Variability, heritability and correlations of some factors affecting productivity in peach

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Abstract

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Factors affecting productivity in peach, such as flower density, initial and final fruit set by open pollination, and yield per m length of shoot were studied in 40 cultivars during a three-year period. Significant differences among cultivars were found for all studied properties. The coefficients of variability were the lowest for initial fruit set and then for final fruit set and flower density; while they were the highest for yield. The relatively high values of heritability were found for flower density and yield. Significant correlation coefficients were found between initial and final fruit set, flower density and yield, as well as between final fruit set and yield. In areas with a higher risk of freeze damage the cultivars characterized by higher flower density and fruit set should be grown because they can provide more consistent yield potential. At the same time, these cultivars require more intensive pruning and fruit thinning to achieve quality fruit.

Keywords: *Prunus persica*; flower density; fruit set; yield

Yield of the peach tree depends on a number of factors, such as density of flower buds and flowers, fruit set, fruit size, winter and late spring freeze damage, precipitation amount, and orchard management. Most peach cultivars are characterized by high productivity potential. Abundance of flowering and fruit set are generally much higher than it is necessary to obtain optimum yield. To achieve satisfactory size and quality of fruit, it is necessary to regulate the crop load using orchard management practices, of which the most important are pruning and fruit thinning.

Peach cultivars differ in flower density. These differences are due to the tendency of a cultivar to produce flower buds and the ability of a cultivar to survive the winter (Marini, Reighard 2008). Peach tendency to produce flower buds is genetically determined (Werner et al. 1988; Okie, Werner 1996).

Successful cultivation of peach in Serbia is possible in areas with rare occurrence of low temperatures, which can cause damage to flower buds and flowers during the winter and spring. In some years there is a considerable freeze injury, which may affect the yield (Pejkić et al. 1987; Ognjanov 2005). In areas with frequent freeze injury to flower buds, the growing of cultivars with multiple flower buds per node can provide regular yields (Byrne 1986). Peréz (2004) studied the flower density in 33 peach genotypes and found values ranging from 24 to 97 flowers per meter.

Almost all cultivars of peach are self-fertile, with the exception of a small number of cultivars having male sterility. Male sterility is most frequently found among the Chinese peach cultivars (Szabó et al. 2003). Male sterile peach cultivars grown in Europe and the USA are J.H. Hale and Flaminia. These cultivars have smaller anthers, are pale colored (light yellow or orange), and contain no pollen at all or just a few pollen grains (Szabó et al. 1996). Mišić et al. (1977) found that the average fruit set by self-pollination in nine peach cultivars was 26.35%. Nyéki (1996) reports that the fruit set by self-pollination in

Table 1. Survey of peach cultivars studied

Cultivar	Origin	Harvest time in relation to Redhaven	Flesh colour
Goldcrest	USA, California	–42	yellow
Royal Gold	USA, California	–35	yellow
Springtime	USA, California	–33	white
May Crest	USA, California	–30	yellow
Hamlet	USA, North Carolina	–26	yellow
Collins	USA, New Jersey	–19	yellow
Maria Cristina	Italy	–18	white
Sentry	USA, Maryland	–15	yellow
Dixired	USA, Georgia	–12	yellow
Botto	Italy	–10	white
Maria Grazia	Italy	–3	white
Redhaven	USA, Michigan	0 (July, 20)	yellow
Maria Luisa	Italy	0	yellow
Triestina	Italy	+2	white
Flavorcrest	USA, California	+3	yellow
Compact Redhaven	USA, Washington	+4	yellow
Redtop	USA, California	+4	yellow
Regina	USA, California	+7	yellow
Maria Bianca	Italy	+9	white
Vesna	Serbia	+10	yellow
Emilia	Italy	+11	yellow
Glohaven	USA, Michigan	+11	yellow
Carolina Belle	USA, North Carolina	+12	white
Maria Rosa	Italy	+15	white
Suncrest	USA, California	+16	yellow
Elegant Lady	USA, California	+18	yellow
Cresthaven	USA, Michigan	+27	yellow
Early O' Henry	USA, California	+31	yellow
Sunprince	USA, Georgia	+31	yellow
J.H. Hale	USA, Connecticut	+33	yellow
Padana	Italy	+35	yellow
Aurelia	Italy	+38	yellow
Fayette	USA, California	+39	yellow
Michelini	Italy	+40	white
Maria Delizia	Italy	+44	white
Autumnglo	USA, New Jersey	+46	yellow
Radmilovčanka	Serbia	+56	yellow
Fairtime	USA, California	+60	yellow
Summerset	USA, California	+62	yellow
Flaminia	Italy	+63	yellow

Average values of harvest time in the Belgrade region during 1996–2003

most peach cultivars is between 15% and 20%, being the highest in processing clingstone peaches, then in fresh-market peaches and the lowest in nectarines. Fruit set by self-pollination is generally lower than by open pollination, but seasonal variability is higher (Nyéki et al. 1998; Szabó et al. 2000).

Studies of genetic variability, heritability and correlation between properties can show the extent to which certain traits are genetically determined and which of them have the greatest importance in the selection and creation of new cultivars. According to the results of Hansche et al. (1972), heritability for peach yield was 0.08, and for amount of bloom 0.38. Heritability for the number of flowers in two-year-old peach seedlings was 0.16 (Hansche 1986), and for flower bud set 0.55 (Rodriquez, Sherman 1986). De Souza et al. (1998) found high values of genetic correlation between flower density and number of flowers per node (r = 0.95), fruit density and fruit set (r = 0.84), and flower density and fruit density (r = 0.71). They recommended the use of flower density in peach selection for productivity. Ruiz and Egea (2008) reported a significant correlation between flower density and fruit density (r = 0.46) as well as between fruit density and fruit set (r = 0.74) in apricot.

The aim of this study was to evaluate the variability, heritability and correlations of some factors affecting yield in peach. The obtained information can be useful for breeders to select the best parents for productivity. It can also contribute to proper site selection and determination of the appropriate intensity of pruning and fruit thinning for a wide range of peach cultivars.

MATERIAL AND METHODS

Research was conducted in the peach germplasm collection situated at the Experimental Station Radmilovac of the Faculty of Agriculture in Belgrade, during a three-year period (2003–2005). The orchard was established in 1993, the rootstock was vineyard peach, tree form was open vase and planting spacing was 4.5 × 4.5 m. This study comprised 40 peach cultivars with different maturation times, of which 30 cultivars had yellow flesh, and 10 cultivars had white flesh (Table 1). The average flowering time of these cultivars was the end of March and the first week of April, and differences between cultivars with the earliest and the latest flowering time were small (4 to 7 days).

During the flowering time, one scaffold branch was selected on three trees of each cultivar. In marked scaffolds five to ten one-year-old shoots 40 to 80 cm long were left after dormant pruning. Their length was measured, and the number of flowers was counted (ranging approximately 100–300). Flower density was calculated as the number of flowers per 1 m length of one-year-old shoots (Lombard et al. 1988). Fruit set percentage was determined in conditions of open pollination as the initial fruit set (three weeks after flowering), and the final fruit set (before harvest). At the time of harvest, on the marked branches all fruits were picked, their weight measured, and the yield per 1 m length of one-year-old shoot was calculated. In the experimental orchard standard cultural practices were applied without irrigation. On the marked scaffolds fruit thinning was not done to evaluate final fruit set. On the other scaffolds fruit thinning was done about 40 days after full bloom.

The results were processed using the analysis of variance method for a two-factor experiment and significance of differences between mean values was determined using the LSD (Least Significant Difference) test. For the studied traits the coefficient of variation (CV) was calculated as the ratio of standard deviation and arithmetic mean and is expressed in percentages. From the ratio of genetic and phenotypic variances, the heritability in the broad sense (H^2), expressed as a percentage, was calculated. Between the studied traits the calculations were also done for correlation coefficients, and testing of significance for these coefficients was conducted using the t-test. Statistical analyses were performed using the Statistica program (StatSoft, Inc., Tulsa, Oklahoma, USA).

RESULTS AND DISCUSSION

Flower density

The average number of flowers per 1 m length of one-year-old shoot in most peach cultivars examined was between 20 and 40 (Table 2). High density of flowers (more than 40 per 1 m) was found in the yellow flesh cultivars: Collins, Autumnglo, Suncrest, Maria Luisa, Vesna, Cresthaven, and Glohaven, as well as in the white flesh cultivars Carolina Belle, Triestina, Maria Bianca, and Springtime. These cultivars have high productive potential. On the other hand, low density of flowers (below 20 per 1 m) was found in the yellow flesh cultivars Gold-

Table 2. Number of flowers per 1 m of shoot length and initial fruit set by open pollination in peach cultivars

Cultivar	No. of flowers/m of shoot length					Initial fruit set (%)				
	2003	2004	2005	average	*CV* (%)	2003	2004	2005	average	*CV* (%)
Goldcrest	14.8	24.5	4.2	14.5	63	95	95	70	86	17
Royal Gold	36.7	48.9	28.0	37.8	29	95	95	63	84	20
Springtime	41.9	48.3	32.1	40.8	24	86	86	78	83	8
May Crest	41.0	53.8	19.8	38.2	42	76	61	88	75	22
Hamlet	32.9	23.6	28.5	28.3	17	92	80	86	86	11
Collins	58.4	44.8	55.3	52.8	24	87	87	83	86	6
Maria Cristina	8.1	35.8	22.9	22.3	56	78	62	76	72	16
Sentry	13.4	23.0	15.5	17.3	39	81	81	69	77	14
Dixired	39.0	36.0	23.4	32.8	28	78	93	79	83	10
Botto	26.3	48.0	39.2	37.9	33	75	75	86	79	17
Maria Grazia	23.0	52.0	6.1	27.0	77	64	66	69	66	26
Redhaven	34.6	34.5	27.5	32.2	18	77	68	83	76	17
Maria Luisa	46.1	48.8	43.0	46.0	18	89	88	84	87	10
Triestina	43.4	47.6	38.2	43.1	17	86	86	74	82	11
Flavorcrest	31.1	35.5	9.8	25.4	51	89	89	78	86	13
Compact Redhaven	35.5	37.4	39.4	37.4	20	89	74	67	77	24
Redtop	27.7	46.5	23.9	32.7	42	86	60	77	74	20
Regina	30.8	44.3	19.2	31.4	39	51	63	49	54	28
Maria Bianca	43.2	49.1	36.1	42.8	22	69	60	85	71	23
Vesna	51.7	39.9	46.2	45.9	19	75	75	76	75	12
Emilia	29.8	35.7	8.7	24.7	52	80	80	69	76	16
Glohaven	44.8	51.0	29.5	41.8	32	85	83	80	83	13
Carolina Belle	43.3	47.0	44.5	44.9	13	78	78	58	71	19
Maria Rosa	32.7	38.1	16.2	29.0	41	76	76	80	78	10
Suncrest	53.0	61.1	34.7	49.6	29	90	52	63	68	28
Elegant Lady	20.5	33.4	23.2	25.7	30	94	94	62	83	22
Cresthaven	47.2	41.5	36.9	41.9	23	64	52	79	65	28
Early O' Henry	18.1	21.7	18.9	19.6	19	77	71	42	63	37
Sunprince	29.1	30.1	17.8	25.7	31	69	58	84	70	22
J.H. Hale	36.5	41.3	31.5	36.4	20	77	41	44	54	36
Padana	37.1	43.6	28.0	36.2	26	82	61	68	70	25
Aurelia	17.2	26.9	14.3	19.4	45	77	77	38	64	33
Fayette	33.7	39.8	17.0	30.2	38	81	52	39	57	35
Michelini	15.9	28.1	15.1	19.7	39	56	56	56	56	18
Maria Delizia	27.4	28.0	27.3	27.6	10	85	85	78	82	10
Autumnglo	65.1	70.4	31.3	55.6	38	84	71	70	75	20
Radmilovčanka	14.1	35.1	19.9	23.1	46	77	77	63	73	20
Fairtime	14.0	43.2	12.9	23.4	67	68	68	77	71	18
Summerset	18.6	21.0	6.6	15.4	51	68	70	43	60	34
Flaminia	32.9	40.0	34.2	35.7	11	60	60	55	58	16
Average	32.8	40.0	25.7	32.8	34	78	72	69	73	20
LSD (P = 0.05) cultivar				6.7					11	
LSD (P = 0.05) year				1.8					3	
LSD (P = 0.05) cultivar × year				11.6					20	

CV – coefficient of variation (the ratio of the standard deviation to the mean)

Table 3. Final fruit set and yield per 1 m of shoot length of peach cultivars by open pollination

Cultivar	Final fruit set (%)					Yield (kg/m of shoot length)				
	2003	2004	2005	average	*CV* (%)	2003	2004	2005	average	*CV* (%)
Goldcrest	69	37	50	52	34	0.5	0.7	0.2	0.5	63
Royal Gold	75	29	57	54	40	1.4	1.1	1.1	1.2	31
Springtime	74	71	58	68	19	1.8	2.7	1.5	2.0	32
May Crest	51	42	56	49	30	1.8	1.3	0.9	1.3	39
Hamlet	81	47	61	63	27	1.6	1.0	1.6	1.4	29
Collins	48	55	49	51	23	1.9	2.2	2.1	2.1	16
Maria Cristina	74	49	41	54	32	0.8	1.9	1.1	1.2	42
Sentry	34	40	45	40	15	0.7	1.8	1.2	1.2	51
Dixired	36	53	62	50	31	1.1	2.0	2.0	1.7	41
Botto	31	20	27	26	34	0.9	1.0	1.1	1.0	25
Maria Grazia	34	40	59	44	49	0.8	2.3	0.5	1.2	78
Redhaven	37	42	62	47	30	2.2	1.8	2.5	2.2	21
Maria Luisa	49	49	70	56	25	2.5	2.9	2.7	2.7	16
Triestina	45	31	34	37	38	1.4	2.0	1.4	1.6	42
Flavorcrest	38	33	41	38	24	1.8	1.9	0.7	1.5	51
Compact Redhaven	38	35	43	39	15	1.2	1.7	1.8	1.6	21
Redtop	60	23	30	38	45	2.5	1.7	1.1	1.8	45
Regina	34	54	25	38	41	1.3	3.3	0.7	1.8	68
Maria Bianca	37	41	45	41	32	2.7	3.7	2.5	3.0	44
Vesna	51	42	47	46	21	3.1	2.8	2.9	3.0	12
Emilia	38	25	53	39	34	2.0	1.4	0.7	1.4	45
Glohaven	55	46	50	51	26	2.5	2.9	2.0	2.5	29
Carolina Belle	51	29	38	39	30	2.1	2.3	2.5	2.3	17
Maria Rosa	34	48	60	47	41	1.1	2.7	1.3	1.7	49
Suncrest	62	38	38	46	33	2.8	3.3	1.9	2.7	28
Elegant Lady	38	47	30	39	30	1.0	2.5	1.2	1.6	49
Cresthaven	47	37	60	48	42	2.1	2.3	2.9	2.5	21
Early O' Henry	44	54	23	40	42	0.9	1.9	0.6	1.1	55
Sunprince	39	37	50	42	42	1.9	2.4	1.2	1.8	51
J.H. Hale	31	31	25	29	36	1.7	1.9	1.3	1.6	37
Padana	51	44	51	49	18	2.2	2.3	2.1	2.2	11
Aurelia	38	53	19	37	45	1.1	2.3	0.5	1.3	73
Fayette	28	20	32	27	42	0.7	1.6	0.9	1.0	46
Michelini	25	20	24	23	19	0.7	0.9	0.7	0.8	34
Maria Delizia	57	38	54	50	25	1.3	1.3	1.9	1.5	24
Autumnglo	33	21	39	31	43	2.6	3.3	2.2	2.7	22
Radmilovčanka	42	26	29	33	40	0.9	2.2	1.0	1.4	68
Fairtime	40	23	30	31	44	1.0	1.9	0.7	1.2	73
Summerset	32	34	14	27	45	0.9	1.2	0.2	0.7	66
Flaminia	28	32	25	28	37	0.9	2.0	1.3	1.4	49
Average	45	38	43	42	33	1.6	2.1	1.4	1.7	40
LSD (P = 0.05) cultivar				11					0.5	
LSD (P = 0.05) year				3					0.1	
LSD (P = 0.05) cultivar × year				19					0.8	

CV – coefficient of variation (the ratio of the standard deviation to the mean)

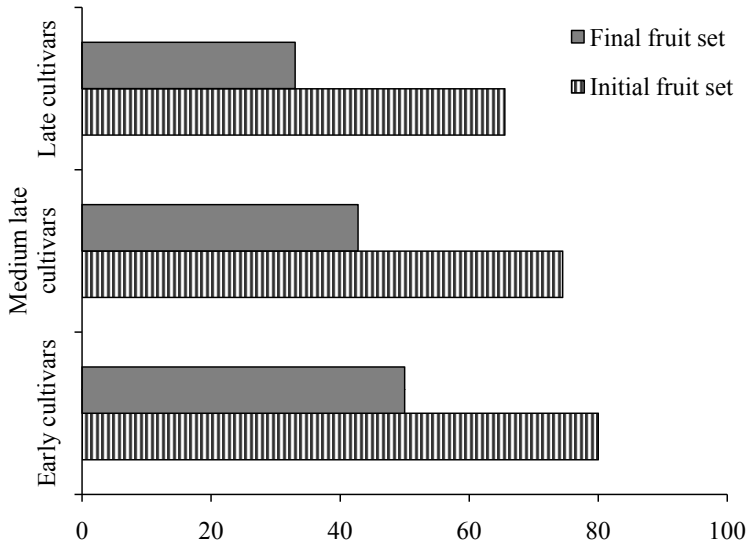

Fig. 1. Initial and final fruit set in peach cultivars by harvest time

crest, Summerset, Sentry, Aurelia, Early O' Henry, and in the white flesh cultivar Michelini.

Werner et al. (1988) studied the number of flower buds per node in 36 peach and nectarine cultivars and concluded that cultivars released from California breeding programs had fewer flower buds than those from Eastern U. S. programs. This indicates that in the Eastern USA more attention in peach breeding was paid to the selection of flower bud density because of a greater risk of freeze damage. Likewise, in our study cultivars originating from the Eastern USA (Autumnglo, Collins, Carolina Belle, Cresthaven, Glohaven) also had a large number of flowers per 1 m, while the cultivars with the lowest flower density (Goldcrest, Summerset, Early O' Henry) originated from California (Okie et al. 2008).

Cultivar, year, and cultivar × year effects on flower density were statistically very significant. Among years, the highest number of flowers per shoot unit length was in 2004, followed by 2003 with the lowest number occurring in 2005. One of the factors causing year-by-year variations could be the influence of low temperatures. In 2003, on April 9, the temperature of –5.5°C was recorded before the start of peach flowering, when most of the cultivars were at the "balloon" flower stage. In 2005, low temperatures were recorded in mid-February and early March (on February 10 the temperature of –19.0°C was registered, and on March 1 that of –18.8°C). Such low temperatures could damage flower buds of susceptible peach cultivars. Besides freeze damage, summer temperatures in the previous year can affect flower bud formation. Blind nodes develop more rapidly under higher temperature conditions and during periods of less tree growth (Boonprakob, Byrne 2003).

Szalay et al. (2000) report that frost resistance of peach flower buds was the highest in December when the LT_{50} (critical temperature which causes damage of 50% of flower buds) was around –20°C to –25°C, dropping constantly to the first half of March

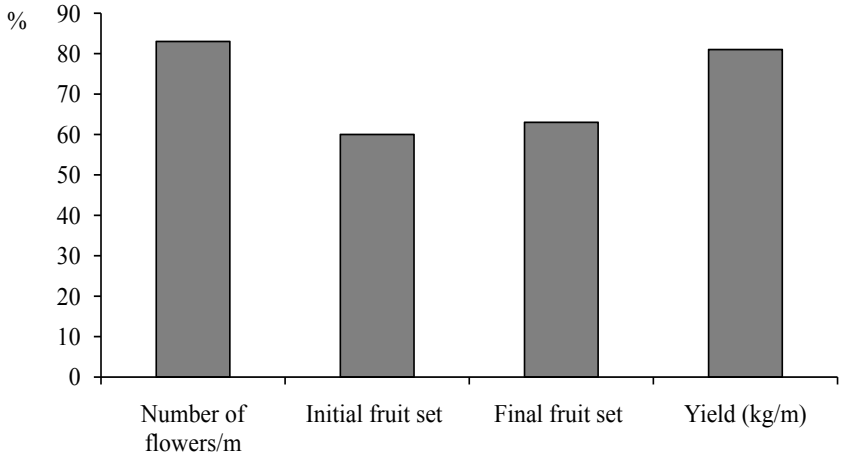

Fig. 2. Coefficients of hertability in the broad sense of investigated traits in peach cultivars (%)

Table 4. Correlation matrix among the variables studied

Trait	Number of flowers/m	Initial fruit set	Final fruit set	Yield (kg/m)
Number of flowers per 1 m	1.00	0.07	–0.01	0.68**
Initial fruit set	–	1.00	0.44**	0.16
Final fruit set	–	–	1.00	0.40**
Yield (kg/m)	–	–	–	1.00

Correlation significant at $^{*}P < 0{,}05$ and $^{**}P < 0{,}01$, respectively

when LT_{50} reached a level of about –15°C. However, if conditions for pollination and fertilization are favorable good yield can be achieved if 20–40% of flower buds are damaged, and a moderate yield if 50–80% flower buds are damaged (Szabó 2003).

Fruit set

Initial fruit set of peach cultivars tested was very high, with three-year average values from 54% to 87%, while the total range of variation was from 38% to 95%. Among years, initial fruit set was highest in 2003 and significantly lower in 2004 and 2005. This seasonal variability is mainly due to the weather conditions during the blooming period, which affect pollination, pollen tube growth and ovule longevity (Sanzol, Herrero 2001).

The average final fruit set ranged from 23% (Michelini) to 68% (Springtime), with the total variation from 14–81% (Table 3). In most cultivars the average final fruit set by open pollination ranged from 30% to 50%. In conditions of abundant flowering, to obtain good yield in peach, there is a need to achieve fruit set of 10–20% (Szabó et al. 2003). Therefore, it can be concluded that fruit set in all cultivars was satisfactory and that it is not a limiting factor for achieving high yield in the given environmental conditions. Final fruit set had greater variability (*CV* = 33%) compared to initial fruit set (*CV* = 20%).

Analysis of fruit set in peach cultivars based on the time of maturation (Fig. 1) indicates that both initial and final fruit set were the highest in the group of early-ripening peach cultivars, maturing before Redhaven. In the middle late-ripening cultivars, maturing between Redhaven and J.H. Hale, fruit set was medium, while the lowest values were recorded in late-ripening cultivars which mature after J.H. Hale.

Results obtained in this study are in accordance with the results of other authors. Mišić et al. (1977) found the average fruit set of 34% by open pollination in nine peach cultivars. In the environmental conditions of Hungary, peach fruit set by open pollination was 34% on average, and most cultivars had medium or high rate of fruit set, from 20% to 40% (Nyéki, Szabó 1996). Nyéki et al. (1998) found fruit set in the range of 14–83%, while Neamtu et al. (2009) in conditions of Romania achieved fruit set from 11% to 91%.

Yield

The average yield per 1 m length of one-year-old shoot ranged from 0.5 kg in cultivar Goldcrest to 3.0 kg in cultivars Maria Bianca and Vesna. Poor yield in some cultivars (Goldcrest, Michelini, Summerset) can be explained by their low flower density or lower fruit set. On the other hand, high-yielding cultivars had high flower density and fruit set. Among years, the highest yield was achieved in 2004, and it was significantly higher than the yields in 2003 and 2005. Lower yields in these two years were the result of freeze injuries of flower buds. The coefficient of variation for yield per 1 m length of shoot was significantly higher compared to other parameters studied (average *CV* was 40%). Cultivars that had high variation of this parameter (*CV* above 50%) were sensitive to the adverse effects of environmental factors, primarily to winter or late-spring low temperatures. Testing sensitivity of flower buds of peach cultivars to freeze injury, Szabó et al. (1998) found that cultivars Aurelia, Flavorcrest, Regina, and Sentry showed high sensitivity, while cultivars Cresthaven, Maria Bianca, and Suncrest showed low sensitivity, which is in accordance with our results.

Heritability

Relatively high heritability values, in broad sense, were found for flower density (83%) and yield (81%),

while the lower values were found for initial fruit set (60%) and final fruit set (63%) (Fig. 2). Contrary to our results, De Souza et al. (1998) reported lower heritability for flower density (h^2 = 0.41) and fruit set (h^2 = 0.43). For the initial and final fruit set Rakonjac (2005) found higher values of heritability (H^2 = 74% and H^2 = 82%, respectively), while the value for yield was lower (55%) compared to our results. Discrepancy in heritability values obtained in this work, compared to the values reported in literature, can be explained by the fact that heritability depends on many factors, such as the variability of a certain trait within the population, environmental conditions, a plan of the experiment and applied statistical procedure (Falconer 1989; Nyquist 1991). Also, some cultural practices (e.g. fruit thinning, previous crop load, nutrient, and water supply) can influence the productivity indicators of peach trees, especially yield. It can also affect the heritability estimation.

It must be however noted that broad sense heritability (H^2), that we studied, is of little use for breeders. The narrow sense heritability (h^2) is of greater importace; it is calculated as a ratio between the additive genetic variance (VA) and total phenotypic variance. Yet, heritability estimates presented in this study are valuable for suggesting potential of investigated cultivars to influence inheritance of studied traits in progeny.

Correlations

A significant correlation was found between initial and final fruit set (r = 0.44), flower density and yield (r = 0.68), as well as between final fruit set and yield (r = 0.40) (Table 4). The coefficients of correlation between other traits did not show statistical significance. Our results are in accordance with those reported by Peréz-González (1993) who found that flower density strongly correlated with fruit density (r = 0.78) and that correlation between flower density and fruit set was weak (r = 0.10). Rakonjac (2005) found significant correlation coefficients between initial and final fruit set and between initial fruit set and yield. The coefficient of correlation between flower density and fruit set (r = 0.24) reported by De Souza et al. (1998) was higher than the value determined in our work (r = 0.07).

Relatively high heritability values found for the studied traits indicate that they are mainly genetically determined. Taking into account that the yield significantly correlated with the flower density and final fruit set, selection for productivity in creating new peach cultivars can be made on the basis of these two properties.

In areas with a high risk of freeze damage the cultivars characterized by greater flower density, higher rate of fruit set and higher yield per 1 m length of shoot, and also by lower seasonal variability of these parameters should be grown. Such cultivars are as follows: early maturing cultivars Collins and Springtime, medium late cultivars: Maria Bianca, Vesna, Maria Luisa, Suncrest, Glohaven, Cresthaven, Carolina Belle, and Redhaven, and late cultivars Autumnglo and Padana. Cultivation of these cultivars can provide higher and more regular yields. On the other hand, these cultivars require more intensive pruning and fruit thinning to achieve quality fruit. Cultivars characterized by lower flower density and higher sensitivity to low temperatures should be cultivated only in warmer areas. These are the following cultivars: early maturing cultivars Goldcrest, Sentry, Maria Cristina, and Maria Grazia, medium late cultivars Flavorcrest, Regina, Emilia, Early O' Henry, and Sunprince and late cultivars Summerset, Fairtime, Aurelia, and Radmilovčanka. The advantage of these cultivars is that they require less labor for fruit thinning.

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