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RESEARCH ARTICLE

Performance and genotypic variability of late ripening vineyard peach

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Abstract Vineyard peach can significantly contribute to the improvement of the most economically important traits of peach cultivars grown today. Thanks to unique and specific taste and aroma vineyard peach fruits are suitable for processing and fresh consumption. Additionally, vineyard peaches are a rich source of various essential elements and might be considered an important dietary mineral supplementation. The study was carried out at the Experimental Station Radmilovac of the Faculty of Agriculture in Belgrade. From the vineyard peach germplasm collection containing more than 100 genotypes, 15 genotypes were selected based on the late ripening, fruit weight and quality. The examined genotypes had ripening time after September 15th, high soluble solids (17.4–23%), and sugar (13.4–17.3%) content. Regarding fruit weight genotypes II/17, III/7 and IV/18 (92.5 g, 87.1 g, and 77.9 g respectively) stood out, and in terms of total organoleptic score III/7, IV/17 and IV/18 (17.0, 17.2, and 17.0 respectively) were distinguished. Hence, these genotypes are the most promising for fresh consumption. The observed divergences of fruit characteristics demonstrated the genetic potential of these genotypes to improve peach late-ripening assortment.

Keywords *Prunus persica spp. vulgaris* Mill. · Genetic resources · Late ripening · Fruit weight · Chemical composition · Fresh consumption

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Introduction

Peach (*Prunus persica* (L) Batsch.) is one of the most economically important fruit crops, originating from East and South-East Asia. In 2022, the world production was 26.4 million tons (https://www.fao.org/faostat/en/#data/QCL), while the Republic of Serbia contributed over 45 thousand tons in this total. However, peach production in Europe has shown a decreasing trend in the last decade (Baccichet et al. 2021) due to

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the overall low fruit quality of commercialized cultivars (Etienne et al. 2002) with poor taste or lack of the characteristic "peach" aroma (Cirilli et al. 2016).

Peach cultivars are mostly used for fresh consumption, but also in the food processing industry. Aside from the economic importance of the production and processing industry, the peach breeding industry is also important, and one of the most dynamic (Reig et al. 2013), with over 6.000 commercial peach and nectarine cultivars worldwide (Nikolić et al. 2016). Environmentally well-adapted and disease-resistant cultivars with high yield and quality, attractive fruits suitable for storage and transport are the main goal of the peach breeding industry (Radović et al. 2020). Additionally, very early or very late ripening genotypes that have higher market prices are of particular interest in selection (Raseira et al. 2018). In modern peach breeding programs, great attention is given to the quality and attractiveness of the fruit (Rakonjac 2006). Fruit's external attributes play a crucial role in the definition of quality market standards. Size, color, shape, and absence of defects directly affect consumer's preferences and acceptance (Cirilli 2021). Also, several breeding programs focused on the enhancement of fruit internal quality to meet consumers' expectations (Cirilli et al. 2016).

In recent years, many efforts have been made to develop new cultivars (Moreno 2005; Cantín et al. 2010). Peaches and nectarines have the highest number of new cultivars released every year by intensive breeding programs worldwide (Iglesias and Echeverría 2021). However, the limited genetic variability of existing genetic sources has always been a major constraint in peach selection and breeding (Rakonjac 2006). Also, due to the limited number of genotypes that have been used as parents in breeding, new peach cultivars have a low level of genetic variability (Trifonova et al. 2021), and it becomes important to describe and use alternate genetic resources that may contribute to genetic improvement of this species (Bakić et al. 2016). As Manganaris et al. (2022) pointed out, there is an urgent need to develop solutions that can leverage the exceptional peach diversity and flavor potential that already exists in the varietal landscape to advance peach fruit production and consumption.

Local peach germplasms could be a basis for the improvement of the assortment of this species. One of them is the vineyard peach (*Prunus persica spp. vulgaris* Mill.), an indigenous peach population cultivated or grown spontaneously in Serbia (Rakonjac et al. 2011). Vineyard peach can significantly contribute to the improvement of the most economically important traits of peach cultivars and rootstocks grown today. Thanks to unique and specific taste and aroma (Nikolić et al. 2010; Janick 2011) vineyard peach fruits are suitable for processing and fresh consumption. Additionally, Serbian vineyard peaches are a rich source of various essential elements and might be considered an important dietary mineral supplementation (Mitić et al. 2013). Unfortunately, due to the much smaller fruits than commercial cultivars (Zec et al. 2000) vineyard peaches are invisible on the market. The selection of vineyard peach genotypes for fresh consumption was carried out by numerous authors (Nikolić et al. 2005; Vasilev et al. 2019). However, despite such intensive breeding work, there is a lack of registered vineyard peaches not just for fresh consumption but also for various purposes. Moreover, vineyard peaches show a wide range of fruit types and some valuable horticultural traits (cold resistance, drought tolerance, disease resistance e.g. to powdery mildew and leaf curl), so far they have been scarcely used in breeding programs (Okie et al. 2008). Thanks to its resistance to abiotic and biotic factors, the vineyard peach could be suitable for organic production.

This study aimed to investigate the fruit quality of 15 late-ripening vineyard peach genotypes that could be recommended for table consumption or peach breeding.

Material and methods

The study was carried out at the Experimental Station Radmilovac of the Faculty of Agriculture in Belgrade (44°45′N and 20°35′E, at 135 m altitude). The ex-situ vineyard peach germplasm collection was established in 2009 with seedlings derived from various types originating from different regions of Serbia. All collected genotypes in situ showed high resistance to leaf curl and powdery mildew. The trees were planted at 4.5 × 2 m and trained to an open vase. Each tree represented a genetically unique accession. The trees were managed using standard cultural practices, with minimal pruning and thinning to allow the expression of natural growth. The collection is an integral part of the production orchard, so standard procedures for disease and pest management were carried out. After phenotypic evaluation and analysis, 15 vineyard peach genotypes from this collection were selected, based on late ripening time (after September 15), pomological characteristics, and fruit quality, and used as material in this research.

Evaluation of eleven qualitative (Table 1) and thirteen quantitative fruit traits was carried out in 2013 and 2014. Fruit quality was determined based on the size, chemical composition, qualitative characteristics, and organoleptic properties. Qualitative traits—fruit shape, fruit ground colour, fruit over colour, extent of fruit over colour, flesh colour, anthocyanin coloration of flesh, flesh fibre and flesh to stone adherence were evaluated according to the European Cooperative Programme for Plant Genetic Resources (ECPGR) priority descriptors for peach (Giovannini et al. 2013). Fruit thickness of skin, fruit density of pubescence, and stone tendency of splitting were evaluated according to the UPOV (1995) descriptor for peach. The starting date of harvest was the beginning of fruit ripening (FR). The fruit development period (FDP) was expressed as days from full bloom to ripening date. To evaluate fruit traits, 30 fruits per genotype were randomly sampled at the stage of eating maturity. Fruit weight (FW) and stone weight were measured using a digital balance, while flesh ratio (FlR) was calculated as the ratio between fruit and stone weight and expressed as a percentage. Soluble solids (SS) content was determined by refractometer (Atago, pocket PAL-1) and total sugar (TS) content using the Luff- Schoorl method (Egan et al., 1981). Titratable acidity (TA) was measured by neutralization to pH 7.0 with 0.1N NaOH, and data are given as g/l of malic acid equivalent. Sweetness index (SI) was calculated as the ratio between total sugar content and titratable acidity. Fruit juice acidity (pH) was determined by Jenco 6173 ph meter. The organoleptic evaluation of fruits, including appearance (A), firmness (F), taste (T) and aroma (Ar) were determined by five panelists. For appearance and firmness sensory score from 0 (lowest grade) to 6 (highest grade) was used, whereas for taste and aroma the scale was from 0 (lowest grade) to 4 (highest grade) was used. In the organoleptic evaluation of vineyard peach genotypes, there were no comparisons with reference peach cultivars.

Data were statistically analyzed using two factorial analyses of variance (ANOVA). The significance of differences between the mean values was performed using the LSD test for $P \leq 0.05$. Ward's method as an agglomeration rule and the Euclidean distance as a measure of dissimilarity was carried out to classify genotypes into homogenous groups by cluster analysis (CA). To avoid the effects due to scale differences, the mean of each character was normalized before CA using Z scores. Statistical analyses were done with Statistica for Windows, version 8.0 (StatSoft Inc., Tulsa, OK).

Table 1 List of qualitative traits studied

Trait	Abbreviation	Code
Fruit shape	FS	5-round; 7-ovate,
Fruit ground colour	FGC	3-cream green; 5-cream; 7-greenish yellow; 9-yellow
Fruit over colour	FOC	1-absent; 2-orange red
Extent of fruit over colour	EFOC	1–0%; 2–10–15%
Flesh colour	FlC	3-cream white; 4-greenish yellow; 5-light yellow; 6-yellow; 7-orange yellow; 8-orange
Anthocyanin coloration of flesh	ACF	1-absent; 2-weak
Flesh fibre	FlF	1-absent or weak, 2-moderate, 3-strong
Flesh to stone adherence	FSA	1-freestone
Fruit thickness of skin	FTS	3-thin; 5-medium; 7-thick
Fruit density of pubescence	FD	3-sparse; 5-medium; 7-dense
Stone tendency of splitting	STS	1-absent or very low

Results and discussion

Table 2 shows a high level of morphological variation obtained for qualitative and quantitative fruit traits of studied genotypes that is in accordance with previous results of Bakić et al. (2016). FS is very important for consumer acceptance and post-harvest handling. Round shapes of the fruit, without protruding tips are preferred (Cantín et al. 2010). Among studied vineyard peach genotypes, the round shape of the fruit was the most present (Table 2). FGC and FOC are very important traits for the market, because consumers associate an intense fruit colour with better quality (Byrne et al. 2011). Our results showed that FGC varied from cream green to yellow that is in accordance with the results of numerous authors (Nikolić et al. 2010; Zec et al. 2000; Milošević and Milošević 2010; Vasilev et al. 2019) who stated that cream, cream-yellow, yellow and cream-green ground skin color was typical among vineyard peach genotypes. Low (10–15%) presence of orange-red over coloration or its total absence on the fruit skin confirms previous statements of Nikolić et al. (2010), Zec et al. (2000) and Vasilev et al. (2019).

The FlC with all six grades showed highest variation of all descriptive traits. It varied from dominant cream white to orange flesh colour. Previous investigations observed yellow (Nikolić et al. 2010) and white (Zec et al. 2000; Milošević and Milošević 2010) flesh colour as most present. Contrary to Zec et al. (2000) who found the presence of anthocyanins in the mesocarp and around the stone in 50% of the studied vineyard peach genotypes, in our sample we didn't observe it in the majority of the genotypes. Within the examined genotypes, fruits with moderately and strongly present FlF dominated. Regarding FSA, all genotypes had freestone type of fruits, which is following the findings of Nikolić et al. (2005). Most of the genotypes had medium and thick FTS, 53% and 40% respectively. Regarding FD, all genotypes had pubescent skin, 6 of them had sparse, 8 medium, and only one had dense pubescence. According to Nikolić et al. (2010), very dense pubescence is dominantly present in vineyard peaches. When it comes to STS, all tested genotypes had the absence of defects such as split-pit, which was expected, given that it appears quite often in the early ripening cultivars (Liverani et al. 2002).

Table 2 Qualitative and quantitative characteristics of vineyard peach genotypes (average 2013–2014.)

Genotype	FS[a]	FGC	FOC	EFOC	FlC	ACF	FlF	FSA	FTS	FD	STS	RT	FDP	FW	FlR
II/13	5	9	2	2	5	2	2	1	5	3	1	26-Sep	184a	64.3a–d	90.6bc
II/17	5	7	2	2	4	2	3	1	5	3	1	21-Sep	178bc	92.5a	93.1ab
II/18	5	5	1	1	5	1	2	1	7	3	1	20-Sep	178bc	43.7d	91.8a–c
II/20	5	9	2	2	5	2	2	1	7	3	1	26-Sep	185a	60.2b-d	88.4c
II/21	7	9	2	2	6	2	2	1	7	5	1	24-Sep	180a-c	49.3 cd	88.9c
II/22	5	9	2	2	8	1	2	1	7	7	1	25-Sep	182ab	49.2 cd	90.2bc
II/24	5	3	1	1	3	1	3	1	9	5	1	19-Sep	177b-d	45.4d	88.7c
III/4	5	3	1	1	4	1	3	1	5	5	1	20-Sep	176 cd	71.9a-d	94.3a
III/7	5	9	1	1	7	1	3	1	7	5	1	22-Sep	178bc	87.1ab	93.0ab
IV/11	5	3	1	1	3	1	3	1	5	5	1	19-Sep	176 cd	71.3a-d	94.3a
IV/13	7	3	1	1	3	1	3	1	7	3	1	24-Sep	182ab	70.0a-d	94.0ab
IV/14	5	3	1	1	3	1	3	1	5	5	1	24-Sep	181a-c	63.5b-d	92.6ab
IV/16	7	3	1	1	3	1	3	1	7	5	1	24-Sep	180a-c	65.2b-d	93.2ab
IV/17	5	3	1	1	3	1	2	1	7	3	1	22-Sep	177b-d	75.3a-c	93.5ab
IV/18	5	3	1	1	3	1	1	1	5	5	1	18-Sep	172d	77.9a-c	94.7a
2013												–	168B	46.7B	90.2B
2014												–	189A	84.9A	94.0A

[a]For an explanation of traits and code symbols, see Table 1

Mean values followed by small different letters within a column are significantly different between genotypes by LSD test at $P \leq 0.05$

Mean values followed by capital different letters within a column are significantly different between years by LSD test at $P \leq 0.05$

According to Radović et al. (2020) most commercial peach and nectarine cultivars have early-medium and late-medium ripening times, achieving moderate prices on the market, despite their quality. On the other hand, very early ripening cultivars, with poor quality, target higher market prices. Also, late and very late ripening peach cultivars are very attractive on the market in spite short storage life (Bassi et al. 2016). According to the same author, late ripening peach cultivars have better taste and aroma. In Serbia agroclimatic conditions vineyard peaches ripen from the beginning of August to the beginning of October (Nikolić et al. 2005). Peach genotypes, analyzed in our study, were with late ripening time (Table 2), from September 18 (genotype IV/18) to September 26 (genotypes II/13 and II/20) which was much later than most commercially grown cultivars. This makes those genotypes interesting for breeding programs with the aim of creating late-maturing peach table cultivars. In vineyard peach, FDP is a highly variable trait (Nikolić et al. 2010), strongly dependable on the genotype with the range from 146 to 179 days (Bakić et al. 2017). In the present work, FDP ranged from 172 to 185 days (Table 2). This trait was highly dependable on the genotype, and there were estimated significant differences among studied genotypes. Genotypes II/13 and II/20 had significantly longer, while genotype II/18 had significantly shorter FDP than other genotypes.

Fruit weight is an important parameter that has priority in selection for fresh consumption, and is in the positive correlation with harvesting date (López and DeJong 2007). Vineyard peach fruits are classified as very small to small (Zec et al. 2000), rarely exceeding 100 g, so fruits over 60 g can be considered as large (Milošević and Milošević 2010). Our results showed that FW varied from 43.7 g (genotype II/18) to 92.5 g (genotype II/17). Among examined genotypes there were significant differences in FW (Table 2). Genotypes II/18 and II/24 had significantly lower and genotype II/17 significantly higher FW than other genotypes. Also, considerable differences were also observed concerning FlR (varying from 88.4 to 94.7%).

From the aspect of chemical composition, the content of soluble solids is the main factor determining the quality and flavor of fruits (Feng et al. 2024). For a long time, it has been well known that high SS in peaches is associated with high consumer acceptance, and by the time minimal content of 10–11% SS has been imposed as part of a quality peach standard. According to Nikolić et al. (2010) in vineyard peaches, this parameter is in positive correlation with ripening time, varying from 11.25 to 18.65%. In relation to these results, the examined vineyard peach genotypes were characterized by higher SS content (Table 3). The content of SS over 20% was found in genotypes II/20, II/21 and IV/13, (23.0%, 21.4%, 21.0%, respectively), and the lowest in genotypes IV/14 and IV/18 (17.4%). Sugar content value may reach up to 20% or more, although the average values found in commercial peach cultivars range from 9 to 15% (Crisosto et al. 1998). The content of TS in vineyard genotypes studied, ranging from 13.4% (genotypes IV/14 and IV/18) to 17.3% (genotype II/20), was higher compared to the results obtained by Nikolić et al. (2010), ranged from 7.13 to 11.08%.

In addition to the content of SS and TS, the content of TA is an important parameter of peach fruit quality. Some even believe that acids are directly responsible for consumers' liking degree (Baccichet et al. 2021). Also, the quality of the peach fruit depends on the relative concentration of each of the organic acids present, since they differ in taste (Rakonjac 2006). Recent research detected at least ten acids in peach fruits of which malate and citrate contribute most to the total peach acidity (Baccichet et al. 2021). Fruit acidity is mainly under genetic control (Cantín et al. 2010), while orchard management practices (rootstock, fertilization, irrigation, and others) have a very small effect. The lowest content of TA had genotype III/7 (4.4%), and the highest genotype II /20 (10.5%). According to Bassi and Selli (1990) for the determination of peach eating quality, SI is a better criterion than TA or TS, individually. In our study, SI ranged from 2.2 (genotype II/20) to 4.1 (genotype III/7). Among the examined genotypes, there were significant differences in SI. Based on fruit pH, analyzed genotypes may be classified as acid or low-acid. Within this group, two of them (II/21 and II/22) had both pH > 4.0 and SS > 20% and could be considered 'sweet' peaches, which are much more appreciated in the modern market and recent breeding programs.

Consumer preferences play a vital role in determining fruit quality, as they primarily base their judgments on appearance and taste. This highlights the importance of breeding and growing cultivars that meet consumer expectations for both appearance and

Table 3 Chemical compounds and organoleptic properties of vineyard peach genotypes (average 2013–2014.)

Genotype	SS	TA (g/l)	TS	SI	pH	A	F	T	Ar	Total
II/13	20.8ab	7.4b	15.8ab	2.8bc	3.6	3.5bc	2.8ab	4.7b-d	3.0a-d	14.0b-e
II/17	19.9b-d	5.8bc	15.6ab	3.4a-c	4.01	4.2a-c	2.7ab	3.8d	3.5a-c	14.1b-e
II/18	20.3bc	5.5bc	15.8ab	3.7ab	3.98	3.7bc	3.5a	2.5e	2.0d	11.7de
II/20	23.0a	10.5a	17.3a	2.2c	3.69	1.8d	2.7ab	4.2 cd	2.8a-d	11.5e
II/21	21.4ab	7.4b	16.5ab	3.1a-c	4.09	5.3a	3.2ab	4.8b-d	2.7b-d	16.0ab
II/22	20.3bc	6.1bc	15.8ab	3.4a-c	4.13	4.5a-c	2.8ab	3.9d	2.8a-d	14.1b-e
II/24	19.5b-e	5.8bc	15.0bc	3.6ab	3.85	4.0a-c	3.2ab	3.8d	3.2a-d	14.1b-e
III/4	19.8b-d	7.4b	15.8ab	2.7bc	4.02	4.0a-c	2.5ab	4.2 cd	2.8a-d	13.5c-e
III/7	17.8de	4.4c	14.1c	4.1a	4.1	4.8ab	2.3b	5.8ab	4.0a	17.0a
IV/11	18.3c-e	7.0b	14.5bc	2.6bc	3.86	4.6ab	2.2b	4.3 cd	3.7ab	14.7a-c
IV/13	21.0ab	7.4b	16.2ab	2.9a-c	3.85	4.8ab	2.8ab	4.3 cd	2.3 cd	14.3b-d
IV/14	17.4e	7.3b	13.4c	2.4c	3.69	4.3a-c	3.0ab	5.3a-c	3.5a-c	16.2ab
IV/16	20.9ab	7.0b	16.5ab	3.1a-c	3.87	3.0 cd	3.0ab	4.8b-d	3.2a-d	14.0b-e
IV/17	19.8b-d	5.8bc	15.5ab	3.5ab	4.16	4.8ab	3.0ab	5.5ab	3.8ab	17.2a
IV/18	17.4e	5.6bc	13.4c	3.2a-c	4.28	4.8ab	2.2b	6.0a	4.0a	17.0a
2013	20.1	6.1B	15.7	3.4A	4.06	3.9	2.9	4.4	2.9	14.1
2014	19.6	7.2A	15.1	2.8B	3.82	4.4	2.7	4.7	3.4	15.1

Mean values followed by small different letters within a column are significantly different between genotypes by LSD test at $P \leq 0.05$

Mean values followed by capital different letters within a column are significantly different between years by LSD test at $P \leq 0.05$

sensory attributes. Taste, aroma, texture and appearance are generally considered to be among the most important sensory attributes (Colaric et al. 2005).

Fruit taste is determined by non-volatile compounds (sugars, acids) contributing to fruit sweetness and acidity, and volatile compounds determining fruit aroma (Klee and Tieman 2018). So far 100 aroma volatile compounds have been identified in peach fruit (Farcuh and Hopfer 2023) that determine flavor differences among peach cultivars (Wanpeng et al. 2017). Vineyard peach fruits are characterized by a specific taste and aroma, which makes them unique within the peach germplasm.

Rakonjac et al. (2011) stated that organoleptic evaluation of vineyard peach fruits is not always correlated with the chemical composition. Therefore, it is very important to evaluate the organoleptic properties of the fruit to define the quality of the peach fruit as completely as possible in addition to determining the chemical content of the fruit. Regarding the appearance of the fruit, genotype II/21 (grade 5.3) was distinguished, as well as genotypes III/7, IV/13, IV/17 and IV/18 (grade 4.8) (Table 3). The firmness fruits had genotype II/18 (grade 3.5). The firmness is not only important from the aspect of better storage and transportability of the fruits, but it is also important since the harvesting of genotypes with firm flesh can be organized in slightly later stage of ripening. The highest scores for fruit taste and aroma got genotypes IV/18 (6.0 and 4.0, respectively) and III/7 (5.8 and 4.0, respectively). Taking into account all the parameters, the highest overall fruit organoleptic score was achieved by genotypes IV/17 (score 17.2), III/7 and IV/18 (both score 17.0). For all organoleptic properties of the fruit, differences between genotypes were significant, while there were no significant differences between years which indicates that these traits are highly dependable on the genotype.

Cluster analysis

Cluster analysis was often applied to classify the genotypes into homogenous groups (Nikolić et al. 2010; Bakić et al. 2017; Muradoglu and Kayakeser 2022; Alqahtani et al. 2024). In our study cluster analysis revealed a dendrogram that separated the studied vineyard genotypes into three main clusters (Fig. 1).

Clusters I and III comprised six, while Cluster II had three genotypes. The observed divergences of fruit characteristics demonstrated the genetic potential of these genotypes to improve peach germplasm. Cluster I genotypes were characterized by moderate FW (68.1 g, on average), SS content (19.5%), TS content (15.3%), and total score (15 on average) for organoleptic evaluation. Genotypes in Cluster II showed the shortest FDP (173.5 days on average),

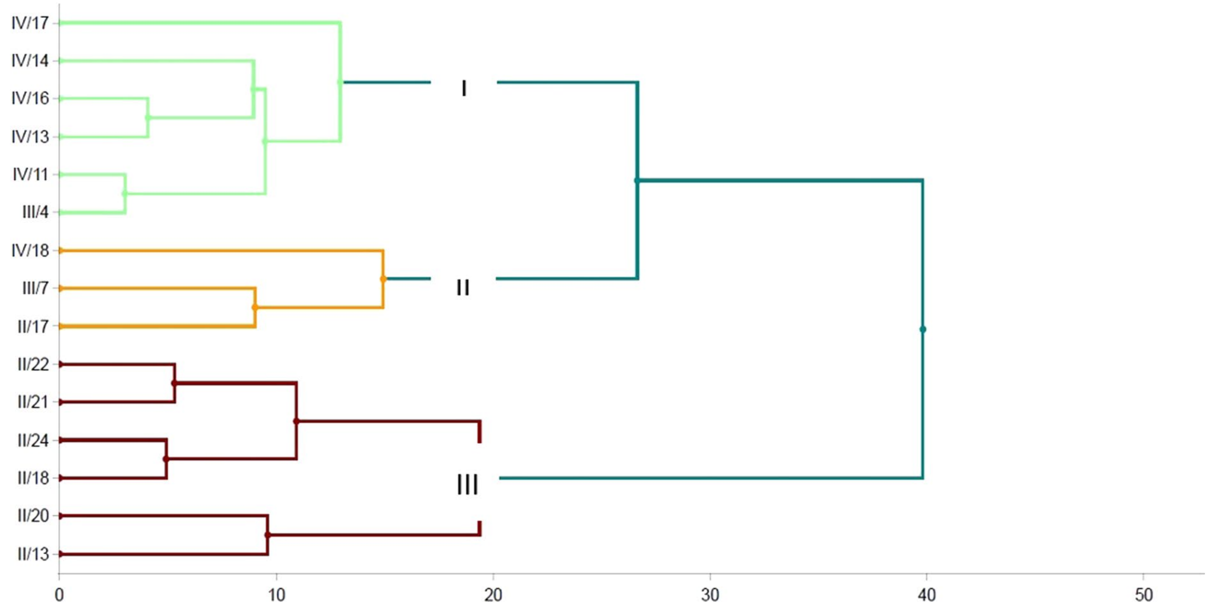

Fig. 1 Hierarchical cluster analysis dendrogram obtained by Ward's method of 15 vineyard peach genotypes

largest FW (84.2 g, on average), SI (3.5 on average), and total organoleptic score (average score 16), and the lowest SS content (18.3% on average), TA (0.5 on average) and TS content (14.3 on average) among all genotypes. On the other hand, genotypes in Cluster III were grouped by longest FDP (177.8 days on average), lowest FW (48.1 g on average), FlR (90% on average), and fruit attractiveness (13.6 on average), and the highest SS content (20.9% on average), TA (0.71 on average) and TS content (16%) among all genotypes.

Conclusion

For most studied traits genotypes showed high variability, which was highly pronounced within descriptive traits such as fruit ground colour and flesh colour. Regarding quantitative traits, the greatest variation was recorded in fruit weight, sweetness index, fruit taste and fruit flavour. For practical application, genotypes from Cluster I and II were superior in terms of fruit quality. Based on fruit weight, and organoleptic properties, especially aroma and taste, the genotypes II/17, III/7, IV/17 and IV/18 stood out. They are good candidates for release as new late ripening peach cultivars. They can also serve as valuable material for use in future breeding work.

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by IB, VR and SČ. The first draft of the manuscript was written by IB and VR and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no financial or other competing conflicts of interest.

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