Assessment of variability of productivity traits and biochemical composition of apple tree varieties and forms, selection of the Orenburg branch of the federal state budgetary scientific institution federal research center of horticulture

Olga Merezhko*, and *Evgenia* Aminova

Orenburg Branch of FGBNU FNTs Gardening, Orenburg, Russia

Abstract. Currently, new varieties are subject to strict requirements for adaptability, productivity, commercial and consumer qualities of fruits. In this regard, it is important to study the interaction of the genotype of apple tree varieties and forms with climatic conditions, and it is also necessary to assess the genotypic variability of economically valuable traits focused on identifying genotypes characterized by stability of fruit quality in growing conditions. The study examined 12 varieties and forms of apple tree, selected by the Orenburg branch of the FGBNU FNTs of Horticulture. The following signs were studied: useful ovary (%), number of fruits (pcs.), average fruit weight (g), productivity (kg/d), sugar content in fruits, soluble solids, ascorbic acid, determination of titrable acidity. The study used mathematical models of two-factor variance and cluster analysis by the Ward method. Statistically significant differences were observed in the number of fruits between the first and third, and second and third clusters ($t = 4.01$ and 4.35, at $p<0.01$, respectively), as well as productivity between the first and third clusters ($t = 9.19$ at $p<0.01$), second and third ($t = 8.7$ at $p<0.01$).

1 Introduction

The main trend in the development of modern world horticulture is the creation of intensive and super-intensive gardens (varieties should have restrained growth, compact crown, early maturity, high annual yield with good commercial qualities) [1-3].

The variety model should consider the presence of biological features that allow to resist limiting environmental factors (high winter hardiness of trees, ability to withstand temperatures up to 45 ^{0}C, drought, diseases, etc.), to use fully the genetic potential of yield and fruit quality [4, 5].

* Corresponding author: merejcko.olga@yandex.ru

The genotype – environment interaction often hinders the determination of the best genotypes in different growing conditions. The process of plant development formation, manifested by the norm of the genotype response to soil and climatic conditions, is different and varies depending on the variety. Therefore, research works on the study of the reaction rate of apple tree varieties and forms in various ecological and geographical conditions are relevant at the present time [6-8].

It is known from literature sources that if a variety retains a high stable productivity in one region, then it has a specific adaptation. At the same time, general adaptation means that the variety has high productivity in different regions and has an extensive growing area. Varieties of this type react poorly to environmental changes and retain the main varietal traits, stable yield with typical fruit quality, despite the deterioration of cultivation conditions [9].

For decades, special attention has been paid to the study of selected apple tree forms with high indicators of valuable biochemical qualities of fruits to select the best sources for breeding.

As a result, the modern assortment of the Orenburg region is represented by winter-hardy large-fruited apple tree varieties, many of which compete with the best varieties of more southern regions in terms of fruit quality: Krasa Sverdlovska, Persiyanka, Sverdlovchanin, Ekrannoye, etc.

The purpose of the study is to evaluate the genotype–year interaction on the variability of productivity traits, the biochemical composition of fruits, and the determination of apple tree varieties and forms with a stable genotype in the conditions of the Orenburg region.

2 Materials and Methods

The paper uses data obtained in 2017, 2019–2021 based on the Orenburg branch of the FGBNU FNTs of Horticulture, located in typical soil and climatic conditions characteristic of the Orenburg region. Orenburg region has a sharply continental climate, with unstable hot, dry summers and harsh dry winters.

The object of the study was 12 apple tree varieties and forms bred by the Orenburg branch of the FGBNU FNTs of Horticulture: Orenburgskoye, Orskoye, Orenburgskoye pozdneye, Arkaim, Trudovoye, Khrustalniy bashmachok, 7-1, 2-1, 1-13, 4-10, 1-31, 18-31. When cultivating varieties and forms in collections, a planting scheme of 5.0 x 3.0 m was used.

Observations and records were carried out according to the Program and Methodology of variety study of fruit, berry, and nut crops generally accepted in the Russian Federation (1999). The following traits were studied: useful ovary (%), number of fruits (pcs.), average fruit weight (g), productivity (kg/d), sugar content in fruits (GOST 15113.6-77), soluble solids (GOST ISO 2173-2013), ascorbic acid (by high-performance liquid chromatography, GOST 24556-89), determination of titrated acidity (GOST ISO 750-2013). For mathematical processing of experimental data on productivity components and biochemical parameters of fruits, the method of two-factor variance analysis without repetition was used using the Microsoft Office Excel 10 analysis package, where A is variety, B is year, and Ward cluster analysis using the Statistica 10 software package.

3 Results and Discussions

In the conditions of the experimental site of the Orenburg branch of the FGBNU FNTs of Horticulture for 2017, 2019-2021, significant differences in all traits were revealed between the studied varieties at a 5% significance level.

The results of two-factor analysis of variance by factor A – "grade", the obtained values of F are marked 1.53 - 77.13 with the standard value of the Fisher criterion Fst. 1.96; by factor B - "year" – 0.15 – 120.71 with the standard Fst. - 2.38; by the variety-year interaction – 1.28-9.63 with the standard Fst. – 1.31.

The realization of traits of productivity and quality of fruits of apple tree varieties and forms, expressed by the norm of the genotype response to climatic conditions, is different and varies depending on the variety. Consequently, the study of the reaction rate in different cultivation years seems to be the next step in establishing the genetically determined stability and adaptability of the traits of apple tree varieties and forms. Dispersion analysis of apple tree varieties and forms revealed that the variety genotype has the greatest effect on ascorbic acid (93.0%) sugar (78.0%), soluble solids (79%), average fruit weight (57%), and the minimum – on the useful ovary (7.0%) and productivity (3.0%). At the same time, the effect of the growing year conditions strongly influenced the useful ovary (87.0%), number of fruits (52.0%), and productivity (89.0%) (Table 1).

Table 1. Interaction of variety and year factors according to the characteristics of apple tree.

Traits	**Correlation, %**		
	variety (A)	year (B)	tolerance
Useful ovary	7	**87**	6
Number of fruits	27	**52**	21
Average fruit weight	**57**	21	20
Productivity from the tree	3	**89**	8
Sugars	**78**	13	9
Soluble solids	**79**	14	7
Ascorbic acid	**93**	2	5
Acidity	49	20	31

According to the obtained average annual values of eight traits – useful ovary, number of fruits, average fruit weight, productivity, sugar content, soluble solids, acidity, and ascorbic acid – we obtained an informative set of traits for each sample, analyzed using cluster analysis by the Ward method (Fig. 1). This method groups objects according to the criterion of maximum intergroup and minimum intraspecific variance. Therefore, this approach will make it possible to identify the most different groups.

The clustering results show that three groups of varieties and forms are distinguished at the level of 20 units (in the first - 22 samples, in the second – 13, and in the third – 13). The average values of the characteristics for each of the selected groups of varieties and forms (Table 2) were subjected to a pair comparison using the Student's t–test. It was revealed that the values of sugars, soluble solids, ascorbic acid, and acidity have no statistically significant differences between the clusters.

The useful ovary trait differs between the second and third clusters ($t = 8.69$ at $p<0.01$), between the first and third clusters ($t = 10.17$ at $p<0.01$), there are no significant differences between the second and first clusters.

The number of fruits differed between the first and third, and second and third clusters ($t = 4.01$ and 4.35, at $p<0.01$, respectively). There were statistically significant differences in productivity between the first and third clusters ($t = 9.19$ at $p<0.01$), the second and third ($t = 8.7$ at $p<0.01$).

The third cluster included apple tree varieties and forms with the highest productivity: Orskoye 36.7 kg from a tree, Arkaim 36.8 kg from a tree, and 7-1 - 38.5 kg from a tree (Table 2). The varieties included in the first cluster had average productivity: Trudovoye (2020) 25.5 kg from a tree, 18-31 - 25.0 kg from a tree (2020), Orenburgskoye (2020) 24.1

kg from a tree. The lowest productivity was shown by varieties and forms from the first cluster: Khrustalniy bashmachok (2021) 18.7 kg from a tree, 2-1 – (2019) 17.9 kg from a tree, Orskoye (2019) 19.5 kg from a tree, 7-1 (2021) 19.2 kg from a tree.

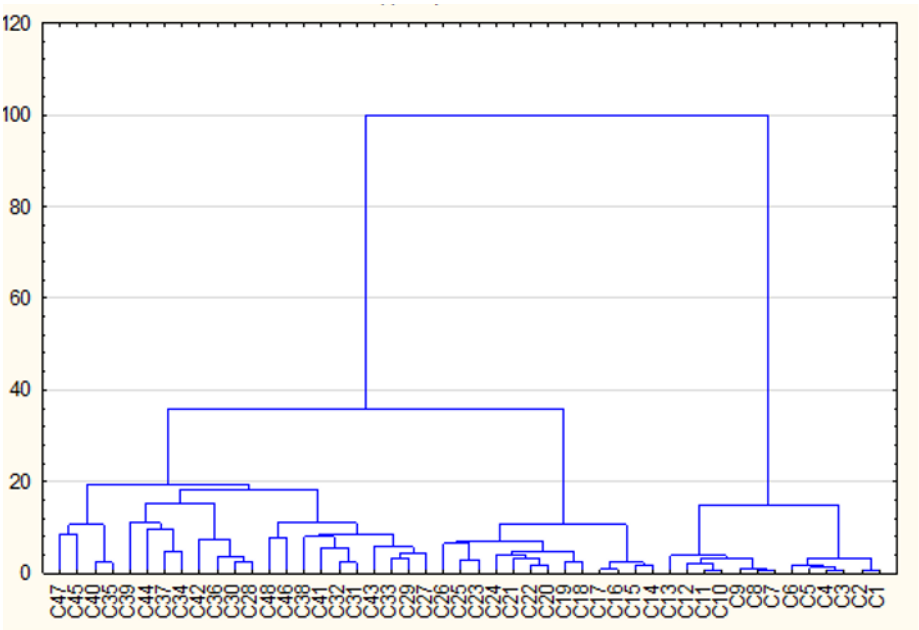

Fig. 1. Cluster analysis of apple tree varieties and forms.

Note: C1 to C12 apple tree varieties and forms (2017): 1. Orskoye, 2. Orenburgskoye pozdneye, 3. Arkaim, 4. Trudovoye, 5. Khrustalniy bashmachok, 6. Orenburgskoye, 7. 7-1, 8. 2-1, 9. 4-10, 10. 1-31, 11. 5-1, 12. 18-31; C13 to C24 varieties and forms (2019): 13. Orskoye, 14. Orenburgskoye pozdneye, 15. Arkaim, 16. Trudovoye, 17. Khrustalniy bashmachok, 18. Orenburgskoye, 19. 7-1, 20. 2-1, 21. 4-10, 22. 1-31, 23. 5-1, 24. 18-31; from 25 to 36 varieties and forms (2020): 25. Orskoye, 26. Orenburgskoye pozdneye, 27. Arkaim, 28. Trudovoye, 29. Khrustalniy bashmachok, 30. Orenburgskoye, 31. 7-1, 32. 2-1, 33. 4-10, 34. 1-31, 35. 5-1, 36. 18-31, from 37 to 48 varieties and forms (2021): 37. Orskoye, 38. Orenburgskoye pozdneye, 39. Arkaim, 40. Trudovoye, 41. Khrustalniy bashmachok, 42. Orenburgskoye, 43. 7-1, 44. 2-1, 45. 4-10, 46. 1- 31p, 47. 5-1, 48. 18-31

The highest content of soluble solids and ascorbic acid was observed in varieties and forms included in the second cluster: 2019 - Arkaim, Trudovoye, Khrustalniy bashmachok, Orenburgskoye, 7-1, 2-1, 4-10, 1-31, 5-1, 18-3, Orenburgskoye pozdneye (2019, 2020), Orskoye (2020). At the same time, the average values of soluble solids in the first and second clusters did not differ significantly (0.01), but exceeded the third cluster by 0.58 and 0.55, respectively.

The difference of ascorbic acid trait between the second and third clusters was 0.61, but exceeded the first cluster by 1.97 and 2.58, respectively. The best indicators were noted in the varieties: Orenburgskoye 19.1 mg%, Trudovoye 16.9 mg%, Arkaim and Orskoye 16.3 mg%.

When comparing clusters with each other for acidity trait, there was no significant difference.

Table 2. Average values of traits for each group of apple tree varieties and forms.

Traits	Cluster		
	1	2	3
Useful ovary	31.79	31.06	39.41
Number of fruits	249.0	236.46	281.15
Average fruit weight	129.72	126.69	120.84
Productivity from the tree	22.23	21.27	34.06
Sugars	12.30	10.89	11.07
Soluble solids	14.63	14.60	14.05
Ascorbic acid	13.78	15.75	16.36
Acidity	0.76	0.78	0.73

The data obtained indicate that all varieties and forms gave average productivity for three years, and in 2017 the same varieties and forms had the highest productivity due to the prevailing favorable weather conditions. The average weight of fruits in some varieties and forms varied significantly over the years: Orskoye from 119.0 to 148.0 g, Arkaim from 121.0 to 156.0 g, Trudovoye from 115.0 to 159.0 g, Khrustalniy bashmachok from 110.0 to 147.0 g, 18-31 from 97.0 to 142.0 g, other apple tree varieties and forms had not significant differences in fruit weight.

Table 3. Interaction of variety and year factors according to the characteristics of apple tree.

Variety (year)	1	2	3	4	5	6	7	8
Orskoye (a)	42.3	312	119.0	36.7*	10.7	14.5	16.3	0.66
Orskoye (b)	30.6	229	144.0	19.5	11.2	14.9	15.9	0.75
Orskoye (c)	35.1	297	135.0	26.7	11.6	15.1	15.6	0.62
Orskoye (d)	32.5	266	148.0	22.9	11.9	15.4	15.3	0.79
Orenburgskoye pozdneye (a)	39.3	274	136.0	30.2*	10.8	13.0	16.2	0.72
Orenburgskoye pozdneye (b)	31.0	249	127.0	21.0	11.2	14.4	15.4	0.80
Orenburgskoye pozdneye (c)	33.6	270	140.0	24.3	11.5	14.2	15.5	0.83
Orenburgskoye pozdneye (d)	31.2	251	131.0	21.1	11.9	14.6	15.1	0.71
Arkaim (a)	39.9	281	121.0	36.8*	10.2	13.5	16.3	0.73
Arkaim (b)	31.8	260	139.0	22.2	10.7	13.9	15.9	0.85
Arkaim (c)	34.2	279	148.0	25.2	10.8	14.0	15.3	0.88
Arkaim (d)	32.7	269	156.0	22.7	11.0	14.2	15.1	0.77
Trudovoye (a)	41.5	304	156.0	33.9*	10.5	13.6	16.9	0.77
Trudovoye (b)	30.9	232	115.0	20.4	10.7	13.9	15.1	0.88
Trudovoye (c)	34.6	282	159.0	25.5	11.0	14.3	15.4	0.79
Trudovoye (d)	30.9	231	149.0	20.4	11.4	14.5	15.0	0.82
Khrustalniy bashmachok (a)	39.2	274	144.0	36.2*	10.0	13.7	16.7	0.65
Khrustalniy bashmachok (b)	30.1	221	139.0	19.3	10.4	14.0	15.6	0.76
Khrustalniy bashmachok (c)	32.8	260	110.0	23.1	10.7	14.3	15.5	0.61
Khrustalniy bashmachok (d)	30.0	220	147.0	18.7	11.0	14.6	15.1	0.74

Orenburgskoye (a)	38.1	269	111.0	34.5*	10.9	14.7	19.1	0.72
Orenburgskoye (b)	31.2	230	103.0	21.8	11.0	15.1	18.7	0.83
Orenburgskoye (c)	33.5	271	99.0	24.1	11.3	15.4	18.4	0.85
Orenburgskoye (d)	32.1	230	113.0	22.2	11.5	15.8	18.1	0.71
7-1 (a)	40.6	282	103.0	38.5*	10.7	13.4	15.9	0.83
7-1 (b)	30.7	231	118.0	19.6	11.0	13.7	14.3	0.72
7-1 (c)	32.9	268	113.0	23.1	11.3	14.0	14.8	0.76
7-1 (d)	30.3	224	129.0	19.2	11.8	13.2	14.2	0.79
2-1 (a)	41.3	301	107.0	34.8*	10.0	14.0	15.7	0.77
2-1 (b)	29.1	201	125.0	19.9	10.6	14.3	14.9	0.88
2-1 (c)	31.7	259	143.0	31.2	11.0	14.6	14.5	0.79
2-1 (d)	30.4	222	121.0	21.5	11.1	14.7	14.3	0.72
4-10 (a)	42.5	315	98.0	35.1*	10.3	12.7	12.8	0.81
4-10 (b)	31.6	257	117.0	21.6	10.8	13.2	12.3	0.86
4-10 (c)	32.2	261	129.0	22.4	11.0	13.5	11.9	0.88
4-10 (d)	30.1	223	122.0	20.4	11.1	13.6	12.5	0.72
1-31 (a)	38.6	271	100.0	34.9	12.8	13.4	15.7	0.65
1-31 (b)	29.0	199	129.0	20.8	13.1	14.2	14.4	0.63
1-31 (c)	30.8	226	116.0	21.6	13.6	14.5	14.5	0.77
1-31 (d)	29.7	209	132.0	18.6	13.4	14.1	14.1	0.69
5-1 (a)	39.0	270	101.0	35.6*	12.5	14.0	15.9	0.77
5-1 (b)	29.6	203	127.0	20.3	13.9	14.7	14.8	0.84
5-1 (c)	31.0	249	122.0	21.0	13.4	14.9	14.6	0.79
5-1 (d)	30.6	226	137.0	19.9	14.0	14.5	14.2	0.72
18-31 (a)	39.4	273	131.0	36.2*	13.2	15.0	12.5	0.66
18-31 (b)	30.2	224	133.0	20.7	14.2	15.4	11.9	0.73
18-31 (c)	33.8	281	97.0	25.0	13.9	15.7	11.6	0.75
18-31 (d)	31.4	258	142.0	21.3	13.5	15.5	11.1	0.79

Note: (a) - 2017, (b) – 2019, (c) – 2020, (d) – 2021 1 – useful ovary, 2 – number of fruits, 3 – average fruit weight, 4 – productivity, 5 – sugar content, 6 – content of soluble solids, 7 – ascorbic acid content, 8 – acidity.

The content of soluble solids, sugars largely depends on the variety and changes under the effect of meteorological conditions of the year and the place of growth [10]. The content of soluble solids by year varied in 2017 from 15.0 to 12.7%, in 2019 from 15.4 to 13.2%, in 2020 from 15.7 to 13.5%, in 2021 from 15.5 to 13.2%.

Varieties with a constant and high sugar content are of value. In our studies, a high sugar content was observed in the forms 18-31 (14,2 – 13,2 %), 5-1 (14,0 – 12,5 %), and 1-31 (13,6 – 12,8 %) [11].

The content of ascorbic acid in fruits largely depends on the growing conditions. Nevertheless, our research has not confirmed this. When comparing the obtained data on ascorbic acid, the greatest difference over the years was in the following varieties and

forms: Trudovoye – 1.9 mg%, 7-1 and 5-1 – 1.7 mg%, Khrustalniy bashmachok and 1-31 – 1.6 mg%.

4 Conclusions

The correlation between the norm of the genotype response and the year to the complex of economically valuable traits that determine the productivity and quality of apple tree fruit varieties and forms grown in the Orenburg region, considering their stability, has been studied. It was revealed that the variety genotype has the greatest effect on ascorbic acid (93.0%), sugars (78.0%), soluble solids (79%), average fruit weight (57%). At the same time, the effect of the growing year conditions strongly influenced the useful ovary (87.0%), number of fruits (52.0%), and productivity (89.0%).

During the conducted research, it was revealed that apple tree varieties and forms Orskoye (148.0 g and 36.7 kg from a tree), Arkaim (156 g and 36.8 kg from a tree), Trudovoye (159 g and 33.9 kg from a tree), and 2-1 (143 g and 34.8 kg from a tree) are characterized by the highest fruit weight and productivity. These varieties form the basis of the modern zoned assortment of fruit crops and guarantee the possibility of creating new adaptive and stably fruiting perennial plantings in the conditions of modern horticulture of the Orenburg region.

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