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Flavonoids of Rhubarb (*Rheum* L.), Wild and Cultivated in the Siberian Region

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Abstract

The species of *Rheum* L. genus (rhubarb) have long attracted the attention of researchers as possible sources of drugs for various purposes. Mostly the underground organs of plants were studied since the main attention was paid to a group of substances specific to the species of this genus – anthraquinones and anthrons that exhibited multiple biological activity. Insufficient attention was given to the study of aboveground organs, while flowers and leaves are a valuable source of flavonoids, an equally important group of biologically active substances. Rhubarb growing both in nature and in culture in the forest-steppe region of West Siberia is characterized by a high content of flavonoids. It was found that during the period of mass flowering of wild plants from the regions of Siberia, the content of flavonoids varies within the limits for *Rheum compactum* 3.87–10.06 % (in flowers), 1.17–5.16 % (in leaves), for *Rheum undulatum* (syn. *R. rhabarbarum*) 5.04–9.62 % (in flowers), 2.00–7.57 % (in leaves) per the mass of absolutely dry raw materials. In culture, *R. compactum* and *R. undulatum* retain their ability to synthesize flavonoids. Their content in the flowers of *R. compactum* reaches 7.68 %, in the leaves – 4.27 %, in *R. undulatum*, respectively, 9.43 and 4.95 %. For 10 individual *R. undulatum* plants, the flavonoid content is in the range 3.53–9.43 % (flowers) and 2.25–4.95 % (leaves), the variation coefficients are 35 and 24 %, respectively, which is a favourable factor for the selection of highly productive rhubarb forms. When introduced into the Novosibirsk region, all 15 tested rhubarb species, regardless of the origin of the seeds, showed the ability to synthesize a large number of flavonoids, especially in flowers, which indicates that its cultivation on an industrial scale is promising. The representatives of the *Rhapontica* and *Palmata* sections are particularly responsive to cultural conditions.

Keywords: *Rheum* L. genus, flavonoids, Siberian species *R. compactum* L., *R. undulatum* L. (syn. *R. rhabarbarum* L.)

INTRODUCTION

Search for the plants containing flavonoids is due to the unique properties of this group of natural compounds. Medicinal agents of anti-inflammatory, antioxidant, capillary strengthening, antiradiation, immunomodulating and other kinds of action were developed on the basis of flavonoids [1].

The plants of *Rheum* L. genus (rhubarb) have been attracting the attention of researchers for a long time as possible sources of medicinal preparations for various purposes [2, 3]. Rheum is an Asian continental genus uniting about 50 species. It is characterized by a broad habitat composed of two regions: humid, which includes the humid forest regions of the Himalayas, China, Mongolia, Siberia and the Far East, and arid, which includes mountainous and plain desert regions of Kazakhstan, Southwest, Middle and Central Asia, Afghanistan and Iran. These plants are herbaceous perennials with thick upright stems and long fleshy rhizomes. The leaves are arranged in rosettes and may reach a huge size [4, 5]. The best studied rheums are the representatives of forest rheums in Central and Northern China from *Palmata* and *Rhapontica* sections: *Rheum palmatum* L., *Rheum officinale* Baill., *Rheum emodi* Wall. ex Meissn., *Rheum undulatum* L. (syn. *Rheum rhabarbarum* L.) and *Rheum compactum* L. [6]. Pharmacopeial items on the underground organs of *R. palmatum*, *Rheum tanguticum*, *R. officinale*, *Rheum coreanum* and their interspecies hybrids are included in Pharmacopeias of Japan [7], China [8], Europe [9]. In the Russian pharmacopeia, officially recognized is *R. palmatum* L. var. tanguticum Regel, its rhizomes are used as anti-inflammatory, purgative and tanning agent [10].

Analysis of the modern research into the chemical composition and biological activity of rheums shows that major attention is paid to the ground of substances which are specific for the species of this genus – anthraquinones and anthrones, possessing a broad range of biological activity: antifungal, antimicrobial, antiviral, antioxidant, cytotoxic, immunomodulating, *etc.* [6]. E the major accumulators of these compounds are underground organs of plants, the roots and rhizomes of rhubarb plants were actively studied in the eastern countries. Insufficient attention was paid to the investigation of aboveground organs, though flowers and leaves are valuable sources of flavonoids, not a less important group of biologically active substances.

The goal of the present work was to study the content of flavonoids in the aboveground organs of the plants of *Rheum* genus growing in the Siberian region and cultivated at the experimental ground of the Central Siberian Botanical Garden SB RAS (CSBG SB RAS, Novosibirsk, Akademgorodok), and to evaluate the outlooks of their use as the sources of these substances.

EXPERIMENTAL

The samples of aboveground organs of the plants (flowers and leaves) of two Siberian wild species *R. compactum* and *R. undulatum* (syn. *R. rhabarbarum*) were collected by the author in nature, as well as were represented by the herbarium materials collected at different times. The plants of 15 species of *Rheum* genus from five sections – *Rhapontica*, *Deserticola*, *Ribesiformia*, *Palmata* and *Spiciformia* – were grown at the experimental ground of the CSBG SB RAS from the seeds obtained through delectus from botanical gardens of Russia, Belarus, Germany, Poland, France and other countries. The material was collected in the third year of plant growth, in the phase of mass blossoming. The analytical sample was composed of 5–7 plants. The chromatographic-spectrophotometric method was used in the work to carry out the quantitative determination of flavonoids on the basis of the separation of substances by means of two-dimensional paper chromatography.

A precisely weighted portion of air-dry raw material (0.1–0.5 g) was ground to particle size 1 mm, placed in a flask 100 mL in volume, poured with 30 mL 40 % ethanol, and boiled on a water bath with a backflow condenser for 30 min. The extract was filtered. Repeated extraction was carried out with 20 mL of 40 % ethanol for 15 min. After filtration, the residue in the flask and on the filter was washed with 5 mL of alcohol. The united extract was concentrated in a rotary evaporator to the volume of 2–3 mL (precisely determined volume).

Thus obtained extracts were studied by meaтs of paper chromatography using Filtrak paper No. 15 in solvent systems: isopropanol – formic acid – water (2 : 5 : 5) (direction I), *n*-butanol – acetic acid – water (40 : 12 : 28) (direction II). The volume of the extract deposited on one paper sheet was 0.10–0.15 mL, depending on the weighted portion of the raw material and the amount of extract. Each sample was deposited three times simultaneously. One chromatogram was developed using the vapour of ammonia and 5 % solution of aluminium chloride, two other chromatograms were used for the quantitative determination of flavonoids. The positions of spots related to flavonoids were determined using the developed chromatogram. Each spot detected in the chromatogram was cut out, ground, and then the paper cuts were placed into glass columns 6 mm in diameter in the upper part and 1 mm in the lower part, 60–70 mm long. Flavonoids were eluted with 40 % ethanol in portions of 0.5 mL to obtain not less than 3 mL of the eluate. The optical density of the eluates was determined with the help of an SF-26 spectrophotometer (Russia) at the wavelength of 360 nm because flavonoids that are present in the species under investigation have their absorption maxima in the longer-wavelength UV spectra region (355–365 nm). The reference was 40 % ethanol. The content of the absolutely dry substance in the air-dry raw material was determined using the gravimetric method.

Calculation of the amount of flavonoids (in % of the mass of absolutely dry raw material) was carried out using the equation

$X = DV_1V_2\ 100/(MV_3(100 - W) \cdot 10^4)$

where D is flavonoid content in 1 mL of the solution under test, determined from the calibration plot which was drawn with respect to rutin, μg; V_1, V_2, V_3 are the volumes of extract, eluate, and extract deposited onto the paper, respectively, mL; M is the mass of air-dry raw material, g; W is mass loss during drying to absolutely dry mass, %.

The calibration plot was obtained using rutin solution in 40 % ethanol (concentration 1 mg/mL), which was subjected to chromatographing and elution under the conditions described above for the separation of the complex of flavonoids in the extracts under study. The total content of flavonoids was calculated by summing the amounts of individual components of the flavonoid complex of the sample. The relative error of the procedure is ±1.39 %.

RESULTS AND DISCUSSION

Two rhubarb species occur in Siberia: *R. compactum* and *R. undulatum* (syn. *R. rhabarbarum*). The *R. compactum* grows along river banks, in forests, valleys, on slopes, in the tundra of West and East Siberia, and the Far East. The *R. undulatum* grows only in East Siberia at the edges of forests, in steppes, in sparse forests, on sandy soil. The plants of these species are grown in gardens and vegetable plots, to be used as food. The high content of flavonoids in the organs of the above-ground parts of the plants of these species was stressed by us elsewhere [11, 12]. It was discovered that the flowers of cultivated *R. compactum* contain flavonoids at a level of 5.24 % (glycosides of kaempferol and quercetin, including rutin 2.82 %), leaves contain flavonoids at a level of 4.27 %, including rutin 1.73 %. The *Rheum altaicum* species, which is close to *R. compactum* but differs from the latter by smaller height, dense and almost bare triangular egg-shaped leaves and the size of the fruit, is recognized not by all botanists and is often considered as a synonym of *R. compactum*. Under the conditions of introduction, the flowers of the plants of this species contained 6.40 % flavonoids (glycosides of kaempferol and quercetin, including 3.70 % rutin), the leaves – 2.86 % flavonoids, including 1.28 % rutin. The dynamic row of flavonoid accumulation in the phases of suckering, budding, blossoming and fruiting looks as follows, %: in the plants of R. compactum – reproductive organs (0, **7.42**, 7.00, 1.74, respectively); leaves (4.07, **4.67**, 3.51, 3.02); in the plants of *R. altaicum* – reproductive organs (0, **7.40**, 5.89, 0.83); leaves (2.16, **3.97**, 3.46, 2.78) [13–15]. The maximum of flavonoid content in the flowers and leaves of both species falls on the budding phase. Flavonols quercetin, kaempferol, rhamnetin, rutin, astragalin were revealed in the flavonoid complexes of *R. compactum* and *R. altaicum* by means of high-performance liquid chromatography. So, the buds, blossoming clusters and leaves may be valuable sources of flavonols. The amount of rutin in the plants of both species reaches 13 mg/g [16, 17].

The above-described results were obtained for cultivated rhubarb plants. The data on flavonoid content in the plants of wild Siberian species are absent because these plants were not considered as a possible source of these valuable biologically active substances. According to our data (Table 1), the plants of *R. compactum* from natural habitats are able to accumulate large amounts of flavonoids; the range of their concentrations during mass blossoming in the plants from the regions of Siberia is 3.87–10.06 % of the mass of absolutely dry raw material (in flowers), 1.17–5.16 % (in leaves). It should be noted that the flowers always contain higher concentrations of flavonoids than the leaves [18]. The highest concentration of the substances was detected in the plants from the Kodar and Udokan Ridges (the Stanovoye Highland). The most frequent sites of *R. compactum* growth in Siberia are confined to goltsy, sub-goltsy or forest belts, in the upper reach of mountainous rivers and brooks, at stony slopes, and these sites are characterized by substantial altitude above the sea level and high insolation. It is quite probable that flavonoid pigments play the role of filters protecting plant tissues from the harmful effect of ultraviolet rays, and the amount of these pigments in the plants is connected with the illumination of growing sites. It was reported previously that the content of flavonoids in plants increases with an increase in the altitude of the growing site [19]. The *R. undulatum* does not grow high in the mountains; it is confined to meadow and steppe communities, the banks of water bodies and river valleys. The

TABLE 1

Flavonoid content in the flowers and leaves of the plants of Siberian species *R. compactum* and *R. undulatum* (syn. *R. rhabarbarum*) from natural habitat, % of the mass of absolutely dry raw material

Sample No.	Collecting site	Flowers	Leaves
R. compactum			
1	Krasnoyarsk Territory, Putorana Plateau, Khantayskoe lake, in the forest belt at a boggy lowland	6.13	3.33
2	The same, in the forest belt at a brook bank	7.04	2.11
3	Polar region, near Igarka city, in the forest belt at the edge of the grassy birch-alder forest	4.14	1.74
4	Irkutsk Region, Cheremkhovo District, Onot settlement, in the forest belt at a river bank	3.87	1.17
5	East Sayan, the Tunkinskie Alps, the Tubota river, in the forest belt at an altitude of 1300 m	7.12	3.40
6	The same, Doda goltsy, in the subalpine belt at a stony slope, at an altitude of 2100 m	4.96	2.95
7	The same, the Pogranichniy Ridge, the upper reach of the Sentsa river, in the subalpine belt on a rocky meadow slope at an altitude of 1850 m	7.40	4.07
8	The sample, the Tunkinskie Alps, the side of lake Khongoldoy, in the goltsy belt on a rocky meadow slope	7.83	4.34
9	Buryatiya, Khamar-Daban ridge, the foot of the Khan-Ula mountain, in the goltsy belt, a stony bank of the river at an altitude of 1900 m	4.72	3.10
10	Buryatiya, Kitayskie Alps, the upper reach of the Ospa river, in the subalpine belt, a slope in the sparse Siberian pine forest, at a meadow	7.33	4.61
11	The southern side of Lake Baikal, at a distance of 8 km up from the mouth of the Khara-Murin brook, in the forest belt at a silty slope of the river	7.57	5.16
12	Irkutsk Region, Mamsko-Chuyskiy District, lower reach of the Bolshaya Slyudyanka river, near Polyanovka settlement, at a stony bank of a brook	6.21	2.94
13	Irkutsk Region, the basin of the Bolshoy Patom river, at a source of the left tributary of the Marakan river, in subalpine belt at a brook bank	5.56	3.56
14	Irkutsk Region, the basin of the Chara river, upper reach of the Khomolkho river, in shrubbery along the brook at an altitude of 850 m	5.82	3.45
15	Buryatiya, the Barguzin ridge, near Dagary settlement, at the upper reach of the Akulikan river, coniferous-poplar grassy forest at an altitude of 1200 m	5.85	4.67
16	The same, upper reach of the Svetlaya river, at the edge of a stony detritus in subalpine belt at an altitude of 1900 m	6.67	4.66
17	Baikalskiy ridge, the right bank of the Poperechnaya river, along the southern slope to the left tributary of the Goremyka river	4.87	3.32
18	Stanovoe highland, the Udokan ridge, the upper reach of the Naminga river, at a stony meadow in supalpine belt	9.51	3.77
19	Stanovoe highland, the Kodar ridge, the upper reach of the Apsata river, in the forest belt at an altitude of 1300 m	10.06	3.11
20	Buryatiya, Dzhidinskiy District, the left bank of the Dzhida river, at a distance of 15 km to the west from the Dyrestuy settlement	5.46	2.57
21	Dauria, Eastern Transbaikalia, near Baley, stony detritus	5.90	3.15
		3.87–10.06	1.17–5.16
R. undulatum (syn. *R. rhabarbarum*)			
22	Irkutsk Region, the side of Lake Baikal, Aya Bay	5.96	4.26
23	North-eastern side of Lake Baikal, near Ongureny, rocks	7.45	2.48
24	Eastern Sayan, Tunkinskiy District, near Zun-Murino settlement, the bank of the Zun-Murin river, meadow	7.75	5.12
25	Irkutsk Region, the side of Lake Baikal, Olkhon island, near Khuzhir settlement, Tashkiney gorge, bushed in the valley	8.60	7.57
26	Dauria, Eastern Transbaikalia, the valley of the Bukukun river, near Kyra settlement, meadow	7.14	6.08
27	Buryatiya, near Kyakhta, Ust-Kiran settlement, a narrow valley	9.62	6.95
28	Chita Region, Olovyanninskiy District, Ulamy settlement, a narrow valley between mountains, wild rye steppe	8.98	7.42
29	Chita Region, near Zabaykalsk, at a distance of 20 km, on a steppe slope exposed to south-east	5.04	2.00
		5.04–9.62	2.00–7.57

Note. The plants were collected at the phase of mass blossoming.

plants of this species also accumulate a large amount of flavonoids (up to 9.62 % in flowers and 7.57 % in leaves). The high content of flavonoids in the aboveground organs of the species growing in Siberia allows using these plants as the medicinal raw material. For example, the following requirements to flavonoid-containing raw material have been adopted: the flowers of sandy everlasting – flavonoid content not less than 6.0 %, flowers of tansy – not less than 2.5 %, hypericum herb – not less than 1.5 %, the leaves of marsh trefoil – not less than 1.0 %, doorweed herb – not less than 0.5 % [20].

Rhubard plants naturally grow separately without forming a massif, so their procurement is hindered. In addition, the use of natural wild-growing material is complicated by depletion or complete disappearance of the populations of valuable species of medicinal herbs. The problem is solved by arranging commercial plantations. At the same time, the necessity arises to study the natural flora of regions as a source of highly active medicinal raw materials for introduction and selection [21]. The studies of wild rhubarbs carried out by us serve as the basis for obtaining valuable initial material both in the form of seeds and as root systems at the first stages of introduction. For example, the population of *R. compactum* (samples No. 18, 19) from the Stanovoye highland and *R. undulatum* (samples No. 24, 26, 27) from the Eastern Sayan, Dauria and Buryatiya may be used to make introduction plantations and for selection in the regions of Siberia. Some other populations also deserve attention: samples No. 1, 2, 5, 7, 8, 10, 11, 12, 16, 22, 23, 25. Our experience in the introduction of the species of Rheum genus, either growing in Siberia or originating from other regions and countries, turned out to be quite satisfactory. All the tested species, independently of the origin of seeds, contain high levels of flavonoids and thus may serve as an excellent medicinal raw material (Table 2).

In the evaluation of the raw material, even the lowest level of flavonoid content for flowers and leaves is quite acceptable: 2.62 % (R. palmatum) and 1.50 % (*Rheum rhaponticum*), respectively. In the culture, R. compactum is stable in conserving its capacity to synthesize flavonoids: their content in the flowers reaches 7.68 %, and in the leaves – 4.27 %, which is comparable with the wild samples. The same is true for *R. altaicum*, the content of flavonoids in its flowers is up to 6.40 %, and in the leaves – up to 2.86 %. Cultivated plants *R. undulatum*, similarly to wild plants, are able to synthesize up to 9.43 % flavonoids in flowers and up to 4.95 % in leaves. In addition to averaged parameters, we also obtained the data for individual *R. undulatum* plants (see Table 2). For 10 individual plants of this species, flavonoid content varies within the range 3.53–9.43 % (flowers) and 2.25–4.95 % (leaves) with variation coefficients 35 and 24 %, respectively. So, high variability of flavonoid content in flowers and medium variability in leaves was detected, which is a favourable factor for the selection of highly productive forms of rhubarb. The Middle Asian species *Rheum wittrockii* Lund. Produces a small mass in culture, but flavonoid content both in flowers (5.29 %) and in leaves (3.95 %) is rather high.

One more representative of the section of *Rhapontica* – *Rheum emodi* Wall. ex Meissn. – is cultivated by the people of Kashmir for more than 5000 years. This species grows in the Himalayas; it is widely used in Ayurveda and Unani medicine. Its curative properties are traditionally used to treat cancer, ulcer, diabetes, the diseases of the liver and kidneys, microbial and fungal infections [22]. The climatic conditions of the forest-steppe zone of West Siberia do not fully correspond to the historically formed needs of the *R. Emodi* growing over highlands (up to the altitude of 3700 m above the sea level); this may be the reason why flavonoid content in the plants grown in Siberia is lower than in other species of the *Rhapontica* section, and equals 2.72–3.86 % (in flowers) and 2.2–3.50 % (in leaves).

Rheum tataricum L. is an endemic Middle Asian species growing in steppes, over rock debris, clay, solonetz, grassy and dry slopes, hills. This species is readily responsive to the conditions of introduction in the forest-steppe zone of West Siberia. It forms an abundant aboveground mass with high flavonoid content: up to 5.79 % (in flowers) and 4.85 % (in leaves).

The *Rheum ribes* L. species (Ribesiformia section) is one of the most important industrial plants in Asian regions. It grows over clay slopes and in the cloughs of the subalpine zone of Southern Caucasus, in Iran, Armenia. This species was widely used as a food and medicinal plant in ancient times [3]. Flavonoids (quercetin, 5-deoxoquercetin, 3-O-rhamnoside, 3-O-galactoside and 3-O-rutinoside of quercetin) were isolated from the plants of this species growing in Turkey; their high antioxidant activity was demonstrated [23, 24]. Under the conditions of cultivation in the Novosibirsk Region, it contains flavonoids up to 5.78

TABLE 2

Flavonoid content in the flowers and leaves of the species of *Rheum* L. genus grown at the CSBG SB RAS from seeds obtained through delectus (in % of the mass of absolutely dry raw material)

Species	Seed origin	Flowers	Leaves
Rhapontica section			
R. compactum	Russia, the Moscow Region, Botanical Garden of VILAR	6.30	2.85
	Russia, Yakutsk, Botanical Garden	5.87	4.27
	Belarus, Minsk, Botanical Garden of BSU	7.68	4.10
R. altaicum Losinsk. (syn. *R. compactum*)	Russia, Moscow, Main Botanical Garden, RAS	6.40	2.86
	Russia, Novosibirsk, CSBG SB RAS, medicinal herbs plot	4.25	2.28
	Poland, Wroclaw, Botanical Garden	6.39	2.25
R. undulatum (syn. *R. rhabarbarum* L.)	Russia, Moscow, Dendrological Garden of the Moscow Agricultural Academy	3.87	2.55
	Russia, Moscow Region, Botanical Garden of VILAR:		
	Plant 1	4.74	2.65
	Plant 2	6.83	3.18
	Plant 3	6.45	3.35
	Plant 4	4.83	2.82
	Plant 5	3.68	2.84
	Plant 6	9.43	2.25
	Plant 7	8.32	4.95
	Plant 8	3.87	3.48
	Plant 9	3.53	4.08
	Plant 10	5.53	4.09
	Romania, Kluzh-Napoka, Botanical Garden named after Aleksandru Borza	4.14	2.17
	Germany, Berlin, Department of Botany and Arboretum of the University of Humboldt	4.26	1.75
	Germany, Bremen, Botanical Garden	5.45	2.30
R. wittrockii	Russia, Moscow, Main Botanical Garden, RAS	5.29	3.95
	Hungary, Budapest, Botanical Garden	3.04	2.98
R. emodi	Russia, Moscow, Dendrological Garden of the Moscow Agricultural Academy	3.86	3.50
	Germany, Bonn, Botanical Garden	2.82	2.28
	France, Dijon, Botanical Garden	2.72	2.30
	Romania, Kluzh-Napoka, Botanical Garden named after Aleksandru Borza	3.51	2.53
Deserticola section			
R. tataricum L.	Russia, Moscow, Main Botanical Garden, RAS	5.79	4.85
	Hungary, Budapest, Botanical Garden	3.14	2.68
Ribesiformia section			
R. ribes	Russia, Moscow, Main Botanical Garden, RAS	5.71	2.84
	Hungary, Budapest, Botanical Garden	2.78	2.88
	Poland, Wroclaw, Botanical Garden	4.70	3.26
	Italy, Torino, Botanical Garden	4.39	2.41
R. macrocarpum	Poland, Wroclaw, Botanical Garden	6.26	3.79
	Hungary, Budapest, Botanical Garden	3.43	2.45
Palmata section			
R. palmatum	Hungary, Budapest, Botanical Garden	4.83	3.53
	France, Dijon, Botanical Garden	2.62	2.60
R. rhaponticum	Russia, Moscow, Dendrological Garden of the Moscow Agricultural Academy	8.11	3.36
	Denmark, Copenhagen, University Botanical Garden	5.38	1.50
	Germany, Berlin, Department of Botany and Arboretum of the University of Humboldt	6.31	2.14
	Czech Republic, Brno, Botanical Garden	3.88	2.07
R. franzenbachii	Hungary, Budapest, Botanical Garden	4.61	1.88
	Denmark, Copenhagen, University Botanical Garden	5.76	2.63
R. officinale	Russia, Kirovsk, Polar Alpine Botanical Garden, RAS	3.66	1.92
	Belarus, Minsk, Botanical Garden of BSU	4.74	3.50
	Hungary, Budapest, Botanical Garden	5.17	2.59
	Germany, Bonn, Botanical Garden	5.85	2.54
Spiciformia section			
R. reticulatum Losinsk.	Hungary, Budapest, Botanical Garden	4.02	2.44
R. moorcroftianum	Hungary, Budapest, Botanical Garden	4.45	3.47
R. webbianum	BHungary, Budapest, Botanical Garden	4.44	1.92
	Poland, Wroclaw, Botanical Garden	5.60	1.52

Note. Plants were collected at the age of three years, in the phase of mass blossoming.

% (in flowers) and 3.26 % (in leaves). This species is promising as a source of raw material containing quercetin derivatives.

A Central Asian species *Rheum macrocarpum* A. Los., endemic of the Tien Shan, belongs to the same section *Ribesiformia*. It contains tanning substances, so it is used by the native population in the production of leather. The level of flavonoids detected in the flowers of the plants introduced in Siberia was detected to be 6.26 %, while leaves contained up to 3.79 %.

The *Palmata* section is represented in the work by four species: *R. palmatum* L., *Rheum rhaponticum* L., *Rheum franzenbachii* Münter. and *R. officinale* Baill. *R. rhaponticum* originating from Bulgaria is distinguished by the high flavonoid content in flowers (up to 8.11 %) and rather high content in the leaves (up to 3.36 %). Other species of this section are also promising. For instance, flavonoid content in *R. officinale* is up to 5.85 % in flowers and 3.50 % in leaves, in *R. franzenbachii* – 5.76 and 2.63 %, in *R. palmatum* – 4.83 and 3.55 %, respectively. *R. palmatum* had been grown since the earliest times as an orchard crop and proved itself in this respect in different regions and countries.

The species of the *Spiciformia* section – *Rheum reticulatum* A. Los., *Rheum moorcroftianum* Royle and *Rheum webbianum* Royle – are confined to the mountainous regions of Asia. Under the conditions of introduction in West Siberia, they contain up to 5.60 % flavonoids in flowers and 3.47 % in leaves, which meets the requirements to the raw material containing flavonoids.

So, during the introduction in the Novosibirsk Region, all the 15 rhubarb species under test demonstrated the ability to synthesize large amounts of flavonoids independently of the origin of seeds, which confirms that it is promising to grow these species on an industrial scale to obtain these valuable biologically active substances.

CONCLUSION

Plants of the *Rheum* L. genus are distinguished by the high flavonoid content both under natural conditions and in culture in the forest-steppe zone of West Siberia. During the mass blossoming of plants from the regions of Siberia, flavonoid content detected in the flowers and leaves of *R. compactum* was up to 10.06 and 5.16 %, respectively, and in the flowers and leaves of *R. undulatum* (syn. *R. rhabarbarum*) up to 9.62 and 7.57 %, respectively (of the mass of absolutely dry raw material).

In culture, *R. compactum* and *R. undulatum* conserve their ability to synthesize flavonoids. Their content in the flowers of *R. compactum* reaches 7.68 %, in leaves – 4.27 %, which is comparable with the wild samples. Cultivated *R. undulatum* plants accumulate flavonoids up to 9.43 % in flowers and up to 4.95 % in leaves. The range of flavonoid content variation for 10 individual *R. undulatum* plants was 3.53–9.43 % (flowers) and 2.25–4.95 % (leaves) with variation coefficients 35 and 24 %, respectively, which is a favourable factor for the selection of highly productive forms of rhubarb.

When introduced in the Novosibirsk Region, all the 15 tested rhubarb species demonstrated the ability to synthesize large amounts of flavonoids, independently of the origin of seeds, which is evidence of the high potential of planting these species on an industrial scale to obtain these valuable biologically active substances.

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REFERENCES

1 Makarova M. N., Makarov V. G., *Molecular Biology of Flavonoids: Chemistry, Biochemistry, Pharmacology. Guidance for Medical Professionals* [in Russian], St. Petersburg: Lema, 2010. 428 p.
2 Bilal S., Mir M. R., Parrah J. D., Tiwari B. K., Tripathi V., Singh P., Mehjabeen, Abidi A. B. Rhubarb: The wondrous drug. A review, *Intern. J. Pharm. Biol. Sci.*, 2013, Vol. 3, No. 3, P. 228–233.
3 Agarwal S. K., Singh S. S., Lakshmi V., Verma S., Kumar S., Chemistry and pharmacology of rhubarb (*Rheum* species) – A review, *J. Sci. Ind. Res.*, 2001, Vol. 60, No. 1, P. 1–9.
4 Lozina-Lozinskaya A. S., Systematic Review of the Wild Species of *Rheum* L. Genus [in Russian], in: Flora and Systematics of Higher Plants. Vol. 5, Moscow, Leningrad, 1936. P. 67–141.
5 Grigoryev Yu. S., Adaptive radiation in the *Rheum* L. genus (reconsidering the problem of the interaction of systematics, geography and plant physiology) [in Russian], *Byull. MOIP*, 1981, Vol. 86, Issue 5, P. 72–82.
6 Vysochina G. I., Anthraquinones and biological activity of the species of *Rheum* L. genus (Polygonaceae) (a review) [in Russian], *Khimiya Rast. Syrya*, 2018, No. 4, P. 29–41.
7 The Japanese Pharmacopoeia, 17th Ed., Tokyo, 2016. 2630 p.
8 Pharmacopea of the People's Republic of China, Vol. 1, Pekin, 2005. 668 p.
9 European Pharmacopeia, 7th Ed., 2010. 4034 p.
10 Kurkin V. A. Pharmacognosy [in Russian], Samara: OOO OFORT SamSMU, 2004. 1180 p.
11 Vysochina G. I., Possibilities of the integrated use of Siberian rhubarb plants in medicine [in Russian], Abstr. All-Union

Conference New Medicinal Preparations from the Plants of Siberia and Far East, Tomsk, 1989, Issue 2, P. 38–39.
12 Vysochina G. I., Phenolic Compounds in Systematics and Phylogeny of Polygonaceae Family [in Russian], Novosibirsk: Nauka, 2004. 240 p.
13 Vysochina G. I., Kukushkina T. A., Kostikova V. A., Dynamics of the content of major groups of biologically active substances in *Rheum compactum* L. during introduction in the Novosibirsk Region [in Russian], *Sib. Med. Zhurn.* (Irkutsk), 2015, No. 1, P. 77–80.
14 Kostikova V. A., Kukushkina T. A., Vysochina G. I., Dynamics of the content of major groups of biologically active substances in *Rheum altaicum* Losinsk during introduction in the Novosibirsk Region, *Chemistry for Sustainable Development*, 2017, Vol. 25, No. 5, P. 484–488.
15 Kostikova V. A., Kukushkina T. A., Vysochina G. I., Content of phenolic compounds in the Siberian species of the *Rheum* L. genus during introduction in the Novosibirsk Region [in Russian], *Plodovodstvo i Yagodovodstvo in Russia*, 2017, Vol. 50, P. 175–178.
16 Kostikova V. A., Vysochina G. I., Petruk A. A., Features of flavonoid accumulation in the organs of the aboveground parts of *Rheum compactum* L. [in Russian], *Khimiya Rast. Syrya*, 2015, No. 4, P. 147–150.
17 Kostikova V. A., Vysochina G. I., Petruk A. A., Features of flavonol accumulation in the organs of the aboveground parts *Rheum altaicum* Losinsk. (Polygonaceae Juss.) [in Russian], *Vestn. VGU. Seriya: Khimiya. Biologiya. Farmatsiya*, 2016, No. 2, P. 135–139.
18 Zaprometov M. N., Fenolic Compounds: Occurrence, Metabolism, and Functions in Plants [in Russian], Moscow: Nauka, 1993. 272 p.
19 Vysochina G. I., Voronkova M. S., Flavonoids of *Bistorta vivipara* (L.) Delarbre in relation to their ecological role, *Contemporary Problems of Ecology*, 2003, Vol. 6, No. 4, P. 426–433.
20 State Pharmacopeia of the USSR, 11th edition, Issue 2, Moscow: Meditsina, 1990. 398 p. (in Russ.).
21 Vysochina G. I., Kukushkina T. A., Kotsupii O. V., Zagurskaya Yu. V., Bayandina I. I., Flora of the forest-steppe zone as a source of biologically active compounds, *Contemporary Problems of Ecology*, 2011, Vol. 4, No. 2, P. 273–284.
22 Kaur A., Kaur S., Kaur M., Mahajan A., Bose S., Rheum emodi: A review on pharmacology and phytochemistry, *World Journal of Pharmaceutical Research*, 2015, Vol. 4, No. 1, P. 1892–1902.
23 Tosun F., Akyuz K. C., Anthraquinones and flavonoids from *Rheum ribes*, *Ankara Universitesi Eczacilik Fakultesi Dergisi*, 2003, Vol. 32, No. 1, P. 31–35.
24 Oeztuerk M., Aydogmus-Oeztuerk F., Duru M. E., Topcu G., Antioxidant activity of stem and root extracts of rhubarb (*Rheum ribes*): An edible medicinal plant, *Food Chemistry*, 2007, Vol. 103, No. 2, P. 623–630.