	18.61 ± 1.59		13.83 ± 0.82	
Top	2012	24.59 ± 1.58	0.914^{ns}	12.90 ± 0.64	0.927^{ns}
	2013	27.21 ± 2.39		13.97 ± 0.96	
Elena	2012	24.80 ± 1.31	2.006*	9.98 ± 0.31	1.044^{ns}
	2013	21.07 ± 1.32		9.46 ± 0.39	
Hanita	2012	22.28 ± 2.10	0.772^{ns}	13.53 ± 0.64	1.691^{ns}
	2013	24.55 ± 2.06		11.69 ± 0.88	

$^{z}t_{0.05} = 1.99$; $t_{0.01} = 2.66$; ns = not signifiant / *nije značajno*

The length of fruiting branches and the number of nodes were not significantly different between the two years for all cultivars except for 'Elena' and 'California Blue'. 'Elena' had significantly longer long bearing shoots in 2012 (24.8 cm) in comparison to 2013 (21.07 cm). However, the opposite was observed with 'California Blue', i.e., long bearing shoots were significantly longer in 2013 (25.84 cm) as compared to 2012 (20.67 cm), while the average number of nodes in this cultivar was also significantly higher in 2013 (16.15) as compared to 2012 (13.07).

Number of buds on long bearing shoots

The average number of vegetative buds on long bearing shoots ranged from 12.55 in 'Elena' in 2013 to 25.65 in 'Čačak's Beauty' in 2012 (Table 2).

The lowest average number of normally differentiated flower buds was observed in 'Renclode Althan' in 2012 (15.42) while the highest average

number was recorded in ‘Čačak's Beauty’ in 2012 (53.29) and in ‘Top’ in 2013 (53.66). ‘Čačak's Beauty’ in 2012, and ‘Top’ and ‘Čačak's Best’ in 2013, did not have any aborted flower buds while the highest average number of aborted flower buds was observed in ‘Hanita’ in 2013 (19.34).

Tab. 2. The average number of vegetative, generative and aborted flower buds on all nodes of one-year-old long bearing shoots of ten plum cultivars
Prosječan broj vegetativnih, generativnih i abortiranih pupoljaka na svim nodusima jednogodišnjih dugih (mješovitih) rodnih grančica u deset sorti šljive

Cultivars *Sorte*	Year *God.*	Vegetative *Vegetativni*		Generative *Generativni*		Aborted generative *Abortirani generativni*	
		$\overline{X} \pm S\overline{x}$	Cv	$\overline{X} \pm S\overline{x}$	Cv	$\overline{X} \pm S\overline{x}$	Cv
California Blue	2012	22.76 ± 0.58	14.26	39.22 ± 1.68	24.65	6.18 ± 0.17	15.35
Kalifornijska plava	2013	25.33 ± 0.92	20.03	29.82 ± 1.48	27.15	2.86 ± 0.06	10.82
Althan’s Renclode	2012	18.65 ± 0.57	17.69	15.42 ± 0.92	32.86	14.91 ± 0.95	35.11
Altanova renkloda	2013	20.85 ± 0.85	22.45	26.15 ± 0.94	20.63	10.79 ± 0.52	25.71
Čačak's Fruitful	2012	14.72 ± 0.61	15.07	31.47 ± 1.72	28.92	5.15 ± 0.16	17.36
Čačanska rodna	2013	20.19 ± 0.48	13.65	23.83 ± 1.11	25.42	4.87 ± 0.19	22.01
Čačak's Beauty	2012	25.65 ± 0.43	9.65	53.29 ± 0.94	10.16	-	
Čačanska lepotica	2013	18.19 ± 0.37	11.30	38.46 ± 1.09	15.62	1.94 ± 0.02	7.35
Čačak's Best	2012	23.67 ± 0.52	13.36	43.44 ± 0.61	9.25	1.46 ± 0.01	6.18
Čačanska najbolja	2013	13.69 ± 0.24	10.92	30.90 ± 0.33	6.36	-	
Stanley	2012	18.99 ± 0.53	16.05	32.56 ± 1.12	18.71	3.83 ± 0.10	15.09
Stenlej	2013	15.36 ± 0.23	9.27	34.66 ± 0.82	12.53	1.50 ± 0.02	7.24
Katinka	2012	22.42 ± 0.28	6.78	31.65 ± 1.64	28.50	11.78 ± 0.51	23.50
	2013	25.45 ± 0.46	10.35	46.12 ± 0.63	8.56	4.66 ± 0,11	12,35
Top	2012	19.48 ± 0.72	21.23	43.86 ± 1.01	12.63	6.81 ± 0.12	10.09
	2013	16.11 ± 0.69	24.29	53.66 ± 1.64	17.52	-	
Elena	2012	14.34 ± 0.64	24.53	22.33 ± 0.94	24.16	6.79 ± 0.23	18.36
	2013	12.55 ± 0.41	19.62	25.56 ± 0.71	15.28	1.69 ± 0.04	14.42
Hanita	2012	23.48 ± 0.25	6.16	37.09 ± 1.39	20.58	8.68 ± 0.41	25.93
	2013	21.75 ± 0.37	10.13	24.81 ± 1.17	26.62	19.34 ± 0.96	27.33

The ratio of average number of generative to vegetative buds on fruiting branches (i.e., the number of normally differentiated flower buds per vegetative bud) is the coefficient of relative yield potential. The highest relative coefficient of yield potential was seen in 'Top' in both 2012 (2.251) and 2013 (3.331) while the lowest relative coefficient of yield potential was observed with 'Renclode Althan' in 2012 (0.826). The value of this coefficient was above 1.00 for all cultivars in 2013 (Table 3).

The number and structure of vegetative and normally differentiated flower buds on nodes of long bearing shoots, which define the basic type of fruiting branch for intensive plum growing systems, represents a basis for estimating yield potential and for defining the intensity of cultural measures that are required in the cultivar-specific treatments for plums (Mićić, 1994).

Tab. 3. The relative coefficient of yield potential – CYV of one-year-old long bearing shootsof ten plum cultivars
Relativni koeficijent rodnog potencijala – CYV jednogodišnjih dugih (mješovitih) rodnih grančica u deset sorti šljive

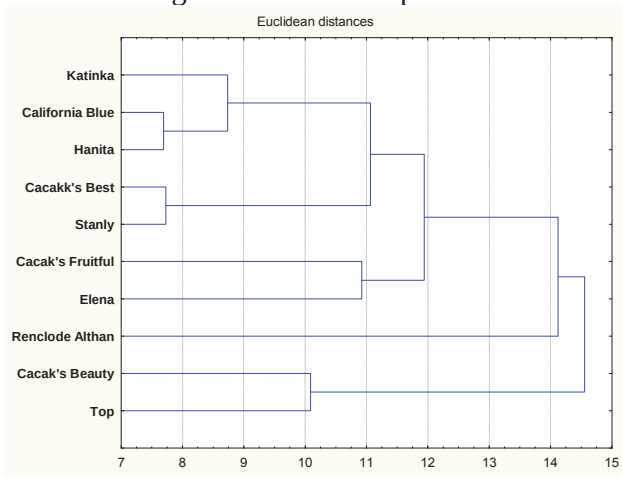
Cultivar *Sorta*	Relative coefficient of yield potential *Relativni koeficijent rodnog potencijala*	
	2012	2013
California Blue/ *Kalifornijska plava*	1.723	1.177
Renclode Althan/ *Altanova renkloda*	0.826	1.254
Čačak's Fruitful/ *Čačanska rodna*	1.776	1.180
Čačak's Beauty/ *Čačanska lepotica*	2.077	2.114
Čačak's Best/ *Čačanska najbolja*	1.835	2.257
Stanley / *Stenlej*	1.714	2.256
Katinka	1.412	1.812
Top	2.251	3.331
Elena	1.557	2.037
Hanita	1.579	1.141

Grouping of the plum cultivars was conducted using cluster analysis on the basis of the average numbers of vegetative and normally differentiated flower buds, and the CYP of long bearing shoots in both years (Graph 1). On this basis, the cultivars could be divided into the following groups: 1) cultivars with the optimal bud structure and a very high yield potential ('Čačak's Beauty' and 'Top'); 2) cultivars with acceptable bud structure and high yield potential ('Čačak's Best', 'Čačak's Fruitful', 'Elena', 'Katinka', and 'Stanley',); 3) cultivars with variation in bud structure and yield potential ('California Blue'

and ‘Hanita’) and 4) cultivars with questionable bud structure and questionable yield potential (‘Renclode Althan’).

Distribution of buds on nodes along the fruiting branch

The distribution of buds on nodes along fruiting branches represents an important cultivar-specific characteristic which should be considered during the pruning of stone fruit trees in general. Flower buds on stone fruit trees, including plums, are purely flower buds (without a meristematic apex) and projected tree yield is, therefore, limited by the relative ratio of generative to vegetative buds on fruit-bearing wood. Consequently, pruning should select for preferred fruiting branches. Long bearing shoots have priority over short branches (spurs), because they have a more vegetative buds which should provide assimilates for fruit growth and development.

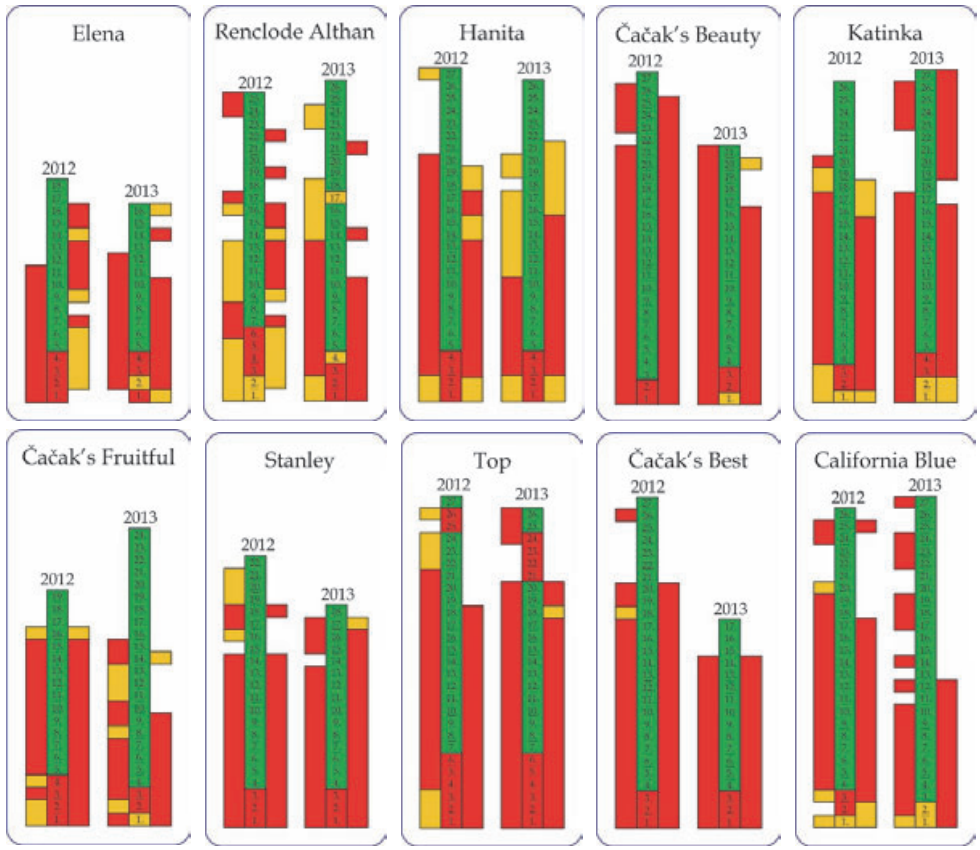


Graph 1. The clustering of ten plum cultivars according to the number of vegetative and generative buds and yield potential of mixed fruiting branches

Klaster analiza deset sorti šljive prema broju vegetativnih i generativnih pupoljaka irodnom potencijalu dugih (mješovitih) rodnih grančica

Flower buds on all cultivars were located only on lateral buds at each node, except at the branch base where they were also located in the central position of the nodes (Graph 2). Vegetative buds were located exclusively in the central position of nodes at the branch top, above the 3rd and up to the 7th node, depending on the cultivar. The position of vegetative buds on these branches is important for the purpose of pruning treatment, while position of flower buds is important because of the burden of supporting fruit on the branches. The position of certain categories of buds on the nodes along fruiting

branches is important for establishing the projected relationship between vegetative and flower buds during pruning. According to the presence and position of vegetative and flower buds at the base of long bearing shoots in the plum cultivars that were studied, pruning treatments without any restrictions can be performed in 'Čačak's Best', 'Čačak's Beauty', and 'Stanley' while in other cultivars these treatments are limited by the presence of aborted flower buds. The presence and distribution of aborted flower buds (empty buds), which exist on the nodes until the start of the vegetative period, have to be considered during winter pruning primarily in 'Hanita', 'Katinka' and 'Renclode Althan'.



Graph 2. Dominant positions of vegetative, normally developed generative and aborted generative buds on nodes along mixed fruiting branches of the examined plum cultivars in 2012 and 2013

Dominantna pozicija vegetativnih, normalno razvijenih generativnih i abortiranih generativnih pupoljaka na nodusima duž mješovitih rodnih grana ispitivanih sorti šljive u 2012. i 2013. godini

Based on an analysis of the dominant distribution of vegetative, normally differentiated flower and aborted flower buds on nodes along the long bearing shoots of the plum cultivars that were studied in 2012 and 2013 (Fig. 6), the cultivars can be grouped as follows: 1) cultivars with only a small variation in the positioning of vegetative, flower and aborted flower buds (‘Čačak's Beauty’, ‘Čačak's Best’, ‘Stanley’, and ‘Top’); 2) cultivars with acceptable variation in the positioning of vegetative, flower and aborted flower buds (‘Čačak's Fruitful’, ‘California Blue’, ‘Elena’, and ‘Katinka’) and 3) cultivars with a high variation in the positioning of vegetative, flower and aborted flower buds (‘Hanita’ and ‘Renclode Althan’).

The structure of buds in a collateral arrangement at each node along the long bearing shoots (i.e., the positioning of vegetative and flower buds at nodes on long bearing shoots) of the plum cultivars that were examined, clearly shows a varietal specificity in the formation of yield potential. When one takes into account this phenomenon of positioning buds on nodes along these fruiting branches (vegetative, flower and buds with aborted apex), it can be seen that the yield potential of these fruiting branches of some plum cultivars depends primarily on the presence of buds with aborted apices.

Acknowledgement

This research was co-financed by the Ministry of Science and Technology of the Republic of Srpska through the project "Initiation of generative differentiation of apex in plum" under the contract signed with the Genetic Resources Institute, University of Banja Luka, and number 19/6-020/961-141/12.

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Received: March 16, 2015
Accepted: May 18, 2015

Rodni potencijal dugih rodnih grana u deset sorti šljive (*Prunus domestica* L.)

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Sažetak

Analiziran je rodni potencijal kod deset sorti šljive: Katinka, Čačanska lepotica, Kalifornijska plava, Altanova renkloda, Čačanska najbolja, Stenlej, Hanita, Čačanska rodna, Elena i Top u agroekološkim uslovima regije Banjaluka tokom dvije godine, na osnovu strukture i stepena diferenciranosti pupoljaka na mješovitim rodnim grančicama. Na osnovu strukture pupoljaka na nodusima duž mješovitih rodnih grančica, posmatrane sorte šljive mogu se svrstati u 4 grupe: 1) sorte sa predispozicijom za visok rodni potencijal bez posebnih zahjeva za specifičnim tretmanima u kontroli rodnosti (Čačanska lepotica i Top); 2) sorte sa predispozicijom za visok rodni potencijal uz genotipski diferenciranu pomotehniku za kontrolu rodnosti (Čačanska najbolja, Stenlej i Elena); 3) sorte koje traže diferenciranu pomotehniku u kontroli rodnog potencijala za redovno plodonošenje (Katinka, Čačanska rodna i Kalifornijska plava) i 4) sorte koje traže inovirane sisteme gajenja i specifične pomotehničke tretmane u kontroli rodnosti (Hanita i Altanova renkloda).

Ključne riječi: vegetativni pupoljci, abortirani generativni pupoljci, pomotehničke mjere

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Primljeno: 16. mart 2015.
Odobreno: 18. maj 2015.