Chapter

Physiological Features of Red Currant Adaptation to Drought and High Air Temperatures

Panfilova Olga Vitalevna, Golyaeva Olga Dmitrievna, Knyazev Sergey Dmitrievich and Kalinina Olga Vitalevna

Abstract

An important requirement for varieties is adaptation to growing conditions. The main indicators of water regime, photosynthesis, and productivity of representatives of different species of *Ribesia* (Berl.) Jancz. subgenus to drought and high temperatures have been studied. Quantitative and qualitative changes of the photosynthetic apparatus are the response to drought and high temperatures. The ratio of chlorophylls to carotenoids is considered to be one of the indicators of adaptability. The total water potential in red currant leaves depends on shoot growth, leaf age, berry formation, variety, and weather conditions, and it is not the main indication of drought resistance. The ratio of bound and free water and water-holding capacity of the leaves is considered to be a determining sign of resistance to hyperthermia. Red currant genotypes do not possess high indicators of heat resistance. The prospects of using physiological rapid diagnostic methods in breeding for adaptability to destructive factors of the growing season are shown. The representatives of *Ribes petraeum* Wulf. ("Hollandische Rote") and *R. multiflorum* Kit. (1426-21-80) have high levels of drought resistance, making them highly potential for wider growing in (semi)arid agroecological condition.

Keywords: *Ribesia* (Berl.) Jancz. subgenus, genotypes, drought resistance, heat hardiness, water regime

1. Introduction

The ecological factors of the environment play an important role in the resistance of fruit plants, their productivity, and crop quality [1, 2]. Global climate change is now threatening. Air and soil summer droughts reduce the quality and quantity of horticultural products. Weather anomalies lead to an imbalance of the protective mechanisms of fruit and berry crops and adversely affect the physiological processes occurring in plants [3, 4]. Recently, the task to obtain new high-yielding, precocious genotypes with an amplitude of adaptation to different conditions, with a high content of nutrients and biologically active substances in the fruit, is faced by scientists from different countries [5]. The search of express methods of plant diagnostics to destructive factors of the environment is a priority direction. It is known that the temperature increase causes morphological and anatomical, physiological, and biochemical changes, which affect the growth and development of plants and can lead to large economic losses

[6, 7]. The study of morphological features, structure of photosynthetic apparatus, and water exchange of plants in connection with the area of growth is the main condition for solving fundamental and applied problems in the biology of the culture. The use of physiological and biochemical rapid methods of diagnostics of plant resistance to adverse weather and climatic factors can significantly optimize the long breeding process, minimize crop losses, and obtain genotypes resistant to the destructive effects of climatic anomalies [8–10]. Plant organisms have different mechanisms of adaptation to stressors [9, 11]. Xeromorphic structure of a plant leaf, changes in a pigment complex, and water balance are important diagnostic signs of drought resistance and heat resistance [12–14]. Issues of adaptation of berry crops to drought and high temperatures are poorly studied. Red currant is one of the valuable berry crops due to the high content of vitamins, microelements, sugars, and organic acids. It is valued as a source of healthy nutrition [15–18]. Vitamin and the healing properties of the berries of this culture are also preserved in processed products [19]. Introduction is considered to be an important link in the distribution and production of new red currant genotypes. The success of the introduction is determined by the nature of the interaction of hereditary biological characteristics of plants with specific environmental conditions [18]. Red currants belong to the *Ribes* L. genus and *Ribesia* (Berl.) Jancz. subgenus. As a culture, it was developed on the basis of four species, i.e., *Ribes vulgare* Lam., *Ribes petraeum* Wulf., *Ribes multiflorum* Kit., and *Ribes rubrum* L., and their hybrids [20]. The world assortment of the *Ribes* L. genus includes more than 200 varieties; however, the genetic resources of the *Ribesia* (Berti.) Jancz. subgenus are poorly studied, since there are a number of wild species that exceed the existing varieties by a number of economic and biological characteristics [21].

2. Anatomical, morphological, and physiological changes of a red currant leaf due to drought and high temperature

The study of the assimilation apparatus in red currants gives a complete picture of the plasticity of the genotype in relation to the ecological factors of the environment [11, 22–24]. The investigation of the anatomical and morphological features of red currant leaf structure showed that some morphological features, such as shape and venation, depend on the biological characteristics of the variety and the anatomical structure is more influenced by the growing conditions. During the periods with insufficient water supply, the leaf surface area decreased in all studied currant samples compared to optimal conditions. A positive relationship between leaf area and hydrothermal coefficient ($r = +0.99$) and a negative relationship between leaf area and ambient temperature ($r = -0.97$) were identified [10]. Rezanova [14], Patzukova [25], Tokhtar [18], and Panfilova [2] studied the anatomical structure of currant leaves and described the structure of the stomatal apparatus and the conduction system of *Ribes rubrum* L. and *Ribes American* L. According to anatomical studies, the red currant leaf had a mesomorphic structure characteristic of the *Ribesia* (Berl.) Jancz. subgenus. Spongy parenchyma prevailed over palisade parenchyma, epidermal cells were large enough, and on the upper side of the leaf, they were larger than on the lower one (**Figure 1**) [10]. It is shown that stomata are formed on the lower side of the leaf rarely and unevenly, at the level of the epidermis. There are varietal species differences in the size and number of stomata per 1 mm^2 of leaf area, in the length of the closing cells, and in their shape. The size of stomata and the degree of their openness depend on the temperature and humidity of the air. During the drought, the degree of stomata opening decreases sharply.

The index of leaf mesostructure is labile in red currant genotypes of different ecological and genetic origins, including *Ribes petraeum* Wulf. ("Hollandische Rote"

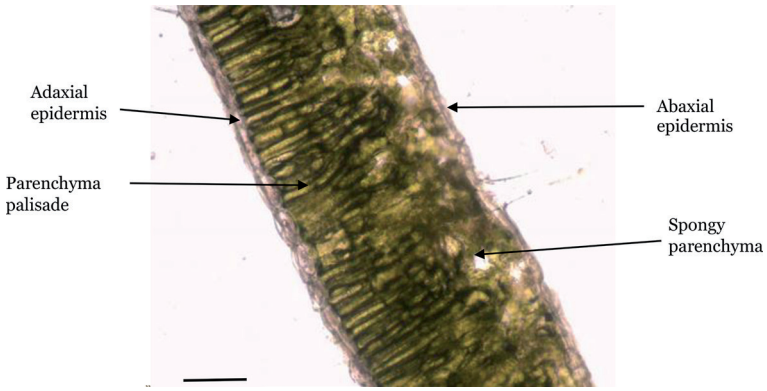


Figure 1.
Anatomical structure of a red currant leaf (cross sectional view, ×40), R. vulgare Lam. Bar represents 10 μm.

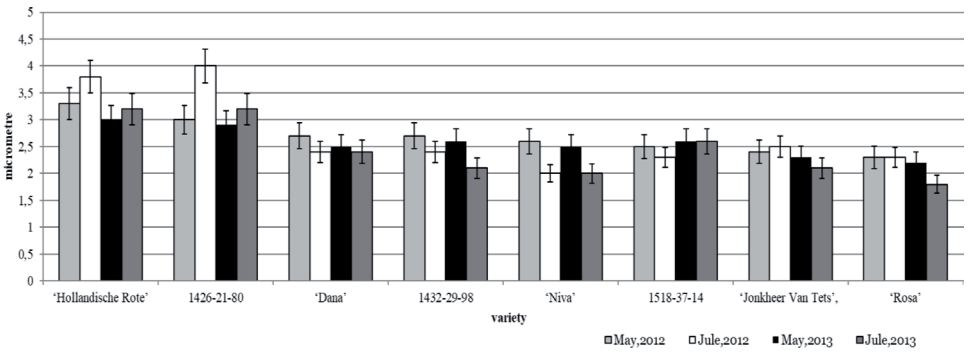


Figure 2.
The average size (±S.E.) of the cells of adaxial epidermis of a leaf in red currant varieties and selected genotypes of the Russian Research Institute of Fruit Crop Breeding, Orel [10].

and 1518-37-14), *Ribes vulgare* Lam. ("Jonkheer Van Tets," "Niva" and "Rosa"), and *Ribes multiflorum* Kit. ("Dana," 1426-21-80 and 1432-29-98), depending on the genotypes and phase of plant development.

High temperature and drought had different effects on cell size of adaxial epidermis and leaf mesostructure. In drought periods (2012, 2013) at the stages of active growth of shoots and formation of berries, the main cells of the adaxial epidermis in "Hollandische Rote" (*Ribes petraeum* Wulf) and 1426-21-80 (*Ribes multiflorum* Kit.) under the action of high temperatures (up to +31.2 … +28.6°C in May and +32.2 … +31.5°C in July) were somewhat stretched due to the decrease in turgor of the cells. The remaining samples showed cell compression in the tangent direction (parallel to the stem surface) (**Figure 2**).

Increased temperature and drought lead to the growth of parenchymal cells and increase of the overall thickness of the leaf (**Table 1**). The growth of mesophyll cells occurs mainly due to the increase in the volume of air-bearing cavities of the spongy parenchyma, which contributes to the improvement of gas exchange between the leaf and the environment (**Figure 3**).

In some previous studies [2, 26, 27], it was confirmed that significantly greater growth of spongy parenchyma cells and leaf blade thickness in dry periods were found in most samples of *Ribesia* (Berl.) Jancz. (with the exception of "Niva"). The largest increase in the thickness of the leaf was noted in "Hollandische Rote" and 1426-21-80. The authors consider these changes as a manifestation of high

Variety name/code (B)	Year (A)								
	2011			2012			2013		
	PP	SP	TLT	PP	SP	TLT	PP	SP	TLT
1426-21-80	10.29	13.62	26.94	12.00	20.00	37.30	9.75	15.80	29.91
"Hollandische Rote"	9.56	15.24	27.70	11.25	18.45	35.35	9.55	16.95	31.40
"Niva"	9.28	12.65	24.63	10.15	15.35	29.60	10.35	15.30	29.10
"Dana"	8.10	12.00	22.70	10.05	16.30	29.92	9.10	14.85	27.70
1432-29-98	7.90	12.35	23.25	11.65	17.55	33.65	10.15	15.10	29.10
1518-37-14	7.70	14.68	25.38	9.15	18.15	30.80	8.55	16.90	29.15
"Jonkheer Van Tets"	7.30	10.10	20.33	10.50	15.90	30.05	9.00	12.30	24.80
"Rosa"	6.80	11.23	20.53	7.95	13.85	25.60	8.10	13.80	25.10

Notes: PP—palisade parenchyma, μm; SP—sponge parenchyma, μm; TLT—total leaf thickness, μm. LSD_{05} for palisade parenchyma A = 1.57, B = 2.56, and AB = 4.42; LSD_{05} for sponge parenchyma A = 1.92, B = 3.14, and AB = 5.43; LSD_{05} for total leaf thickness A = 1.39, B = 2.27, and AB = 3.93.

Table 1.
Leaf mesostructural parameters in red currant varieties from the Russian Research Institute of Fruit Crop Breeding, Orel, in 2011–2013 vegetation period [10].

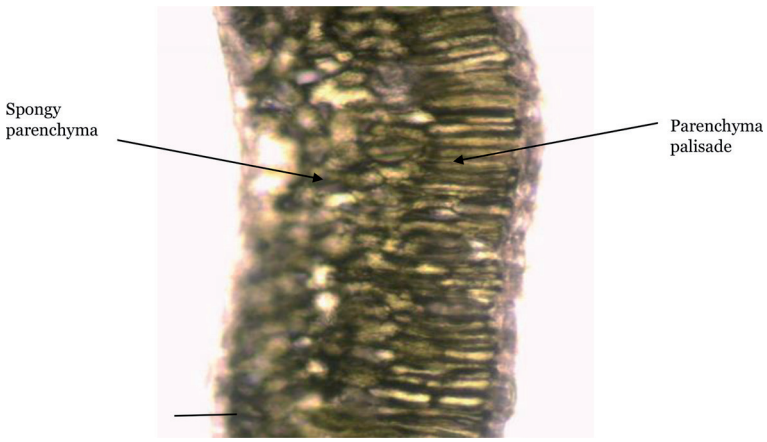


Figure 3.
The leaf mesophyll cells in a red currant exposed to drought ((cross sectional view, ×40), R. multiflorum Kit.). Bar represents 10 μm.

adaptability of the anatomical structure of the leaf to stressors (high temperature) during the growing season (**Table 1**).

Knowledge of the anatomical structure of the leaves helps to fully reveal the biological characteristics of the variety and species as well as the flow of the most important physiological processes [28]. In the process of evolution, many currant species have acquired a high potential of photosynthetic productivity, and, for the most part, in the real environment, this potential is not fully used [29, 30].

Drought is one of the reasons for the decrease in the intensity of photosynthesis, respiration, and changes in the hormonal status of plants. Violation of hormonal metabolism significantly increases the process of natural fall of the ovaries of red currants, as well as the appearance of necrotic points on the leaves and a decrease in the number of laid generative buds; leads to a decrease in yield, during both current and subsequent years; and also reduces the stability of plants in winter [31–33].

The process of photosynthesis largely depends on the quantitative and qualitative composition of pigments. Changes in the pigment complex can be considered as important mechanisms of culture adaptation to environmental conditions. The impact of high temperatures and low soil moisture leads to a decrease in the concentration of chlorophyll [22, 34–36]. Studies of different red currant species have confirmed the impact of air and soil drought on the work of the assimilation apparatus.

In the dry period (in the Orel region it was 2012), there was a decrease in the content of chlorophyll *a* and chlorophylls *a+b* in the leaves of all red currant genotypes in comparison with the favorable weather conditions (2011) (**Figure 4**).

A sharp (maximum) decrease in the number of pigments was observed in all derivatives of *R. vulgare* Lam. in 2012; the minimum decrease was observed in the representatives of *R. petraeum* Wulf. and *R. multiflorum* Kit. A slight decrease in drought in 2013 contributed to a slight increase in pigment content.

Drought at high temperatures stimulates the formation of carotenoids in the cell, which is consistent with the literature data on the protective function of this group of pigments under stress [5, 37, 38]. In the representatives of *Ribesia* (Berl.) Jancz. subgenus, the content of carotenoids in drought conditions increased by 2–3 times compared to a favorable period. A positive correlation in red currants was found between the carotenoid content and temperature (r = +0.77) [2, 10]. An indirect indicator of drought resistance and high temperature is the ratio of the sum of chlorophylls to carotenoids [23, 39, 40]. In stressful conditions, the high value of this indicator was observed in the variety "Hollandische Rote" (the value of the coefficient 5.14) and the selected form 1426-21-80 (the value of the coefficient 5.51), which may indicate the stability of these samples to drought and high summer temperatures. Hydrothermal regime affects productivity by affecting the functional state of plants, which was confirmed by high correlations between the amount of chlorophyll *a* and yield (r = +0.85) and the sum of chlorophylls and yield (r = +0.78) [10].

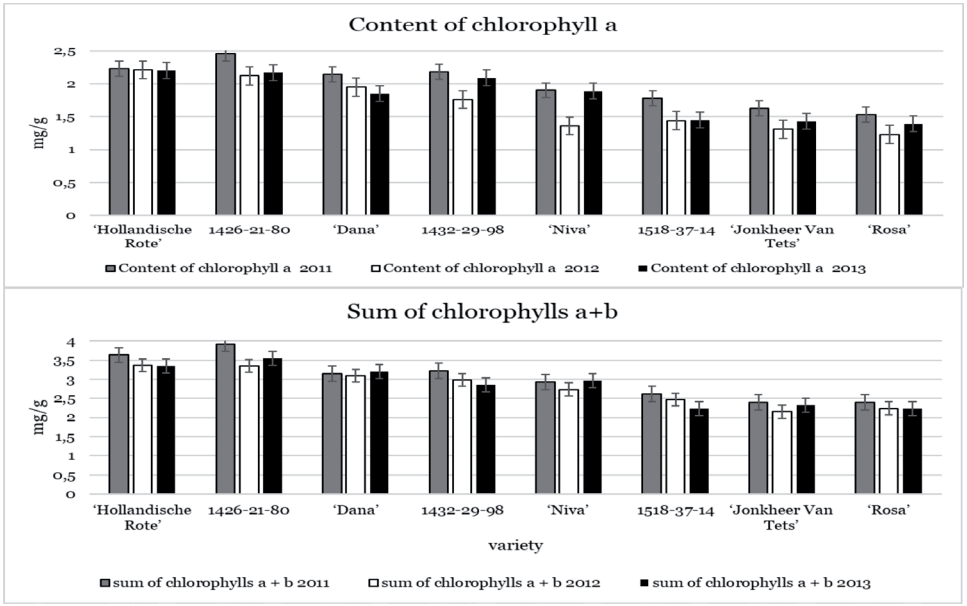


Figure 4.
Content of chlorophyll a and sum of chlorophylls a+b in red currant varieties and selected genotypes of the Russian Research Institute of Fruit Crop Breeding, Orel [10].

3. Features of water regime in red currants (drought resistance, heat hardiness)

Changes in the hydration of tissues and their water balance under the influence of adverse environmental conditions are reflected in the level, direction, and relationship of physiological processes that determine the formation of the crop and its quality. The ability to retain and economically consume water in arid conditions is a protective and adaptive reaction of resistant plants, which is due to a number of internal factors [33, 43].

It is established that the increase of water-holding capacity of leaves in extreme conditions of water supply allows stable red currant plants to regulate water metabolism [33, 41]. High water-holding capacity against the background of low water potential (61–67%) was observed in the varieties "Jonkheer Van Tets," "Hollandische Weisse," and "Englische Grosse Weisse." It is noted that the water potential of red currant leaves is not the main indicator of plant resistance to drought, because it depends on a number of factors (weather and climatic conditions, genotype, leaf age, shoot growth, and berry formation). The maximum reduction of water potential of leaf tissues in representatives of the subgenus *Ribesia* (Berl.) Jancz. occurs during the formation of berries, as most of the water is used to form the ovary [10, 42].

The resistance of red currants to hyperthermia is determined by the high content of bound water and water-holding capacity of leaves, low water deficit, and intensity of transpiration [43–45]. High values of the coefficient of bound water to free water and minimal water losses were observed in the variety "Hollandische Rote" and selected form 1426-21-80. The genotypes of these samples of *R. petraeum* Wulf. and *R. multiflorum* Kit. species exhibit higher adaptability to high temperatures against the background of soil moisture deficit (**Table 2**) [10]. In terms of transpiration intensity, red currant samples exhibit different mechanisms of adaptation to drought: either reduce the level of transpiration intensity (plants save water) or the level of transpiration intensity remains high (drought level for these genotypes is not critical) [43].

The relationship between physiological characteristics was revealed in representatives of different red currant species, which was confirmed by the coefficient of pair correlation between the amount of chlorophylls and water loss ($r = -1.00$), the amount of chlorophylls, and the amount of free water ($p = +0.98$). The content of pigments, fractional composition of water, and water-holding capacity of the leaf were associated with the development of water deficit, which depended on the air temperature ($r = +0.84$). The relationship between water regime indicators and meteorological features of the growing season was described using multiple regression coefficients (**Table 3**) [10].

In the study of plant resistance to abiotic environmental factors, their ability to withstand high air temperatures is important. Abnormally high temperatures, regardless of the dehydrating effect of dried soil and air, lead to disruption of water metabolism in plants and damage to membranes and proteins of the cell [46–50]. In this regard, an important feature of the variety is heat resistance [51]. Heat resistance largely depends on the duration of high temperatures and their absolute value. Temperature limits are specific to an individual genotype. In most cases, fruit plants begin to suffer when the temperature rises to 35–40°C. At these and higher temperatures, normal physiological functions are inhibited, and at temperatures around 50°C protoplasm, coagulation and cell death may occur. The exceeding the optimum temperature level leads to partial or global denaturation of proteins. In heat-resistant genotypes in the lipid complex, the saturated fatty acids predominate, and their appearance is a consequence of adaptation to this damaging factor. The mechanism of increasing the heat resistance is interconnected with the genetic apparatus of the cell and is aimed at stabilizing the membrane lipids in the direction of reducing their poly saturation. Under the action of elevated temperatures in the cells, the synthesis of stress proteins is induced [52]. Heat resistance is also associated with a certain

Variety name/code (B)	Year (A)							
	2011		2012		2013		Average	
	BW/FW	**WL, %**	**BW/FW**	**WL, %**	**BW/FW**	**WL, %**	**BW/FW**	**WL, %**
"Hollandische Rote"	1.33	35.82	2.09	20.36	2.03	21.11	1.82	25.76
1426-21-80	1.31	36.16	2.41	20.62	2.09	19.37	1.94	25.38
1432-29-98	1.12	30.17	1.42	25.01	1.20	26.98	1.25	27.39
"Jonkheer Van Tets"	1.01	38.10	1.31	21.85	1.04	27.40	1.12	29.12
1518-37-14	0.96	40.91	1.06	27.62	1.08	26.66	1.03	31.73
"Niva"	0.82	42.56	1.71	24.84	1.50	25.58	1.34	30.99
"Dana"	0.70	40.97	1.76	25.51	1.66	25.44	1.37	30.64
"Rosa"	0.63	39.75	0.98	26.82	0.87	27.85	0.83	31.47
LSD_{05}	0.08	2.06	0.11	3.03	0.14	1.86		

Notes: BW/FW—ratio of bound and free water; WL—water loss in 24 hours; % of water content, LSD_{05} for BW/FW^—A, 2.18; B, 4.59; and AB, 7.95; and LSD_{05} for WL—A, 0.13; B, 0.21; and AB, 0.37.

Table 2.
The main indicators of the water regime in red currant varieties from the Russian Research Institute of Fruit Crop Breeding, Orel, in 2011–2013 vegetation period [10].

Indicator	Regression ratio
Hydration	0.90×F; r = 0.22
Free water fraction	0.84×F; r = 0.33
Water loss	−0.88×F; r = 0.30

Notes: F—the values of hydrothermal coefficient; and r—the standard error of the experiment.

Table 3.
Correlation between physiological indicators and meteorological conditions in studied red currant varieties from the Russian Research Institute of Fruit Crop Breeding, Orel [10].

stage of plant development: young actively growing tissues are less stable than old ones. For berry plants, high temperatures are especially dangerous during flowering, because they cause sterility of flowers and the fall of ovaries. Plant organs differ in their heat resistance: shoots and buds are most stable, and the root system is less stable. The cambial tissue is most stable among tissues.

Russian and foreign researchers have achieved certain results in the study of water metabolism and physiological and biochemical parameters of resistance of fruit plants and developed methods for determining heat resistance. Water loss and the degree of water content recovery are informative indicators of heat resistance assessment [34, 53–64].

The effect of temperature "shock" +50°C on the red currant genotypes showed that this culture does not have high heat resistance. Leaves at a young age (less heat-resistant) are most severely damaged by high temperatures; the older the leaf, the higher its heat resistance [65]. The degree of water recovery in red currant leaves increases by the time of berry ripening. The leaves of red currant genotypes recover water better during berry ripening and are less susceptible to damage by temperature +50°C; they are more heat-resistant than the leaves during the active growth of shoots. One hundred percent recovery of water loss does not occur after exposure to temperature stress (+50°C) on the leaf. The most heat-resistant varieties are considered "Niva" (*R. vulgare* Lam.) and "Hollandische Rote" (*R. petraeum* Wulf.) [66].

Field assessment of red currant plants was carried out in Adygea after a long and gradually increasing heat in 1998. "Jonkheer Van Tets," "Natali," "Nenagliadnaya," "Boulogne Blanche," and *Ribes biebersteinii* Berl. showed resistance to heat (damage up to 2.5 points). The red currant samples of "Englische Grosse Weisse," "Hollandische Weisse," "Boulogne Rouge," "Versailles Rouge," "White Viksne," "Hollandische Weisse," and "London Market" dropped all the leaves, but the kidneys were still alive. Necrotic spots of different degrees appeared on the leaves of "Jonkheer Van Tets," "Nenagliadnaya," and "Boulogne Blanche" [33].

4. Conclusion

Summarizing the above, it can be approved that the problem of drought resistance and heat resistance of varieties is currently particularly acute. The increase of variety stability now gets the great relevance, since the numerous experiments prove that only the use of the adapted varieties and the transition to adaptive, biological, and low-cost technologies of cultivation of fruit-growing production are possible [67]. Many issues related to the peculiarities of the water regime and physiological and biochemical processes remain unclear. In our work we have shown that berry crops, including red currants, have complex and little-known mechanisms of adaptation to drought and abnormally high temperatures. The prospects of using physiological methods in assessing the resistance of *Ribesia* (Berl.) Jancz samples to adverse weather factors have been proved. The obtained results were fully confirmed by field observations of stability of red currant varieties and selected forms under conditions of high temperature and moisture deficit. This makes it possible to use the considered methods as a rapid diagnostics and significantly intensify the selection for adaptability. As shown by the complex physiological assessment, the derivatives of different species of the *Ribesia* (Berl.) Jancz subgenus have a different ecological plasticity, which is explained by the difference of their genetic and ecological-geographical origins. The derivatives of different species of the *Ribes petraeum* Wulf. ("Hollandische Rote") and *R. muliflorum* Kit. (1426-21-80) showed the greatest resistance to dry conditions of the vegetation period in the Central Chernozem Region that gives reason to use them in introduction. Low drought resistance was observed in the varieties and selected forms of *Ribes vulgare* Lam.

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