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MAIN TYPES OF RESPONSE OF STRAWBERRY GENOTYPES TO DROUGHT AND THEIR RELATION TO DROUGHT RESISTANCE

Annotation

Aim of the research is to find out which behaviour specifics of strawberry genotypes lead to differences between cultivars in drought resistance, and how damage rate caused by drought is associated with specifics of plant response to it. In two studies which included 20 and 16 strawberry genotypes, respectively, rates and symptoms of plant injuries have been estimated, and behaviour habits of each genotype established. Cultivars and selections that developed vigorous crowns with large and tough leaves—Saint Williams, Pandora, Or 967-9-15 and Or 975-12-72—resisted drought more successfully compared with others, maintaining high levels of water content in leaves at the cost of growth breaking and thanks to redistribution of a part of inner water from the lowest leaves to upper ones.

Keywords: *Fragaria* x *ananassa* Duch., cultivar, selection, water stress, drought resistance

Introduction

Strawberries in Russia are mostly grown in field conditions. One of limiting factors of the crop growing is dry conditions of summer period. Drought in the Middle zone of Russia is a common phenomenon, while irrigation opportunities are frequently limited. Water demand of strawberry plants is very high, and the majority of cultivars, by force of their specific characters and load of yield, withstand drought poorly [1, 2, 3].

Drought resistance of plants is a complex attribute [4]. The slower tissue water is lost, and the higher capability of protoplasm to dry off remaining intact the more chances the plant has to survive. Plant organisms differ in methods of adaptation to drought. Some of them are able to maintain high tissue water contents; the others, missing sufficient water-retaining capacity, can tolerate lower water contents in their tissues for some time; and some plants possess high capabilities to restore the proper water contents [5, 6]. There exist mechanisms protecting plants from dehydration and mechanisms providing tissues with the capability to withstand a lower water, or osmotic, potential in them [7, 8]. First of all, in order to avoid dehydration, transpiration rate is reduced to a minimum thanks to stomata closure [7]. Besides, a number of morphological and physiological alterations occur; mechanisms of inhibition of growth processes [9, 10] and re-distribution of inner water [11] are engaged.

Most investigations on drought resistance of strawberry cultivars were devoted to determination of water-retaining capacity of leaves and their capability to restore tissue water contents at soil saturation [6, 12]. Only a very few genotypes are capable to tolerate drought at high temperatures more or less successfully; besides, injury symptoms in cultivars may differ [1, 13, 14]. In conditions of drought, signs giving evidence of breakings in different processes appear in plants; however, such specifics of plant behaviour of different genotypes and their relation to drought resistance have been studied insufficiently. There is no information concerning types of response to drought and peculiarities of injury signs, which could allow classification of cultivars, using the particulars of plant behaviour. Investigations in this direction need to be analysed and generalized. Studying plant behaviour in droughty conditions is important to allow selection of genotypes most adapted to them and estimation of their adaptation rate to drought by the specifics of their behaviour.

Aim of the research is to find out main types of response to drought distinctive of different genotypes of the garden strawberry *Fragaria* × *ananassa*

Duch., based on specifics of plant behaviour in droughty conditions and injury symptoms, and to trace their relation to drought resistance.

Research methodology

In two studies conducted in drought conditions, visual evaluations of plant damage rates and symptoms were carried out. Injury rate assessments were performed in 2.5 and 4.5 weeks from the beginning of drought periods. The injury rates were expressed in damage scores, using 4-point scale where 0 = no damage, 1 = a few leaves are injured, 2 = up to 50% leaves are injured, and 3 = almost complete withering of leaves, in accordance with an appropriate section of a generally accepted book of methods of fruit and berry cultivars trialing, devoted to strawberries [15, p. 424]. Additionally to this, particulars of behaviour of genotypes under study, damage symptoms and time of their appearance were recorded every week. In study 2, also, samples of functioning leaves were picked to determine water contents in them (in %). They were found by weighing before and after drying up the samples, in accordance with a proper section of the same book of methods [15, p. 80].

Dispersion (Duncan’s test) and correlation analyses of data were performed using packs of statistics of the Federal state budgetary research institution ‘All Russian Research Institute of Horticultural Breeding’ (developed by Vitaly Timoshuk) and SAS Institute (USA, 1995).

Base of experiment and research process

The studies were carried out in the Federal state budgetary research institution ‘All Russian Research Institute of Horticultural Breeding’ (Russian abbreviation FGBNU VNIISPK), Orel district, Orel county. Climate is temperate, continental, with cold winters and usually poor snow cover, hot summer seasons and noticeable lack of precipitation.

Soil type is a dark gray loam, with 23 to 25-cm humus layer, humus percentage ranging from 3.0 to 3.5%, phosphorus contents ranging from 260 to

300 mg per kg soil, and potassium contents within the range of 250–280 mg per kg soil. Soil solution is mildly acid; soil pH ranged from 5.6 to 6.0.

Data obtained in measures, analyses and observations in the two studies, in 2002 and 2012, when drought periods lasted longer than a month at temperatures ranging from 33 to 42°C, served as the material for the investigation. In study 1 (2010), the period lasted since mid-July till the beginning of September; in study 2 (2012)—since the third decade of July till the second half of the third decade of August. The absolute minimum of temperature recorded during the investigation period was +44°C (August 2010). Sun of effective temperatures exceeding 5°C in 2010 amounted to 2060°C; in 2012—1980°C. Annual precipitation amounted to 480 mm and 560 mm, respectively.

In study 1, 15 cultivars and 5 selections: Alice, Alpha, Dukat, Emily, Festivalnaya, Florence, Kokinskaya Zarya, Pandora, Polka, Rannyaya Plotnaya, Rubinovy Kulon, Rusich, Sumas, Saint Williams, Tsaritsa, Or 965-7-1, Or 967-9-15, Or 975-12-72, Or 1416-7-35 and Or 1416-9-12 were subjects of evaluations and observations.

Following 16 genotypes: cultivars Alice, Alpha, Dukat, Emily, Festivalnaya, Florence, Kokinskaya Zarya, Pandora, Polka, Rannyaya Plotnaya, Rubinovy Kulon, Rusich, Tsaritsa, and selections Or 965-7-1, Or 967-9-15 and Or 975-12-72 were subjects of research in study 2.

Strawberry plants in both experiments were studied in the first cropping year; fruiting approached finish just before the periods of drought began. All the variants were repeated three times. The studies were designed as complete blocks, with randomized plots arrangement within each block, at 25 plants per plot. In both studies, when 20 days passed since the beginning of drought, maintaining watering was carried out, so that 5-cm soil layer was drenched.

Results and discussion

In 2010, drought coincided with substitution of old leaves for new ones and beginning of crown branching. Differences in response to the dry conditions and in injury symptoms began to emerge during the second week; genotypes significantly differed in capability to withstand the drought (table 1).

Table 1. Rates of damage caused to strawberry plants by drought, specifics of response of genotypes to dry conditions and injury types in study 1

Genotype	Damage score at the end of dry period	Main kinds of damage and specifics of plant behaviour
Alice	1.9 de	Lower leaves started to turned yellow after 1 week of drought; the process advanced quickly spreading to other leaves; by the end of the drought period only a few leaves surrounding apical buds left; plants kept growing
Alpha	1.6 abc*	Subsequent to week 2 some lower leaves turned yellow and started to wilt; the other leaves showed a partial loss of turgor, but it was generally regained in the nighttime and after watering
Dukat	2.0 ef	Most leaves lost turgor rather quickly and began to wilt; they gradually died off with no change in colour, beginning from lower leaves; the process advanced, and 2/3 of the leaves withered by the end of the dry period
Emily	1.6 abc	Temporary loss of turgor was observed, but it was usually regained by the morning time and after watering; leaf margins of new upper leaves died back, while a number of lower leaves turned red
Festivalnaya	2.2 fg	Leaves lost turgor and wilted, beginning from week 3 on; turgor regaining by the morning time and even after watering was poor, the leaves gradually withered without colour changing
Florence	1.8 cde	Turgor loss and leaf wilting appeared, beginning from week 3; leaf margins of some upper leaves became as if burned; whereas lower leaves turned red and started to die off
Kokinskaya Zarya	1.9 de	Wilting of leaves was observed, turgor loss was only partially compensated in the nighttime and after watering; a number of lower leaves slowly died off with no change in colour
Pandora	1.4 a	Tips of new unfolding leaves started to die back after 2 weeks of the dry period; plant growth fully ceased after 4 weeks; some lower leaves turned red and began to die off
Polka	1.9 de	Gradual turgor loss and leaf wilting took place; turgor regaining was insufficient even after watering; margins of upper leaves and sometimes whole immature leaves died off; lower leaves turned red and slowly withered
Rannyaya Plotnaya	1.5 ab	Leaves that lost turgor, as a rule, regained it in the course of the nighttime and after watering; leaf margins of a part of upper leaves died back; most lower leaves turned red
Rubinovy Kulon	1.6 abc	Temporary turgor loss and leaf wilting could be observed in the daytime; turgor was usually regained in the nighttime and subsequent to plant watering; leaf margins

		of some new leaves died back, as lower leaves turned red
Rusich	2.2 fg	Leaves gradually lost turgor and wilted; turgor regaining was poor even after plant watering; the leaves slowly died off with almost no change in colour, beginning from lower ones
Saint Williams	1.4 a	When 2 weeks of the dry period passed, tips of new unfolding leaflets started to die back; growth totally ceased by week 4; the oldest lower leaves turned red
Sumas	2.8 i	Plants quickly lost turgor and began to wilt; most leaves got rolled up in the course of the 2^{nd} week of the drought; wilting and withering became irreversible by week 4
Tsaritsa	2.5 h	Beginning from week 2, turgor loss and leaf wilting appeared; turgor regaining was very poor even after watering; leaves got rolled up and died off with no change in colour; the process became irreversible by week 4
Or 965-7-1	1.8 cde	Partial turgor loss and leaf wilting could be observed in the daytime; turgor was regained after watering; the ability of turgor regaining visibly descended by the 4^{th} week of the drought period; a part of lower leaves turned red and started to die off
Or 967-9-15	1.7 bcd	Partial turgor loss was observed, but it was regained in the nighttime; beginning from week 2, leaf tips of unfolding leaflets and some upper immature leaves began to die back; a significant part of lower leaves turned red and started to die off
Or 975-12-72	1.5 ab	Subsequent to week 2 of the dry period, growing points of new immature leaflets began to die back, growth stopped after the lapse of 4 weeks; turgor loss was observed by day ends, but it was regained in the nighttime, particularly after watering; a number of lower leaves turned red
Or 1416-7-35	1.8 cde	Turgor loss and leaf wilting revealed themselves steadily; turgor was partially regained after watering; beginning from week 2, lower leaves began to turn yellow and die off
Or 1416-9-12	2.4 gh	Turgor loss and leaf wilting appeared in several days after the beginning of the drought; leaves got rolled up and spiraled; turgor regaining was poor even after watering; leaves died off almost with no colour change
LSD_{05}	0.3	–

* Differences between means are not significant at P = 0.05, if any of letters following them coincide

Turgor loss showed by leaves and their wilting, one way or another, were present in all the genotypes, but some of them revealed practically no symptoms except these. They differed from each other only by wilting rate and by rate of turgor regaining during the nighttime and after watering; the latter steadily descended with the progress of the drought period. Cultivars Sumas, Tsaritsa, Rusich, Festivalnaya, Dukat and selection Or 1416-9-12, injuries of which were revealed in such a way, appeared to be damaged most heavily of all others. ‘Sumas’ and ‘Tsaritsa’ were most sensitive to drought; leaves of their plants started to roll up and wilt, beginning from the second week of the dry period (fig. 1), and by its end were on the verge of death. The capabilities of ‘Florence’, ‘Kokinskaya Zarya’, ‘Polka’, selections Or 965-7-1 and Or 1416-7-35 plants to regenerate were somewhat higher. In the genotypes, also, some other, though vaguely detectable, signs of damage were revealed. ‘Rannyaya Plotnaya’ and ‘Rubinovy Kulon’ withstood drought still better. In addition to turgor loss which was usually regained in the nighttime and especially after watering, another kind of damage was observed in their plants: margins of upper immature leaves became as if burned. Plant growth slowed, and in some time practically stopped. A few lower leaves turned dark red with a purple or violet hue.

Fig. 1. Injuries caused by drought to Alice (in the middle) and Sumas (below) cultivars

Plants of the remaining genotypes differed from each other first of all by colour which older lower leaves gradually gained. They turned either yellow (brighter tones could appear later) or dark red with a purple (violet) hue. Growth of the former continued; leaves of the most susceptible cultivar, Alice (fig. 1), kept permanent turning yellow and dying off, and by the end of the drought period only upper immature leaves remained green. More vigorous and branched plants of ‘Alpha’ got through the drought much more successfully thanks to the better developed crowns and deeper root penetration. The plants lost not more than one fourth of their leaves, oldest ones. Selection Or 1416-7-35 lost approximately one third of its leaves.

Another distinctive feature of the genotypes whose lower leaves turned red and slowly died off in the course of the drought, was appearance of died back tips of new unfolding leaflets. Their basal parts kept growing, but leaf tips became as if cut and burned. Growth processes slowed down, and ceased in the end. These cultivars and selections, Pandora, Saint Williams, Or 975-12-72 and Or 967-9-15, were damaged less significantly. In the latter selection, negative alterations were more evident. Its plants kept inconsequential growing yet, despite injuries caused to new immature leaves (fig. 2), and the amount of lower leaves that turned red by the end of the dry period was more significant, over 30%. The plants, unlike those of the other three genotypes, were less vigorous, and their leaves were less tough. All these genotypes were mid-late or late-season. Also, berries of ‘Alice’ and ‘Florence’ ripened in late terms, crowns were vigorous as well; however, leaves were smaller and less tough, which conditioned the differences in response to drought and in damage symptoms.

Fig. 2. Injuries caused to selection Or 967-9-15 (below) by drought

The other period of drought, in 2012, started a bit earlier, when plants of late-season cultivars and selections still bore the last berries, and was several days shorter. Nonetheless, plant behaviour of the same genotypes and damage signs caused to the plants by drought in study 2 differed from those in study 1 insignificantly; only rates of plant damage in the majority of them were a bit less heavy (table 2). Differences between indices of leaf water content of different genotypes were significant both in the middle of the dry period and at its end; tendencies of changing of leaf water contents generally remained alike [9], but results of the last analysis were most indicative. As well as in study 1, damage to plants of ‘Dukat’, ‘Festivalnaya’, ‘Kokinskaya Zarya’, ‘Polka’, ‘Rusich’ and ‘Tsaritsa’ consisted only in turgor loss and wilting. Their plants were injured most significantly.

Table 2. Water contents in leaves, rates of damage caused to strawberry plants by drought, injury types and specifics of genotypes behaviour in study 2

Genotype	Leaf water content (24th August), %	Damage score at the end of dry period	Main kinds of damage and specifics of plant behaviour
Alice	62.7 a	1.7 def	Beginning from week 2 of the dry period, lower leaves started to turn yellow; the process gradually moved on, spreading to other leaves; plants lost the majority of leaves by the end of the period, but kept growing
Alpha	62.0 abcde*	1.4 abc	Partial turgor loss took place, but turgor was usually regained by daybreaks; some lower leaves turned yellow
Dukat	61.3 cdef	1.8 ef	Turgor loss was observed permanently; its regaining was incomplete even after watering; leaves died off practically with no change in colour, beginning from lower ones on
Emily	61.2 def	1.3 ab	Turgor was partially lost in the daytime, but usually regained in the nighttime and after watering, margins of immature upper leaves died back; a number of lower leaves turned red
Festivalnaya	61.4 bcdef	1.7 def	Turgor loss and plant wilting regularly occurred; lower leaves withered without change in colour; the process moved on, spreading to other leaves
Florence	62.3 abcd	1.8 ef	Turgor loss was commonly observed; margins of immature upper leaves died back; lower leaves withered; a few of them turned purplish red
Kokinskaya Zarya	60.8 fgh	1.8 ef	Turgor loss and leaf wilting were typical of plants; turgor was regained poorly; lower leaves withered with no change in colour
Pandora	62.8 a	1.5 bcd	After week 2 tips of upper unfolding leaflets started to die back; lower leaves turned dark red
Polka	61.1 efg	1.6 cde	Turgor loss took place repeatedly; water loss compensation during the nighttime and after watering was incomplete; margins of some upper leaves died back; lower leaves slowly withered
Rannyaya Plotnaya	62.6 a	1.3 ab	Temporary turgor loss and its regaining by the morning time and after watering were distinctive of plants; lower leaves turned red; margins of immature leaves died back
Rubinovy Kulon	62.3 abcd	1.3 ab	Temporary turgor loss and its regaining by the morning time and after watering were characteristic of plants; a few lower leaves turned purplish red and slowly died off
Rusich	62.5 ab	1.9 f	Turgor loss was commonly observed; turgor regaining was incomplete even after watering; lower leaves died off without change in colour
Tsaritsa	60.0 gh	2.2 g	Quick turgor loss and plant wilting were almost permanent; the leaves rolled up; lower leaves died off rather shortly without change in colour
Or 965-7-1	59.9 h	1.5 bcd	Temporary turgor loss and its regaining by the morning time and after watering were typical, but after 3 weeks of the dry period turgor regaining became partial; a few lower leaves died off only

			with slight changes in colour
Or 967-9-15	61.4 bcdef	1.2 a	Turgor loss gradually appeared, thereafter tips of upper immature leaves began to die back; a significant part of lower leaves turned red
Or 975-12-72	62.8 a	1.2 a	Subsequent to week 2 of the dry period growth points of upper leaflets began to die back; growth ceased; a part of lower leaves turned dark red
LSD_{05}	1.2	0.3	–

* Differences between means are not significant at P = 0.05, if any of letters following them coincide

Leaf margins “burn” was observed in cultivars Emily, Florence, Polka and Rubinovy Kulon, as some of lower leaves turned dark red with a violet hue. The same colours appeared on lower leaves of the genotypes that revealed signs of dying back tips of new immature leaves, such as ‘Pandora’, ‘Or 975-12-72’ and ‘Or 967-9-15’. In ‘Alice’, a significant part of leaves turned yellow and withered. In Alpha cultivar, only a few lower leaves turned yellow.

Water contents in leaves of Tsaritsa cultivar and selection Or 965-7-1 were lowest, but plants of the latter were significantly less injured. High leaf water contents in cultivars Alice, Alpha, Florence, Pandora, Rannyaya Plotnaya, Rubinovy Kulon, Rusich and selection Or 975-12-72 were achieved in different ways, and accompanied with dissimilar damage rates. Plants of ‘Alice’ lost two third of their leaves; whereas ‘Pandora’ and ‘Or 975-12-72’ stopped growing and branching, but preserved the majority of leaves; the two latter were capable to regenerate more successfully when the drought period came to its end.

Plant damage rate was negatively correlated with leaf water content (r = –0.73***). However, low water contents in leaves did not unavoidably lead to the heaviest injuries. Plants of ‘Rusich’ and ‘Florence’, despite higher water contents in their leaves, were damaged more significantly compared with plants of selection Or 965-7-1.

Plants of the same genotypes always responded to drought similarly. Dying back tips of new immature leaflets in ‘Pandora’, ‘Or 975-12-72’ and ‘Or 967-9-15’ in study 2 (2012) were somewhat less marked, as well as quantities of lower leaves that gained a red colouration. Lower leaves of ‘Alice’ plants turned yellow, following the same schedule as in study 1; watering had no effect on the process.

Three main groups of strawberry genotypes were discerned by type of response to drought conditions. The first, most widespread reaction type is turgor loss and plant wilting, practically without appearance of any other distinctive signs. These signs of stress appeared in different periods of time, and damage rates were dissimilar. Quick turgor loss at the absence of other symptoms of damage was characteristic of the genotypes with small and compact crowns, medium-sized leaves and thin leaf blades which frequently rolled up. This was evidence of a rather high transpiration rate and an evidently low water-retaining ability [6, 8]. Regeneration of the plants after the drought periods turned out to be practically impossible. Water losses led to incorrect chemical reactions and irreversible alterations in tissues. Cultivars Sumas, Festivalnaya, Tsaritsa and selection Or 965-7-1 belonged to this type. Selection Or 965-7-1 endured the dehydrating stress longer, symptoms were less detectable, and turgor after watering was regained sooner. Most likely, its plants compensated water losses faster thanks to deeper root penetration.

The second type was characterized by appearance of yellow colours on lower leaves which afterwards died off; it was typical of ‘Alice’, ‘Or 1416-7-35’, and, to a significantly lesser extent, of ‘Alpha’. The plants compensated water and nutrients shortage in tissues of new leaves owing to their withdrawal from lower leaves. Removal of nitrogen along with the water was the main reason of appearance of yellow colouring on the lower leaves. Also, other nutrients were withdrawn from the leaves, which led to necroses and multi-coloured specks; the plants kept growing. Plants of these cultivars are moderately vigorous, with thick crowns, but leaf blades are thin or moderately thick and tough. Plants of ‘Alpha’ tolerated rather low leaf water contents more successfully compared with ‘Alice’ and ‘Or 1416-7-35’. Proteins and nucleic acids of plant tissues comprise the largest quantities of nitrogen. Most likely, hot and dry conditions led to coagulation and decomposition of these vitally important compounds in leaves of the two latter genotypes. Water and nutrient transport from dying off leaves to new immature leaflets maintained their growth. Analogous phenomena were observed in a study on egg-plants that was conducted in conditions of drought [11].

The third type of response to drought was characteristic of cultivars and selections with vigorous robust crown and large and thick leaves. Under conditions of long heat and water deficit, growing points of new unfolding leaves began to die back. Dying back of leaf margins of relatively new leaves and particularly of leaf tips of new unfolding leaflets was accompanied by appearance of red colours on lower leaves. The latter turned dark red with a purple hue, which usually is a sign of potassium deficiency in plant tissues. Judging overall, the plants maintained higher water contents in leaves thanks to drastic restriction of transpiration losses. They regained turgor quickly after watering. Growth ceased by the end of the drought periods because of shortage of water and nutrients, but mature leaves were almost completely preserved (leaf losses in selection Or 967-9-15 were more significant). The plants got through the drought and regenerated when it was over more successfully compared with others. ‘Pandora’, ‘Saint Williams’, ‘Or 967-9-15’ and ‘Or 975-12-72’ belonged to this type. Besides, robust plants shaded soil surface better and protected roots from overheating. Reasons of such plant behaviour may be explained with the same molecular mechanisms. Requirements of vigorous plants are higher, hence, water and nutrient lacks told on them earlier. Their lower leaves almost did not die off; therefore, new leaflets got no source of nutrients to keep growing. Plant parts compete for nutrients. In a stress situation, those tissues survived, which not only got water and nutrients, but also could retain them, having maintained more or less normal vital activity. Transpiration losses in this group of genotypes were evidently low, but water uptake from the soil was also strictly limited. This resulted in dying back growing points of new leaves and inhibition of growth processes. In cultivars Emily, Florence and Rannyaya Plotnaya, plants of which were about to finish growing, damage was revealed as “burn” of leaf margins. Dark red colours of lower leaves are evidence of removal of cations from them, but, apparently, no dissimilation of proteins and nucleic acids occurred; leaves remained functioning for a long time.

Genotypes within each of the three groups differed from each other in damage rate, to some extent in combination of symptoms and in water content of unharmed leaves. Indices of leaf water content were fully matching with analogous indices obtained in 2002 on the genotypes that were included in the study carried out in that year [13], where maiden plants were subjected to drought impact. Divergences in values were negligible. Damage symptoms of the genotypes that were included in both studies of this research repeated themselves with minor differences.

Thus, strawberry plants responded to heat and severe water deficit in soil and plant tissues in three main ways: (1) turgor loss and wilting; except for a very few ones, these were genotypes least resistant to drought; (2) withdrawing water from the oldest leaves and its re-distribution; appearance of autumn colouration on lower leaves and their gradual dying off; these plants withstood drought somewhat more successfully, but only on an initial stage; and (3) inhibition of growth process, dying back growing points of new unfolding leaflets at the maintenance of relatively high tissue water contents and rather low transpiration rate.

The genotypes, which originated from locations with a relatively cool climate and high annual precipitation, generally appertained to the first type. Belonging to the second type allowed plants withstanding drought for some time thanks to re-distribution of their inner water. Such genotypes were more tolerant to water deficiency, but they did not possess resistance to high positive temperatures and long-lasted soil drought. Most likely, their roots partially lost the ability to absorb water at high soil temperatures, while transpiration rate remained rather high. The third type comprised the most resistant genotypes which under threat of dehydration switched on mechanisms leading to minimal water losses. These plants were able to withstand hot and dry conditions more successfully, although their potentials also differed.

‘Sunas’, ‘Festivalnaya’, ‘Tsaritsa’ and ‘Or 1416-9-12’ were susceptible to drought conditions. Selection Or 965-7-1 was tolerant to lower tissue water contents compared with others. Plants of ‘Alice’, ‘Alpha’, ‘Pandora’, ‘Saint Williams’ and ‘Or 975-12-72’ maintained top levels of leaf water content, but they differed in ways which they used to achieve it.

Sphere of putting results into practice

The results may be successfully used at selecting strawberry cultivars for commercial growing in conditions close to studied; testing of other strawberry cultivars for drought resistance; for assessment of selections, contestants to become cultivars, and hybrid seedlings for drought resistance, using the data obtained during the evaluations, classification of the genotypes and symptomatic revelations of plant responses to drought conditions.

Conclusions

1. Drought resistance of strawberry is dependent first of all on capability to strictly control transpiration rate and to maintain high water contents in leaf tissues. Only selection Or 965-7-1 was distinguished for the ability to endure relatively low water contents in leaves (close to 60.0 %). Of high importance was the way used by plants to maintain high tissue water content.

2. The strawberry genotypes under study demonstrated three main types of behaviour in drought conditions. The first one that revealed itself as turgor loss and leaf wilting at the absence of any other particulars of behaviour was distinctive of cultivars least resistant to drought. The second one was distinctive of those maintaining high levels of tissue water content generally by re-distribution of inner water and nutrients from old leaves to more active newer ones. They possessed a higher tolerance to drought, but poorly endured its long-lasted periods, especially if they quickly lost leaves at very high temperatures (Alice cultivar). The third type was characteristic of cultivars and selections that maintained high water contents in mature leaves (over 62.0%) thanks to strictly limited transpiration rate and

inhibition of growth processes. Plants of the same genotypes under drought conditions always behaved similarly.

3. Cultivars and selections of the third type, with fairly robust thick crowns and large thick leaves, withstood long-lasted drought conditions better compared with others. Among them, cultivars Pandora, Saint Williams, and selections Or 967-9-15 and Or 975-12-72 resisted drought most successfully.

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Main types of response of strawberry genotypes to drought and their relation to drought resistance

Summary

Aim of the research carried out in two studies under drought conditions, in 2010 and 2012, in the Orel district, was to find out specifics of strawberry genotypes response to drought leading to differences in drought resistance. Plant damage rate was visually estimated, and injury signs, time of their appearance and specifics of behaviour habits of cultivars and selections were recorded. In study 2 in 2012, leaf water contents were also determined, using methods of weighing before and after drying up. Genotypes were discerned into three groups, in accordance with response to drought and symptoms appearance. The most sensitive cultivars were those whose response appeared as turgor loss, wilting and gradual dying off leaves without colour change. The genotypes, which compensated water lack in young leaf tissues, withdrawing it up along with nutrients from the older lowest leaves, which was accompanied by their turning up yellow and rapid dying off, withstood drought slightly longer. Cultivars and selections that developed vigorous crowns with large and tough leaves—Saint Williams, Pandora, Or 967-9-15 and Or 975-12-72—resisted drought more successfully, maintaining high levels of leaf water content (higher than 62.0%) at the cost of growth breaking, which showed itself as dying back tips and margins of young leaves, and at the cost of redistribution of a part of inner water from the lowest leaves that turned dark red to upper ones. Having preserved the majority of leaves, they better succeeded in plant regeneration when the drought period ceased. Although drought resistance varied within each group, genotypes of the last type were on average more adapted to growing in conditions of insufficient watering and high summer temperatures.

Keywords: *Fragaria* x *ananassa* Duch., cultivar, selection, water stress, drought resistance