Physiological response of Phlox paniculata L. varieties to different growing conditions of Western Siberia

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Abstract. Physiological indicators of plants are essential characteristics of plant adaptation to adverse environmental factors. *Phlox paniculata* varieties (originated from North America) introduced into the southern taiga subzone of Western Siberia experience stress caused by numerous factors. The physiological response to different growing conditions of the southern taiga subzone of Western Siberia was analyzed for 3 varieties of *Ph. paniculata*. The study employed handheld optical instruments for vital analysis of plant physiological parameters: a compact LI-600P porometer (LI-COR) and a CI-710 leaf spectrometer (CID Bio-Science). Stomatal conductance of phlox leaves in partial shade studied with respect to different varieties was found to virtually remain unchanged. The studied varieties exhibit different degree of resistance to water deficiency. The variety 'Stanislas' was found to be resistant to insufficient soil humidity and light, it can be grown in both moderately shaded areas and arid conditions. The studied varieties showed high indices of anthocyanins and carotenoids under good light conditions and natural humidity, which indicates these conditions as the most stressful for *Ph. paniculata* due to a high degree of water and temperature stress. The greatest difference in the measured indices was found for the variety 'Antarktida', which indicates its susceptibility to water deficiency.

1 Introduction

Phlox includes numerous interspecific hybrids and varieties, many of which have formed independent groups. *Phlox paniculata* L. is the most valuable ornamental crop known for long flowering, a huge variety of flower colors, responsiveness to care, and better winter hardiness [1]. The species is native to eastern North America (Mississippi River basin), the USA, the states from New York to Georgia, and westward to Illinois and Arkansas. Under natural conditions, *Phlox paniculata* typically grows in wetlands, river floodplains, wet meadows among shrubs, and in moist forests [2-4]. Phlox as an ornamental plant is extensively grown around the world; large breeding centers are located in Europe – France, Holland, Germany, and in Russia. The popularity of phloxes is constantly increasing;

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however, in Western Siberia, not all varieties can adapt to sharply continental climatic conditions [5].

The quality of flower products depends on hereditary characters of varieties and hybrids, the quality of the planting material, personnel, the cultivation technology used, and environmental factors (light and heat conditions, ambient humidity and root environment, etc.) [6]. Resistance of different phlox varieties to abiotic factors differs, which affects their vegetative and generative characters.

Varieties bred from *Phlox paniculata*, which grew in natural habitat under much milder conditions of the forest zone in eastern North America, experience stress caused by numerous factors when introduced into the subzone of the southern taiga of Western Siberia. For example, in the natural species habitat, the average annual precipitation attains 1000–1500 mm, and the average annual temperature is about +17 °C [7]; the city of Tomsk and its environs belong to the zone of moderate humidity; the average annual precipitation attains 517 mm, and the average annual temperature is –0.6 °C [8].

Important indicators of plant adaptation to adverse environmental factors include the rate of photosynthesis and transpiration, stomatal conductance, and other functional state indicators. These indicators can be attained using spectral handheld instruments for vital analysis of plants, which greatly facilitate experimental data acquisition. In Russia, such studies are meager and are conducted mainly on agricultural crops [9–11]; therefore, this study is of current relevance.

The aim of the study was to analyze the physiological response of 3 varieties of *Phlox paniculata* grown under different conditions of the southern taiga subzone of Western Siberia.

2 Materials and methods

The experiment was launched in 2020 in the territory of the Siberian Botanical Garden, Tomsk State University (Tomsk, Russia); measurements were performed in 2022. The study objects were 3 phlox varieties: ‘Antarktida’ (A.F. Chigaeva, 1957, Tomsk), ‘Stanislas’ (M. Gerbeaux, 1904, France), ‘Panama’ (V. Lemoine, 1888, France), bred in different regions, which show stability under growing conditions of the southern taiga subzone of Western Siberia. The plants were grown on a plot with gray forest podzolized cultivated soils [12]. We used 3 variants of experimental conditions to cultivate 5 individuals of the studied phlox varieties:

1 and 2. Partial shade and good light conditions with humidity natural for the southern taiga subzone of Western Siberia, which is insufficient for invasive species from North America. The amount of precipitation during the active growing season (May–August) is 295 mm.

3. Partial shade, natural and extra humidity (1 or 2 times a week as the soil dries up). This experimental version mimics the natural habitat of *Phlox paniculata*. The amount of precipitation during the active growing season (May–August), including extra humidity, is 623 mm.

For assessment of the physiological state of plants, stomatal conductance and transpiration rate were measured using a compact LI-600P porometer (LI-COR). This device was also used to measure the microclimatic variables of the experimental conditions (Table 1).

Other physiological indicators were studied using a CI-710 miniature leaf spectrometer (CID Bio-Science): Anthocyanin Reflectance Index I, Chlorophyll Normalized Difference Vegetation Index, Chlorophyll A, Chlorophyll B, Chlorophyll Total, Carotenoid Reflectance Index I, Carotenoid Reflectance Index II, Normalized Difference Vegetation Index, Structure Intensive Pigment Index, Water Band Index. In each experimental version, we measured 15–20 leaves of 5 individuals of each variety during mass flowering.

Table 1. Characteristics of the experimental microclimatic conditions when measuring physiological indicators.

Characteristic	Conditions		
	Light + natural humidity	**Partial shade + natural humidity**	**Partial shade + extra humidity**
Ambient light, photosynthetically active radiation, umol·m^{-2}·s^{-1}	1070.89	545.11	469.75
Relative humidity, %	42.91	43.33	44.60
Air temperature, °C	20.45	20.65	18.99
Leaf temperature, °C	21.47	19.46	16.31

Leaf sizes were measured on scanned copies using the Axio Vision 4.8 software. In each experimental version, we measured not less than 25 leaves from the middle part of the shoots of 5 individuals of the studied varieties.

The measurement results were statistically processed using Statistica 8.0. For the measured values, the arithmetic mean *M* and the arithmetic mean error *m* were calculated. When assessing the statistical significance for independent samples, we evaluated the t-test statistic value calculated assuming similarity in sample variances, the t-test statistic value calculated assuming difference in sample variances, and the F-test statistic value. Statistically significant differences were determined at a significance level of $p < 0.05$.

3 Results

The results of the study show that the stomatal conductance of phlox leaves virtually does not change in different varieties grown in partial shade. Thus, the stomatal conductance was 0.23 mol·m-2·s-1 for the variety ‘Antarktida’, 0.21 for the variety ‘Panama’, and 0.26 for the variety ‘Stanislas’ grown in extra humidity; in natural humidity, it attained 0.21, 0.22 and 0.22, respectively; no statistically significant differences were found. Under good light conditions, the variety ‘Panama’ exhibited a 2-fold decrease in the stomatal conductance of leaves (0.14 mol·m-2·s-1), and the variety ‘Antarktida’ showed a 3-fold decrease (0.06), while the variety ‘Stanislas’ maintained a high level of stomatal conductance (0.29) and did not exhibit statistically significant differences (Table 2). Consequently, the studied varieties show different degree of tolerance to water deficiency.

Table 2. Stomatal conductance and transpiration rate of *Phlox paniculata* varieties grown under different conditions.

Variety	Characteristic	Conditions		
		Light + natural humidity	**Partial shade + natural humidity**	**Partial shade + extra humidity**
‘Antarktida’	Stomatal conductance, mol·m^{-2}·s^{-1}	0.06^{B}±0.01	0.21^{A}±0.01	0.23^{A}±0.01
	Transpiration, mmol·m^{-2}·s^{-1}	1.12^{C}±0.15	2.20^{A}±0.10	1.66^{B}±0.07
‘Panama’	Stomatal conductance, mol·m^{-2}·s^{-1}	0.14^{B}±0.01	0.22^{A}±0.01	0.21^{A}±0.01
	Transpiration, mmol·m^{-2}·s^{-1}	2.10^{B}±0.15	2.96^{A}±0.18	1.92^{B}±0.10
‘Stanislas’	Stomatal conductance, mol·m^{-2}·s^{-1}	$0.29^{A,C}$±0.02	0.22^{B}±0.01	$0.26^{B,C}$±0.02
	Transpiration, mmol·m^{-2}·s^{-1}	3.11^{A}±0.15	2.40^{B}±0.10	1.96^{C}±0.12
Note – Within each line, letters indicate statistically significant differences at a significance level of $p < 0.05$				

Under good light conditions, leaves of the variety 'Stanislas' exhibited a high level of stomatal conductance and transpiration (and higher leaf temperature).

The study of the morphometric characteristics of phlox leaves showed the smallest leaf sizes in partial shadow for the European varieties 'Panama' and 'Stanislas' with the length, width and leaf area increased by 15–45% under good light conditions (Table 3).

Table 3. Leaf sizes of *Phlox paniculata* varieties grown under different conditions.

Variety	Characteristic	Conditions		
		Light + natural humidity	Partial shade + natural humidity	Partial shade + extra humidity
'Antarktida'	Leaf length, cm	$7.67^{C}\pm0.12$	$10.33^{A}\pm0.13$	$9.58^{B}\pm0.13$
	Leaf width, cm	$2.29^{C}\pm0.05$	$3.12^{A}\pm0.05$	$2.86^{B}\pm0.06$
	Leaf area, cm^2	$11.42^{C}\pm0.45$	$19.67^{A}\pm0.48$	$17.16^{B}\pm0.56$
'Panama'	Leaf length, cm	$11.58^{A}\pm0.22$	$9.51^{B}\pm0.17$	$9.53^{B}\pm0.23$
	Leaf width, cm	$3.16^{A}\pm0.08$	$2.77^{B}\pm0.07$	$2.14^{C}\pm0.06$
	Leaf area, cm^2	$21.66^{A}\pm0.94$	$16.83^{B}\pm0.60$	$12.53^{C}\pm0.63$
'Stanislas'	Leaf length, cm	$10.95^{A}\pm0.16$	$9.25^{C}\pm0.16$	$9.76^{B}\pm0.12$
	Leaf width, cm	$3.50^{A}\pm0.04$	$2.94^{B}\pm0.06$	$2.88^{B}\pm0.05$
	Leaf area, cm^2	$23.01^{A}\pm0.52$	$15.82^{B}\pm0.57$	$16.53^{B}\pm0.44$
Note – Within each line, letters indicate statistically significant differences at a significance level of $p < 0.05$				

On the contrary, in partial shade, the Siberian variety 'Antarktida' exhibited the maximum leaf size, which decreased by 25–60% under good light conditions.

The varieties 'Antarktida' and 'Stanislas' typically exhibit the lowest values of Anthocyanin Reflectance Index I, Carotenoid Reflectance Index I, Carotenoid Reflectance Index II, Normalized Difference Vegetation Index, and Structure Intensive Pigment Index under good light conditions. The highest values of these indices were found in the variety 'Panama' grown in partial shade and natural humidity (Table 4).

The maximum amount of Chlorophyll A, Chlorophyll B, and Chlorophyll Total was found in leaves of plants grown in the light. In partial shade, the amount of Chlorophyll A and Chlorophyll Total was higher in plants grown in areas with extra humidity.

A similar trend in the dynamics of the Chlorophyll Normalized Difference Vegetation Index was observed in the varieties 'Antarktida' and 'Stanislas': high values with no statistically significant differences both in partial shade with extra humidity and in the light with natural humidity. The variety 'Panama' showed the highest Chlorophyll Normalized Difference Vegetation Index in partial shade and extra humidity, and the lowest one under good light conditions and natural humidity.

For all the studied varieties, the highest Water Band Indices were found under extra humidity conditions (> 1.005), and the lowest ones were observed in plants grown in partial shade and insufficient humidity, which is not typical of these varieties.

Table 4. Physiological indicators of *Phlox paniculata* varieties grown under different conditions**.**

Variety	Characteristic	Conditions		
		Light + natural humidity	Partial shade + natural humidity	Partial shade + extra humidity
'Antarktida'	Anthocyanin Reflectance Index I	$0.050^{A}\pm0.007$	$0.012^{B}\pm0.004$	$0.006^{B}\pm0.001$
	Chlorophyll Normalized Difference Vegetation Index	$0.429^{A}\pm0.013$	$0.307^{B}\pm0.012$	$0.412^{A}\pm0.006$

	Chlorophyll A (μg/cm^3)	$40.388^{A}\pm1.025$	$4.432^{C}\pm0.640$	$10.680^{B}\pm0.073$
	Chlorophyll B (μg/cm^3)	$81.660^{A}\pm4.058$	$17.868^{B}\pm2.048$	$17.128^{B}\pm0.133$
	Chlorophyll Total (μg/cm^3)	$122.380^{A}\pm4.948$	$22.308^{C}\pm2.682$	$27.910^{B}\pm0.203$
	Carotenoid Reflectance Index I	$1.706^{A}\pm0.128$	$0.715^{B}\pm0.072$	$0.097^{C}\pm0.003$
	Carotenoid Reflectance Index II	$1.756^{A}\pm0.133$	$0.727^{B}\pm0.072$	$0.103^{C}\pm0.004$
	Normalized Difference Vegetation Index	$0.933^{A}\pm0.006$	$0.860^{B}\pm0.013$	$0.795^{C}\pm0.005$
	Structure Intensive Pigment Index	$0.924^{A}\pm0.004$	$0.867^{B}\pm0.009$	$0.809^{C}\pm0.004$
	Water band index	$0.935^{B}\pm0.001$	$0.926^{C}\pm0.001$	$1.005^{A}\pm0.001$
‘Panama’	Anthocyanin Reflectance Index I	$0.026^{A}\pm0.007$	$0.033^{A.B}\pm0.014$	$0.007^{B}\pm0.001$
	Chlorophyll Normolized Difference Vegetation Index	$0.264^{C}\pm0.009$	$0.318^{B}\pm0.018$	$0.406^{A}\pm0.012$
	Chlorophyll A (μg/cm^3)	$42.504^{A}\pm1.294$	$6.027^{C}\pm2.008$	$10.480^{B}\pm0.191$
	Chlorophyll B (μg/cm^3)	$112.212^{A}\pm5.490$	$21.456^{B}\pm3.963$	$16.919^{B}\pm0.348$
	Chlorophyll Total (μg/cm^3)	$154.982^{A}\pm6.538$	$27.503^{B}\pm5.947$	$27.498^{B}\pm0.539$
	Carotenoid Reflectance Index I	$0.651^{B}\pm0.046$	$0.890^{A}\pm0.094$	$0.098^{C}\pm0.004$
	Carotenoid Reflectance Index II	$0.678^{B}\pm0.049$	$0.923^{A}\pm0.093$	$0.104^{C}\pm0.005$
	Normalized Difference Vegetation Index	$0.828^{B}\pm0.010$	$0.888^{A}\pm0.012$	$0.798^{C}\pm0.004$
	Structure Intensive Pigment Index	$0.847^{B}\pm0.007$	$0.891^{A}\pm0.007$	$0.815^{C}\pm0.005$
	Water band index	$0.933^{B}\pm0.001$	$0.920^{C}\pm0.001$	$1.008^{A}\pm0.002$
‘Stanislas’	Anthocyanin Reflectance Index I	$0.055^{A}\pm0.025$	$0.032^{B}\pm0.033$	$0.013^{C}\pm0.005$
	Chlorophyll Normalized Difference Vegetation Index	$0.413^{A}\pm0.012$	$0.361^{B}\pm0.015$	$0.429^{A}\pm0.007$
	Chlorophyll A (μg/cm^3)	$39.572^{A}\pm2.591$	$3.578^{C}\pm0.806$	$10.542^{B}\pm0.120$
	Chlorophyll B (μg/cm^3)	$84.018^{A}\pm5.773$	$16.511^{B}\pm2.757$	$16.737^{B}\pm0.236$
	Chlorophyll Total (μg/cm^3)	$123.901^{A}\pm8.254$	$20.089^{C}\pm3.551$	$27.379^{B}\pm0.355$
	Carotenoid Reflectance Index I	$1.897^{A}\pm0.121$	$1.101^{B}\pm0.113$	$0.130^{C}\pm0.003$
	Carotenoid Reflectance Index II	$1.952^{A}\pm0.121$	$1.134^{B}\pm0.118$	$0.143^{C}\pm0.004$
	Normalized Difference Vegetation Index	$0.942^{A}\pm0.005$	$0.923^{B}\pm0.007$	$0.836^{C}\pm0.002$
	Structure Intensive Pigment Index	$0.930^{A}\pm0.003$	$0.916^{B}\pm0.005$	$0.855^{C}\pm0.002$
	Water Band Index	$0.938^{B}\pm0.001$	$0.927^{C}\pm0.001$	$1.010^{A}\pm0.001$
Note – Within each line, letters indicate statistically significant differences at a significance level of $p < 0.05$				

4 Discussion

As is known from the literature [13], various stress factors trigger the antioxidant defense system in plants, which indicates a decreased effectiveness of photosynthetically active radiation [14]. The studied varieties are characterized by increased anthocyanin and carotenoid indices (stress substances) under good light conditions and natural humidity, which shows that these conditions are most stressful for phloxes as they are characterized by a high degree of water and temperature stress. Under good light conditions, the variety 'Antarktida' exhibited significantly decreased stomatal conductance and leaf size, and decreased transpiration, which reduces the photosynthetic potential of plants and indicates water deficiency [15–16]. According to L.M. Yudina [16], the decreased transpiration in low humidity can have a positive effect on the heat tolerance of plants since it reduces water loss.

Studies into other plants showed that water deficiency changes the spectral characteristics of leaves, which are more pronounced in varieties that are not tolerant to drought compared to drought-tolerant varieties [17]. In our study, the greatest difference in the measured indices was observed for the variety 'Antarktida', which indicates its sensitive to water stress.

High and stable values of stomatal conductance and transpiration under various conditions indicate the heat tolerance of this variety [18], since water deficiency and high light intensity are often related to high temperatures [19]. In our study, such values are characteristic of the variety 'Stanislas'.

Water Band Index can be used as a criterion for assessing the water status of plant varieties under various conditions.

5 Conclusion

The variety 'Stanislas' showed resistance to insufficient soil humidity and light; therefore, it can be used for cultivation both in moderately shaded residential areas and in arid conditions of the south of Russia. This variety is a promising donor of economically valuable traits.

The variety 'Antarktida' was bred in the middle of the last century in the southern taiga subzone of Western Siberia, where 60% of the territory is covered by taiga, and 30% is occupied by swamps [20]. The variety needs partial shade and extra humidity, which are optimal for this plant.

The obtained results show the potential of non-invasive optical methods for field studies to assess the intensity of the photosynthetic apparatus and the water balance of various plant varieties.

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