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PHYSIO-BIOCHEMICAL CRITERIA FOR APPLE TREE TOLERANCE TO SUMMER ABIOTIC STRESSES

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Abstract

In Russia's North Caucasus where drought is frequent the apple tree is one of the most important garden crops. Physiological and biochemical studies are necessary to assess adaptiveness of apple varieties to stressors during summer, in particular, to summer drought. The purpose of this work is to study physiological, biochemical and anatomical parameters of leaves to assess the water regime, photosynthetic activity of apple trees in summer conditions, and to identify the most drought tolerant varieties for cultivation in the North Caucasus region. Research was carried out in 2011-2013 in fruit-bearing plantations (Central'noe Farm, Krasnodar) on apple varieties of different ecogeographical origin and ploidy: Idared, Earle Mack, Dayton (United States), Ligol (Poland), Prikubanskoe, Rassvet, Fortuna, Soyuz, Rodnichok (Russia). Varieties Soyuz and Rodnichok are triploids, the rest ones are diploids. Monthly, fully formed leaves were collected from (from the middle part of annual shoots of three trees in 3 replicates for each variety, 10 leaves per replicate. Indicators of water regime (total, free and bound water contents) were analyzed gravimetrically. The total water was determined after drying samples at 105 °C to a constant weight. For anatomical examinations, leaf blade transverse sections (temporary preparations) were used. It was shown that the leaf tissue water content, as well as the ratio of the bound and free water depend on both the variety specificity and the meteorological conditions of the year. Leaf water content in Prikubanskoe, Fortuna, Soyuz, and Rodnichok trees during July and August decreased by an average of 1-4 % compared to June, and the bound-to-free water ratio was the highest. Also, direct correlation between the leaf area and water availability (r = +0.98), and negative correlation between the leaf area and air temperature (r = –0.99, ($p \le 0.05$) were characteristic of these varieties. Pair correlation coefficients between (a + b) chlorophylls and fruit yield (r = +0.87), and between water content of tissues and fruit bud initiation (r = +0.97) ($p \le 0.05$) indicate that water and temperature regimes influence the yield and fruit bud formation. In the varieties of Prikubanskoe, Fortuna, Soyuz, Rodnichok, the chlorophyll content was more constant during the summer, and the ratio of the sum of chlorophylls to carotenoids is the highest. A positive correlation was found between the carotenoids and the air temperature (r = +0.91) ($p \le 0.05$). Morpho-anatomical structure of the leaf has varietal characteristics and depends on temperature and water availability. In 2012, the varieties exhibited xeromorphic features of leaves to varying degrees, which determined the resistance to drought, and the highest palisade index (1.47-1.49) was characteristic of the varieties Prikubanskoe, Fortuna, Soyuz, Rodnichok. The obtained results are in line with the field data obtained in the gardens without irrigation. The varieties showed different responses to summer stress factors, i.e. high temperatures and drought. Idared, Earley Mack, Dayton, Ligol plants were "passive" with a reduced water content, high solids, and smaller leaves. The rest varieties maintained high water and pigments in leaves and showed sustainable growth. Thus, Russian apple varieties Prikubanskoe, Fortuna, Soyuz, Rodnichok possess greater ecological plasticity and adaptive reserves compared to the studied introduced foreign varieties. The revealed adaptive features make it possible to involve these varieties in breeding for drought resistance. The applied tests provide accurate assessments of apple drought resistance and can be

used in breeding.

Keywords: apple tree, adaptation, drought resistance, heat resistance, proline, frost resistance

The apple tree (*Malus domestica* Borkh.) is the important food crop occupying 60 to 95 % of crop areas in different zones of the North-Caucasus region of Russia. The stress factors of summer season, drought and high temperatures negatively affect the apple tree growth and development, with leaves and fruits falling down, and setting up of generative organs worsening thereby resulting in reduction in yields by 15-30 % [1-3]. Stress causes changing in plant metabolism, photosynthesis, water exchange affecting physiological, biochemical and anatomo-morphological values [4]. Analysis of the apple tree physiological and biochemical features in unstable climatic conditions is required for accelerating and enhancement of genetic-selection process efficiency and for revealing the highly adaptive varieties in various horticultural activities [5-8].

A leaf is the most plastic vegetative organ, responding to environmental changes [9-11]. Peculiarities of water regime, pigment complex, xeromorphous structure of the leaf are considered to be reliable criteria of the plants drought resistance [12, 13]. Genotypes with the largest potential of the drought resistance were taken from 40 apple varieties and forms by indicators of water content tissues, water deficiency, water-retaining capacity of leaves in central Russia. Column-like apple varieties as Kumir, Vasyugan, Stela were found to lose 17.7-19.3 % of water per green weight after being affected by thermal shock and wilting [14, 15]. In various soil and climatic zones chlorophylls and carotinoids content was used as drought resistance markers for fruit, nut and decorative crops [16, 20]. Chlorophyll content in hazel nuts was decreasing under temperature rising and water supply reducing, with carotinoids content increasing two times [20].

The anatomo-morphological indicators of the leaf may be used to identify the drought resistance [21, 22], however, correlations of the traits is to be analyzed in more detail. According to some data amount of mesophyll cells was decreasing, relationship between mesophyll tissues was retained and the cuticle was thickened under insufficient water delivery in various pear varieties in subtropical parts of Russia [23]. On the contrary, the other papers provide data that change in relation among the mesophyll tissues, and reduction of upper epidermis cells are due to peach drought resistance [24]. In the North Caucasus characterized by specific climatic conditions, mainly by acute fluctuations of both water and temperature regimes, peculiarities of the apple-tree drought resistance physiology are analyzed insufficiently.

Complex of physio-biochemical and anatomic indicators of the leaf blade is presented herein to find the resistance of the apple varieties of different eco-geographic origin to the summer period stressors in specific conditions of the North Caucasus. Peculiarities of these plant varieties to resist high temperatures and drought are indicated.

The objective of this paper is to analyze the peculiarities of water regime, photosynthetic activity of apple-tree in the summer time period, as well as to find the most drought-resistant varieties based on the leaf physio-biochemical and anatomic indicators, to be cultivated in the North-Caucasus region of the Russian Federation.

Techniques. The analysis took place in 2011-2013 in commercial plantation of Experimental Production Farm Tsentralnoe, Krasnodar. The apple varieties from various eco-geographical areas, Idared, Earley Mack, Dayton varieties (USA), Ligol (Poland), Prikubanskoe, Rassvet, Fortuna, Soyuz, Rodnichok (Russia), have been analyzed. Soyuz and Rodnichok varieties are triploid, the other ones being diploid. Idared, Ligol, Prikubanskoe varieties were planted in 2010 using SK4 rootstock at 0.9 m×4.5 m planting scheme; Rassvet, Fortuna, Soyuz, Rodnichok varieties were planted in 2000 using M9 rootstock (2 m×5 m); Earley Mack and Dayton varieties were planted in 1998 with M9 (2 m×5 m) rootstock.

Every month fully preformed leaves were taken from 3 trees (middle part of one-year increment) of each variety in three-fold biological replication to be analyzed. Each replication consisted of 10 leaves. Content of both free and bound water was found by weighting [25]. The total water content in leaves was found by drying the weighed quantities in thermostat at 105 °C until the constant weigh thereof. The experiments were made in 3-fold analytical replication. Anatomic features of leaf blade were studied on temporary slides of transversal sections made with razor by hand applying elder-tree stem pith as an additional material. Sections without staining and fixing were microscoped in water drop with Olympus BX41 microscope (Olympus Corporation, Japan; magnification of ×400). Biometric values of the leaf blade were measured in microns by ocular micromere according to the specified procedure [26]. Pigment content was found spectrophotometrically in 85% acetone extract (spectrophotometer Unico 2800, United Products & Instruments, USA) at λ = 663, 644, 432 nm (red color-filter) [27].

Statistical analysis was made by B.A. Dospekhov [28]. All calculations were processed with Microsoft Excel 2010. Significance of differences between the analyzed values (LSD_{05}) was found with statistical reliability of 95%, arithmetic mean (*M*) and standard deviation (±SD) were calculated. Pair correlation coefficient (*r*) between physio-biochemical indicators was calculated with 95% statistical significance.

Results. The weather condition differed significantly by years. In 2011, the drought was noted in July, with maximum air temperature being 39.5 °C, and rainfall 3.1 mm. In 2012, the period from late July till the mid-August was abnormally hot and dry, maximum air temperature was 38.3 °C (above normal by 4.7 °C), the rainfall was 0.3-0.4 mm (2% of the norm). In 2013, maximum air temperature was 32 °C (above normal by 1.5-2.5 °C), the rainfall was 35 mm.

The adaptation to conditions of cultivation is of complex character and is based on plasticity of anatomic structures, change in physio-biochemical indicators, with limits thereof being determined by certain genotype. Extremely high temperatures and insufficient water supply negatively affect the water status of the apple-tree vegetative organs [29-31].

Water regime indicators for the apple-tree varieties are significant to assess drought resistance thereof. We have analyzed total water content of the leaf tissues taken from one-year shoots and fractional composition of water. Idared variety widely presented in the southern part of Russia was a control one. Water content in all varieties changed variously during summer period. In June, it ranged from 60.53 to 70.56% depending on variety features and environmental conditions (Table 1). In July and August, in the period of the highest stress factors (especially in dry year of 2012), water content in Idared, Earley Mack, Dayton and Ligol varieties was significantly reduced by 8-14%.

In other varieties the water content of leaf tissues decreased on the average by 1-4%. The largest reduction in water content of Idared, Earley Mack, Dayton, Ligol varieties in August was accompanied by enhancement of synthetic processes and accumulation of dry matter in the leaf tissues up to 48.71% (up to 47.69% in 2012) (Fig. 1). In other varieties dry matter content ranged from 29.44% in June to 34.87% in August.

1. Water content (%) **in leaves of various apple (*Malus domestica* Borkh.) varieties depending on month and year** (*M*±SD, Experimental Production Farm Tsentralnoe, Krasnodar)

Variety	2011			2012			2013		
	June	July	August	June	July	August	June	July	August
Idared (control)	69.12±5.71	59.26±5.65	58.63±5.92	68.45±5.42	57.84±5.89	58.88±5.28	69.21±6.05	58.24±6.24	57.25±6.27
Earley Mack	62.54±5.17	55.87±5.84	52.41±4.89	60.53±3.67	54.76±3.89	53.78±3.85	61.25±4.52	55.89±4.28	51.29±4.85
Dayton	65.28±6.58	54.26±6.27	52.84±6.28	64.28±6.84	53.26±6.58	52.31±6.78	66.58±7.12	55.43±7.18	52.43±7.58
Ligol	64.32±4.25	56.24±4.28	55.61±4.29	63.53±5.56	54.28±5.28	53.72±5.76	64.23±4.28	56.27±4.89	56.87±4.12
Prikubanskoe	70.56±0.94	69.27±1.03	68.71±0.49	68.57±0.58	67.53±0.82	67.58±0.46	68.75±0.28	69.12±0.85	69.58±0.45
Rassvet	67.81±1.15	65.28±1.28	65.28±1.86	66.21±0.58	65.24±0.46	65.41±0.83	68.23±1.53	65.13±1.59	66.57±1.28
Fortuna	69.31±1.25	68.71±1.48	66.41±1.46	69.87±1.49	67.24±1.27	66.23±1.53	68.72±0.48	68.42±0.27	67.24±0.46
Soyuz	70.12±0.86	69.25±0.78	68.42±0.49	69.21±0.58	68.27±0.58	68.21±0.27	69.82±0.78	68.52±0.58	69.27±0.46
Rodnichok	70.56±2.15	69.23±2.16	66.41±2.46	68.25±0.57	68.91±0.56	67.24±0.58	69.15±1.27	69.24±1.87	66.85±1.53
LSD_{05}	1.36	2.01	2.05	1.39	2.04	2.06	1.32	1.96	2.13

2. Pigments (mg/g dry matter) **in leaves of various apple (*Malus domestica* Borkh.) varieties in summers of 2011-2013** (*M*±SD, Experimental Production Farm Tsentralnoe, Krasnodar)

Variety	2011			2012			2013		
	(a + b)	c	(a + b)/c	(a + b)	c	(a + b)/c	(a + b)	c	(a + b)/c
Idared (control)	4.72±0.42	1.04±0.07	4.54±0.41	5.12±0.49	0.96±0.08	5.33±0.19	4.22±0.46	0.90±0.09	4.68±0.42
Earley Mack	4.22±0.13	1.24±0.01	3.40±0.24	4.42±0.18	1.24±0.02	3.56±1.33	4.16±0.28	1.42±0.07	2.92±0.34
Dayton	4.82±0.12	1.22±0.08	3.95±0.35	4.96±0.28	1.20±0.02	4.13±0.12	4.72±0.24	1.20±0.08	3.93±0.12
Ligol	4.70±0.34	1.28±0.23	3.67±0.28	5.02±0.35	1.22±0.51	4.11±0.17	4.42±0.28	1.36±0.02	3.25±0.43
Prikubanskoe	5.38±0.12	0.96±0.05	5.60±0.75	5.51±0.28	0.96±0.28	5.72±0.10	5.62±0.21	1.02±0.07	5.51±0.10
Rassvet	4.70±0.50	1.02±0.08	4.60±0.25	5.62±0.49	1.18±0.05	4.76±0.14	5.50±0.78	1.16±0.03	4.74±0.41
Fortuna	5.36±0.05	0.90±0.05	5.95±0.24	5.44±0.02	0.86±0.02	6.32±0.28	5.28±0.05	0.96±0.04	5.50±0.42
Soyuz	5.32±0.11	0.96±0.06	5.54±0.46	5.46±0.12	0.92±0.08	5.93±0.44	5.22±0.16	0.92±0.04	5.67±0.19
Rodnichok	5.58±0.04	0.91±0.09	6.13±0.57	5.66±0.05	0.84±0.04	6.73±0.19	5.62±0.02	0.96±0.03	5.85±0.42
LSD_{05}	0.34	0.22	0.41	0.25	0.24	0.51	0.27	0.28	0.45

Note. a + b — chlorophyll content, c — carotenoids.

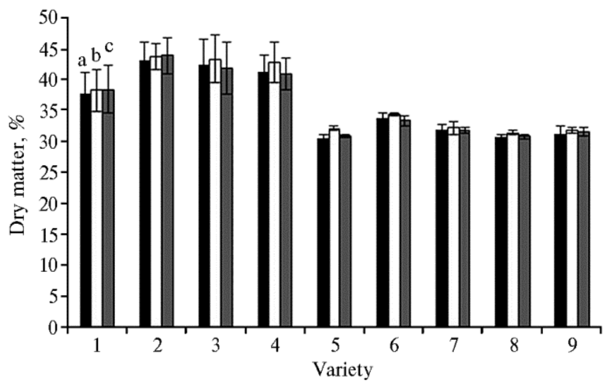

Fig. 1. Average content of dry matter in leaves of various apple-tree (*Malus domestica* Borkh.) varieties during summer of 2011 (a), **2012** (b) **and 2013** (c)**:** 1 — Idared, 2 — Earley Mack, 3 — Dayton, 4 — Ligol, 5 — Prikubanskoe, 6 — Rassvet, 7 — Fortuna, 8 — Soyuz, 9 — Rodnichok. LSD_{05}: a — 0.89, b — 0.68, c — 0.81 (Experimental Production Farm Tsentralnoe, Krasnodar).

The indicator of the plants resistance to the low water supply and drought is a bound to free water ratio ($K_{bound/free}$). The bound water provides water-retaining capacity of cells. The high coefficient of bound to free water quantitative ratio indicates the high drought resistance of the variety.

The highest values of $K_{bound/free}$ from 2.06 to 2.61 in 2011 and 2013 were found in Prikubanskoe, Fortuna, Soyuz, Rodnichok varieties (Fig. 2). In dry year of 2012, this value for all varieties was higher as compared to 2011 and 2013 varying within 1.53-2.99. In Earley Mack variety, the value $K_{bound/free}$ was the lowest ranging within 0.41-0.82 in the vegetation period, indicating low resistance to stress-factors of the summer time.

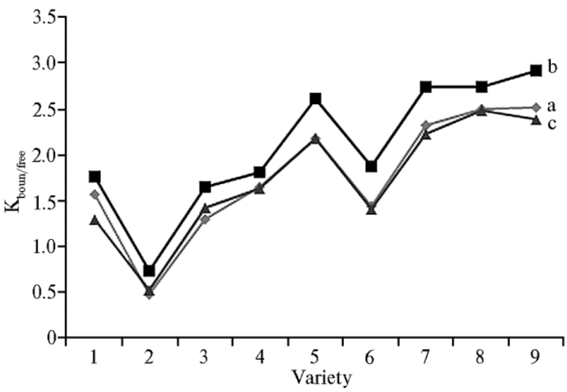

Fig. 2. Bound to free ratio of water ($K_{bound/free.}$) **in leaves of various apple-tree (*Malus domestica* Borkh.) varieties during summer of 2011** (a), **2012** (b) **and 2013** (c)**:** 1 — Idared, 2 — Earley Mack, 3 — Dayton, 4 — Ligol, 5 — Prikubanskoe, 6 — Rassvet, 7 — Fortuna, 8 — Soyuz, 9 — Rodnichok. LSD_{05}: a — 0.54, b — 0.58, c — 0.61 (Experimental Production Farm Tsentralnoe, Krasnodar).

Physiological condition of the plants is best characterized by increase of the leaf area. According to literature data, the leaf area was reducing in the periods of insufficient water supply with red currant and mango varieties (32, 33), and on the contrary remaining the same with almond (34). In our analysis, the linear parameters of the leaf within the vegetation period depended on the varieties and climatic conditions of the year. In this way the leaf area of Idared, Earley Mack, Dayton and Ligol varieties was decreasing in driest year of 2012 amounting to 68.29 cm^2 on the average (as compared to that of 72.52 cm^2 on the average in 2011) (Fig. 3).

Changes in the leaf size were insignificant in other varieties. The positive correlation was found between the leaf area and water supply (r = +0.98), and the negative one between the area and air temperature (r = −0.99) ($p \le 0.05$). Both water and temperature regimes affect the crop productivity and fruit bud setting as well, specifying the yield for the next year and influencing the functional condition of assimilating apparatus, that was confirmed by the pair correlation coefficient between content of chlorophylls and crop productivity (r = +0.87), and between water content of the tissues and fruit bud setting (r = +0.97) ($p \le 0.05$).

Drought and higher temperature affect the leaf pigment composition either

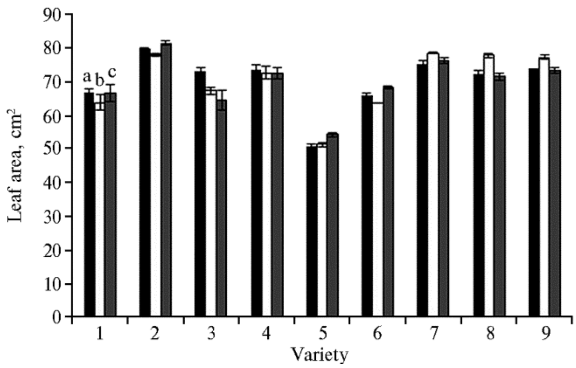

Fig. 3. Average leaf area of various apple-tree (*Malus domestica* Borkh.) varieties during summer of 2011 (a), **2012** (b) **and 2013** (c): 1 — Idared, 2 — Earley Mack, 3 — Dayton, 4 — Ligol, 5 — Prikubanskoe, 6 — Rassvet, 7 — Fortuna, 8 — Soyuz, 9 — Rodnichok. NSR_{05}: a — 0.65, b — 0.51, c — 0.51 (Experimental Production Farm Tsentralnoe, Krasnodar).

[35, 36], that is also confirmed by our analysis. Correlation between content of chlorophylls (a + b) and carotenoids in the leaves of apple-tree varieties analyzed was changing variously during a summer period. Content of chlorophylls in Prikubanskoe, Fortuna, Soyuz, Rodnichok varieties was more stable during a summer period, but sharp accumulation of carotenoids was noted in July—August, that was confirmed by the positive correlation between the content of carotenoids and ambient temperature ($r = +0.91$) ($p \leq 0.05$). Carotenoids possessing the antioxidant properties play an important part in the plant defense reactions. The increased accumulation thereof under unfavorable conditions of the summer period is required for stimulating the adaptive response and reducing general stress. Quantitative correlation between the chlorophyll content and carotenoids indicating plant adequacy to unfavorable environmental conditions is considered to be the most informative value, with this value being the highest for all the varieties in 2012. The correlation between the chlorophyll content and carotenoids was higher in Prikubanskoe, Fortuna, Soyuz, Rodnichok varieties (5.72-6.73) than in the other ones. In 2011 and 2013, this value was 5.50-6.13 (Table 2).

Prikubanskoe, Fortuna, Soyuz, Rodnichok home-selected varieties proved to be highly resistant to dry weather conditions due to water regime and pigment complex.

Changes in physiological processes affect leaf anatomy and morphology. The apple tree leaf is dorsoventral, and mesophyll is differentiated into palisade and columnar tissues. The palisade tissue is composed of two cell layers. The stomata apparatus is of anomocytic type, the stomata are concentrated on abaxile side of leaf blades. The anatomo-morphological structure of the leaf had the variety features, and depended on temperature and water supply as well. Cells of leaf in triploid Soyuz and Rodnichok varieties were larger than in other varieties analyzed, and leaf thickness thereof was of maximum size.

The xeromorphous traits of leaves, indicating resistance to drought, namely an increase in thickness, in cuticle, palisade index, in stomata number per unit of leaf area, and reduction of stomata linear size, were found in dry year of 2012 in all varieties except Earley Mack.

The palisade index (relation between thickness of palisade and spongy layers) is the most informative estimate of drought resistance. In 2012, this index was growing in all varieties, with the largest value thereof being found in Prikubanskoe, Fortuna, Soyuz, and Rodnichok varieties (1.47-1.49) identified as the highly drought-resistant. Idared, Dayton, Ligol, Rassvet varieties with palisade index of 1.27-1.35 were marked as the drought-resistant, and Earley Mack variety with palisade index of 1.01 as a non-drought resistant (Table 3).

In some papers, the relationship between water supply and stomata number per unit of leaf area was established. Amount and size of pear stomata in

3. Leaf morphology indicators (μm) **in various apple (*Malus domestica* Borkh.) varieties during summers of 2011-2013** (M±SD, Experimental Production Farm Tsentralnoe, Krasnodar)

Variety	2011			2012			2013		
	TTLB	CE	PI	TTLB	CE	PI	TTLB	CE	PI
Idared (control)	176.2±2.65	10.0±0.12	1.27±0.01	180.3±2.34	10.2±0.12	1.30±0.01	175.4±2.34	10.0±0.12	1.29±0.01
Earley Mack	171.5±0.17	9.1±0.01	1.01±0.01	171.5±0.18	9.1±0.01	1.01±0.01	171.2±0.27	9.1±0.02	1.01±0.01
Dayton	191.3±3.75	10.1±0.23	1.28±0.01	198.5±3.45	10.5±0.23	1.29±0.01	192.8±3.57	10.1±0.21	1.28±0.01
Ligol	163.8±4.12	10.2±0.10	1.30±0.01	170.2±4.15	10.4±0.10	1.32±0.01	162.3±4.17	10.3±0.12	1.30±0.01
Prikubanskoe	199.2±3.45	11.2±0.21	1.47±0.01	205.3±3.48	11.5±0.19	1.49±0.01	199.5±3.27	11.1±0.21	1.46±0.01
Rassvet	169.4±3.12	10.3±0.05	1.32±0.02	175.4±3.27	10.3±0.05	1.35±0.02	170.7±3.17	10.2±0.03	1.31±0.02
Fortuna	178.5±2.81	11.1±0.10	1.46±0.01	181.4±2.47	11.3±0.11	1.47±0.02	175.6±2.42	11.2±0.13	1.45±0.01
Soyuz	213.9±15.23	11.2±0.12	1.45±0.01	243.6±15.21	11.4±0.15	1.48±0.01	221.3±14.27	11.1±0.17	1.46±0.01
Rodnichok	215.4±14.21	11.2±0.24	1.45±0.01	241.5±13.78	11.6±0.25	1.48±0.01	216.1±11.24	11.2±0.24	1.46±0.01
LSD_{05}	3.46	0.67	0.30	4.21	0.71	0.31	3.63	0.67	0.30

N o t e. TTLB — total thickness of leaf blade, CE — cuticle with upper epidermis, PI — palisade index.

4. Stomata apparatus (number of stomata and guard cell size) **of various apple (*Malus domestica* Borkh.) varieties during summers of 2011-2013** (M±SD, Experimental Production Farm Tsentralnoe, Krasnodar)

Variety	2011			2012			2013		
	number	width, μm	length, μm	number	width, μm	length, μm	number	width, μm	length, μm
Idared (control)	215.1±1.12	31.1±0.54	54.4±0.41	216.5±1.25	32.1±0.64	55.2±0.42	217.5±1.24	32.2±0.58	54.9±0.43
Earley Mack	189.4±0.15	34.0±0.04	56.2±0.52	189.7±0.14	34.1±0.07	55.6±0.51	189.5±0.27	34.1±0.02	55.2±0.49
Dayton	245.2±0.84	31.0±0.23	54.8±0.24	245.8±0.84	31.3±0.19	54.4±0.21	244.2±0.71	31.4±0.24	54.4±0.26
Ligol	231.6±0.46	32.1±0.21	54.2±0.10	232.4±0.42	31.7±0.18	54.3±0.12	231.60.43±	31.8±0.17	54.4±0.12
Prikubanskoe	270.4±3.87	30.1±0.27	53.7±0.25	275.3±3.57	30.2±0.22	53.6±0.25	267.4±3.84	30.5±0.16	53.2±0.27
Rassvet	236.7±1.02	31.7±0.17	54.3±0.31	237.4±1.01	31.4±0.17	54.7±0.34	235.4±1.04	31.4±0.18	54.1±0.31
Fortuna	265.3±2.34	31.0±0.27	53.2±0.42	270.6±2.54	31.5±0.42	53.8±0.42	267.3±2.47	30.6±0.42	54.0±0.42
Soyuz	281.4±5.13	30.1±0.24	53.2±0.58	289.7±5.24	30.6±0.24	53.2±0.56	280.4±5.27	30.4±0.22	54.2±0.54
Rodnichok	284.7±2.14	30.2±0.57	53.1±0.04	289.3±2.47	30.8±0.39	53.1±0.04	284.6±2.37	30.1±0.34	53.0±0.58
LSD_{05}	4.34	0.89	0.79	4.50	0.84	0.70	4.33	0.87	0.64

humid subtropical areas of Russia were changing depending on vegetation conditions: stomata density was decreasing together with increasing of size thereof in the years of intensive rainfall during active growth of shoots and leaves, with the reverse process taking place in dry years [23]. Peach varieties with high density of stomata analyzed by the Chinese scientists possessed higher drought resistance [24]. No such dependence is found in other papers. Water supply had no similar effects on the stomata density of young almond plants [34]. Increase in stomata number per unit of leaf area and reduction of the guard cells as compared to non-resistant varieties is typical of the drought-resistant varieties, according to our data (Table 4). Therewith the stomata number per 1 mm^2 of leaf surface in Prikubanskoe, Fortuna, Soyuz, Rodnichok varieties varied from 265.3 to 289.7, while in other varieties analyzed it ranged within 189.4-245.8. Maximum length and width of stomata (56.2 μm and 34.1 μm respectively) was in the non-drought resistant Earley Mack variety, while minimum size of stomata (53.2 μm and 30.1 μm) was in highly drought-resistant Soyuz variety. The obtained results agreed with those of field trials in non-irrigated gardens (data not given).

Therefore, by assessing physio-biochemical and anatomic parameters, we revealed the characteristic features of tolerance to summer stresses (high temperature and low water supply) among the apple varieties of different eco-geographical origin grown in the North Caucasus region of Russia. The introduced varieties Idared, Earley Mack, Dayton, and Ligol show passive drought resistance (water content reducing, high content of dry matter, reduced leaf area). Domestic varieties keep high water content, stability of both growing and synthetic processes, and high concentration of pigments. The domestically-derived apple varieties Prikubanskoe, Fortuna, Soyuz, Rodnichok possess better environmental plasticity and adaptation abilities than the introduced varieties of foreign selection. The adaptation features found in the apple varieties enable using thereof in breeding programs as the sources of drought resistance. The methods applied herein provide accurate estimates of apple tree tolerance to drought and may be used in selection process.

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