Ecophysiological characteristics of the coastal plants in the conditions of the tidal zone on the coasts of Svalbard

Evgenia Markovskaya[1], Nataliya Schmakova[2], Liudmila Sergienko[1*]

[1]*Petrozavodsk State University, Ecological-Biological Faculty, Department of Botany and Plant Physiology, Lenina, 33, Petrozavodsk, 185910, Russia.*
[2]*Polar–Alpine Botanical Garden Institute, Kola Research Center, Russian Academy of Sciences, Kirovsk, Murmansk region, 184250, Russia.*

Abstract

Content of chlorophylls, carotenoids, and flavonoids were determined in leaves of 26 plant species growing in the tidal zone of the Grønfjord coast at the Western Spitsbergen. Species of *Ranunculaceae, Polygonaceae, Boraginaceae*, *Juncaceae*, *Caryophyllaceae, Cyperaceae, Saxifragaceae*, *Poaceae* families were included in the study. The analyses showed that chlorophyll (Chl) content (chlorophyll *a*+*b*) of the investigated species varied from 0.16 to 2.4 mg g^{-1} of fresh mass, carotenoids varied from 0.1 to 0.7 mg g^{-1} of fresh mass, and flavonoides ranged from 0.8 to 9.7%. This comparative study aimed to the evaluation of differences in functional activity of photosynthetic apparatus of the dominant species under natural conditions of their habitats on the coastal zone of high tidal seas of the Arctic. Most of the dominant species of the tidal zone had higher values of Chl content and flavanoides. The study showed that plants grown along a transect from the water line through a tidal zone exhibited different ways of adaptation. The differences were found in the contents of photosynthetic pigments, and flavonoids. Besides that, some plants formed special morphological structures of leaves (grey dead vegetative organs and cuticular vax) and growth forms.

Key words: vascular plants, plastid pigments, chlorophyll, flavonoids, West Spitsbergen.

Abbreviations: Car - carotenoid, Chl - chlorophyll, FM - fresh mass, LHC - light-harvesting complex, MLWNT - mean low water neap tide, PAR - photosynthetically active radiation, UV - ultraviolet active radiation

---

Received November 19, 2012, *accepted* December 19, 2012.
[*]Corresponding author: muddycoast@gmail.com
Acknowledgements: The work was executed with the financial supports of grant No. 5.5829.2011 AVCP, grant from the RFBR No. 12-04-01008-a, grant by the Ministry of Economic Development and Trade of Russian Federation (project No. 42_08/09). The authors thank Dr. V. Kostina (PABSI KRC RAS) for the determinations of plants species.

Introduction

The Spitsbergen archipelago (between 76° 26' and 80° 50' N and 10° and 32° E), except for the the Nordaustlandet Island, it is located in the subzone of arctic tundra (its northern band). At this latitude, the polar day lasts from April 19th to August 24th; a steady transition to above-zero temperatures occurs on June 5th and to below-zero temperatures on September 18th. The warmest month is July (average temperature of 8°C). The average annual precipitation is 563 mm with most of them during the winter. Relative air humidity is high over the year, the average multiyear value is 78% (Koroleva et al. 2008). Such climatic characteristics determine a short growth period (40-70 days). Its duration is determined by the time of snow thawing and the length of snow-free period in local habitats. The natural flora of Spitsbergen archipelago comprises 164 species of vascular plants (more than 75% of them form the populations around internal fjord (Rønning 1996). In the high Arctic, the flora of vascular plants is characterized by a clearly expressed dependence on the extreme climatic factors. Plant adaptations to the climatic factors are reflected in functional characteristics and activity of their photosynthetic apparatus. Quantification of photosynthetic pigments in plants adapted to extreme climate can be considered a component of ecological and physiological characteristics permitting them successful living in such extreme environment like tidal zone. Salt marshes and coastal beaches with the lowest abundance of species within habitats are the azonal communities at the Western Spitsbergen. The lowest α-diversity (sensu Whittaker) was recorded for halophytic communities and mineral fens. Only several species, with the Arctic circum-polar areas are typical for these habitats (Koroleva et al. 2008). Therefore, investigation of morphological and eco-physiological plasticity of coastal species along the gradient of environmental factors has a specific importance in the estimation of the plants responses to extreme environmental conditions. The aim of our study was to estimate contents and the ratio of plastid pigments for several salt marsh species growing on the east coast of Grønfjord at the Western Spitsbergen.

Material and Methods

The study was performed in several regions with costal vegetation of the internal fjord of West Spitsbergen in 2009-2010. The study sites were located close to the settlements of (1) Barentsburg (78° 04' N, 14° 12' E), eastern shore of the Grønfjord, and (2) Pyramiden (78° 39' N, 16° 16' E). Halophytic meadows on the seashore marshes belong to ass. *Puccinellietum phryganoides* Hadač 1946, ass. *Caricetum ursinae* Hadač 1946, type community *Mertensia maritima* on the pebble beach on Grøn River (Koroleva et al. 2008). This investigation was performed within tundra vegetation of the internal fjord of West Spitsbergen, which is characterized by unbroken plant cover and a great diversity of vascular plant species. The pigments content was studied in plants growing along the transects from the line of mean low water at neap tide (MLWNT) towards the shore. Samples of vascular plant leaves, mainly at the flowering stage (when the plants did not bloom, the assimilating organs were been collected) were collected from 5–10 representative plants (or their groups). Chlorophylls (Chl *a* and *b*) and carotenoids (Car) contents were estimated in ethanol extracts spectrophotometrically with a SF-26 spectrophotometer (LOMO, Russia) and a PD-303S spectrophotometer (Appel, Japan) at corresponding absorption maxima. Chl contents in the light harvesting complex (LHC) was calculated, assuming that the whole amount of Chl *b* is present in the LHC, where the Chl *a/b* ratio is 1.2 (Sapozhnikov et al. 1978, Lichtenthaler 1987). The total of flavonoids content was determined using a SF-26 spectrophotometer at 410 nm (Zaichikova et al. 1983).

Results

For pooled data from all plants (26 species), total Chl content (chlorophyll *a+b*) showed the values ranging from 0.16 to 2.4 mg g^{-1} of fresh mass (FM). The values of yellow pigments (carotenoids) varied from 0.1 to 0.7 mg g^{-1} FM, flavonoides ranged from 0.8 to 9.7% (Table 1). The species from families *Caryophyllaceae, Ranunculaceae, Polygonaceae, Boraginaceae* and *Saxifragaceae* had low Chl content (below 1 mg g^{-1} FM) and were classified in the first group. The plants from families *Juncaceae, Cyperaceae* and *Poaceae* had higher Chl content (about and above 1 mg g^{-1} FM) and were put in another group.

In the further text, we report the ecophysiological characteristics of some dominant species of tidal zone in detail. *Puccinellia phryganodes* was the first species appearing on the mud coast at the distance of 40 m from MLWNT in the form of single plants of dirty-brown color (costal zone about settlement Barentsburg). At the distance of 90 m from MLWNT, the *P. phryganodes* had a projective cover up to 70% and looked like an orange-colored belt. These changes in color were related to the changes in content of the pigments: reduction of Chl (decrease from 0.96 to 0.57 mg g^{-1} FM). The orange-colored plants, their leaves, respectively, had a high content of flavonoids (7.3%), which could be related to their photoprotective role. At the distance of 50 - 70 m from the water edge, the *Stellaria humifusa* appeared. It had bright green sprouts covered by grey dead vegetative organs, which protected the green leaves from an excess sunlight. The content of Chl in grey vegetative organs were 0.16 mg g^{-1} FM, while it reached 0.7 mg g^{-1} FM in the underlying green leaves that had a low content of flavonoids (3%). Thus, *Stellaria humifusa* is naturally adapted to the quantity of sun light at high latitudes. *Carex ursina* appeared at a distance about 100 m from the water edge, then *Carex subspathacea* emerged at longer distance from the edge. The content of pigments in both species increased with the distance from the shoreline (up to 120 m for *Carex ursina* and up to 150 m for *Carex subspathacea*). For *Carex ursina*, the content of Chl increased from 1.16 to 1.72 mg g^{-1} FM. For *Carex subspathacea*, it increased from 1.0 to 2.1 mg g^{-1} FM. These species from family *Cyperaceae* had higher content of pigments than the other dominant species of tidal zone. The *Mertensia maritima* is a seashore perennial plant with blue-grey color leaves. In the high Arctic, the plants of *M. maritima* have a prostrate leaf form, the sprouts are spreading along the ground. In our study, *M. maritima* had average (*c.f.* the overall range of pooled plant species) content of Chl (0.98 mg g^{-1} FM), the higher means of LHC (more than 70%) and very high content of flavonoids (9.7%). The blue-grey color of leaves covered with a cuticle and having high content of flavonoids represent an effective protection mechanisms that help the plants to avoid negative effects of high light doses of PAR and UV to leaf photosynthetic apparatus.

Species	Chl (*a*+*b*) [mg g^{-1}(F.M.)]	*a/b*	LHC %	Car [mg g^{-1}(F.M.)]	Flavonoids %
Polygonaceae					
Koenigia islandica L.	0.83±0.04	2.2	69	0.29±0.04	6.9
Caryophyllaceae					
Honckenya peploides (L.) Ehrh.	0.53±0.04	3.4	50	0.15±0.02	7.8
Stellaria humifusa Rottb.	0.70±0.08	2.7	60	0.14±0.02	3.0
Cerastium alpinum L.	0.83±0.06	2.8	59	0.22±0.04	4.1
Sagina nivalis (Lindb.) Fr.	0.89±0.07	4.0	44	0.28±0.03	-
Ranunculaceae					
Ranunculus hyperboreus Rottb.	0.90±0.08	1.9	75	0.24±0.03	-
Saxifragaceae					
Saxifraga cespitosa L.	0.39±0.03	2.5	62	0.10±0.01	5.7
S. aizoides L.	0.57±0.06	2.9	56	0.16±0.03	6.6
S. foliolosa R. Br.	0.51±0.06	2.7	60	0.19±0.02	0.8
S. rivularis L.	0.66±0.08	3.5	50	0.19±0.03	4.7
Boraginaceae					
Mertensia maritima (L.) S.F. Gray	0.98±0.1	2.1	72	0.19±0.02	9.7
Juncaceae					
Luzula confusa Lindeb.	1.22±0.09	1.3	96	0.34±0.03	7.8
Juncus biglumis L.	2.44±0.18	3.6	48	0.69±0.07	-
Cyperaceae					
Eriophorum scheuchzeri Hoppe	1.21±0.08	1.6	85	0.38±0.04	5.5
Carex ursina Dew.	1.72±0.21	3.3	52	0.44±0.05	2.9
C. subspathacea Wormsk.	2.10±0.27	3.6	48	0.44±0.03	6.5
Poaceae					
Puccinellia phryganodes (Trin.) Scribn. &Merr	0.96±0.12	3.7	46	0.26±0.03	7.3
P. capillaris (Liljebl.) Jansen.	1.19±0.09	3.5	49	0.33±0.04	4.3
Dupontia psilosantha (Rupr.) Griseb.	1.17±0.11	3.2	53	0.34±0.03	8.1
D. pelligera (Rupr.) A.	1.38±0.12	3.1	53	0.35±004	-
Alopecurus borealis Trin.	0.89±0.09	2.6	61	0.25±0.02	7.6
Deschampsia alpina (L.) Roem. et Schult.	1.0±0.08	3.5	48	0.39±0.04	3.0
Poa arctica R. Br. var. vivipara	0.80±0.09	4.1	44	0.30±0.02	6.1
P. alpigena (Fr.) Lindm.	1.46±0.18	3.2	53	0.43±0.03	5.4
P. alpina L. var. vivipara	1.30±0.12	3.6	47	0.37±0.03	7.1
Phippsia concinna (Th. Fr.) Lindeb.	0.78±0.04	4.1	42	0.31±0.03	-

Table 1. The pigments and flavonoids content in the leaves of plants from the tidal zone at the Western Spitsbergen.

Discussion

The range of values of pigments content (chlorophylls, carotenoids and flavonoids) found in our study for plants of tidal zone are very close to that found in the majority of species of higher plants of the Western Spitsbergen (Schmakova et al. 2010, Markovskaya et Schmakova 2012). However, we identified two groups of families differing in the content of Chl. The first group comprises more primitive families (*Caryophyllaceae, Ranunculaceae*, and *Saxifragaceae*), which take a leading position in Arctic plant populations. The second group comprises more advanced families (*Juncaceae, Poaceae, Cyperaceae*). As it was reported, the members of more primitive or moderately advanced families (*Ranunculaceae, Saxifragaceae, Papaveraceae, Brassicaceae,* and *Caryophyllaceae*) are characterized by more active morphogenesis and a wide range of adaptations (Chernov et Matveeva 1983). These species have low values of Chl content. However, most of the dominant species of the tidal zone is included in the second group and has the higher values of Chl content (*see* Table 1). In accordance with our previous investigation (Markovskaya et Schmakova 2012), our data showed that the total content of Chl in *Carex subspathacea* decreased with latitude from 4.3 mg g^{-1} FM found at settlement Kolezma (the White Sea coast: 64° 14′ N, 35° 53′ E) to 2.1 mg g^{-1} FM in plants at settlement Dalnii Zelencty, (the Barents Sea coast: 69° 07′ 05″ N, 36° 03′ 30″ E). In a location further to the North (West Spitsbergen), the Chl contents was not changed (2.1 mg g^{-1} FM), but the lowest values (about 1 mg g^{-1} FM) was found in plants growing on the transect at the most extreme conditions for the species. The lowest Chl content in *Puccinellia phryganodes* plants was found in the belt zone (Western Spitsbergen), where their leaves had intensive red color. Lack of reproductive abilities and a high content of flavonoids found in these plants may indicate their lower adaptive capacity in the rigorous conditions of high Arctic. At the locality, the species has not enough vigor for sexual reproduction and maintains only vegetative organs required for their survival at the place.

Most of plants growing in tidal zones have high amounts of flavonoids. It is known, that the synthesis of flavonoids depends on different stressful environmental factors, such as *e.g.* high levels of UV-radiation (Dixon et Palva 1995), high level of photosynthetically active radiation and low temperature (Christie et al. 1994). Nybakken (2003) reported that incident UV radiation were absorbed by 88 - 98% by the epidermal pigments, including flavonoids in leaves of several Arctic plants species.

Our study showed that the most of investigated dominant species of tidal zones of the Western Spitsbergen had high Chl, Car and flavonoids contents. The plants growing along a transect from the water line through a tidal zone exhibited different ways of adaptation. The differences were found in the contents of photosynthetic pigments, of flavonoids and the special morphological structures of leaves (grey dead vegetative organs and cuticular vax) and growth forms in particular plant species.

References

CHERNOV, YU. I., MATVEEVA, N.V. (1983): Taxonomic Composition of Arctic Flora and Pathways of Flowering. Plants Settling in the Tundra Zone. *Zhurnal of General Biology,* 44: 187–201.

CHRISTIE, P.J., ALFENITO, M.R., WALBOT, V. (1994): Impact of low-temperature stress on general phenylpropanoid and anthocyanin pathways. Enhancement of transcript abundance and anthocyanin pigmentation in maize seedlings. *Planta*, 194: 541-549.

DIXON, R.A., PALVA, N.L. (1995): Stress-induced phenylpropanoid metabolism. *Plant Cell*, 7: 1085-1097.

KOROLEVA, N.E., KONSTANTINOVA, N.A., BELKINA, O.A., DAVYDOV, D.A., LIKHACHEV, A.YU., SAVCHENKO, A.N., and URBANAVICHENE, I.N. (2008): Flora and vegetation of Grønfjord area (Spitsbergen archipelago). Apatity, K & M, 110 p.

LICHTENTHALER, H.K. (1987): Chlorophylls and Carotenoids Pigments of Photosynthetic Biomembranes. *Methods Enzymology*, 148: 350–382.

MARKOVSKAYA, E. F., SCHMAKOVA, N. YU. (2012): The flavonoid content in the leaves of vascular plants from the West Spitsbergen. *Plant recourses*, 4: 547–554.

NYBAKKEN, L. (2003): UV-screening in Arctic and alpine vascular plants and lichens. Doctor scientiarum theses, Agricultural University of Norway, 2003, 357 p.

RØNNING O.I. (1996): The flora of Svalbard. Oslo, 1996, 128 p.

SAPOZHNIKOV, D.I., MASLOVA, T.G., POPOVA, O.F., POPOVA, I.A., AND KOROLEVA, O.YA. (1978): Method for Fixation and Storage of Leaves for Pigment Quantification in Plastids, *Botanical Journal,* 63: 1586–1592.

SCHMAKOVA, N. YU., MARKOVSKAYA, E. F. (2010): Photosynthetic Pigments of Plants and Lichens Inhabiting Arctic Tundra of West Spitsbergen. *Russian Journal of Plant Physiology*, 57: 764–769.

ZAICHIKOVA, S.G., KRIVUSHA, B.A. and BARABANOV, E. A. (1983): Spectrometric Method for the quantitative determination of the amount of flavonoids in the rough grass hypericum. *Modern methods of research of medicinal plants*. Moscow, pp. 103-109.