

Dynamics of the Accumulation of Flavonoids in *Polygonum L.* Species

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There are 300 species of *Polygonum L.* genus of *Polygonaceae* Juss. family in the temperate zone of the world. Some of them are medicinal plants, which are used for the treatment of diseases or as a raw material for preparing medicines. Flavonoids are active substances of the species belonging to the *Polygonum L.* genus. Flavonoid content, distribution, dynamics of accumulation throughout growth phases, productivity of above-ground parts have been studied in various organs of *P. aviculare* and *P. patulum L.* species. Uneven distribution of flavonoids was detected in plant organs. In generative organs maximum accumulation of flavonoids was observed in buds, while in vegetative organs it was observed in leaves. Maximum biomass productivity and flavonoid content were observed in the flowering phase of both species.

Keywords: *Polygonum*, flavonoid, dynamics of accumulation, vegetative, generative organs, biomass

INTRODUCTION

Owing to a wide range of biological activity of flavonoids, taxa rich in flavonoids are being searched and plants with known flavonoids are being studied more comprehensively. There were reports on anti-radiant, antispasmodic, antioxidant, antimutagenic and other properties of flavonoids (Baraboy, 1976; 1984; Mashkovskiy 2005, Cook and Samman, 1996; Tijburg et al., 1997; Dicarbo et al., 1999). The ability to decrease conductivity of capillaries and increase their elasticity are main biological properties of flavonoids and other polyphenols of plant origin. Recently, antioxidant properties providing the protection from free radicals as stress factors causing pathological changes in the human organism have been extensively studied (Rice-Evans and Müller, 1996; Kang and Kapoor, 2002). Plants containing flavonoids are considered to be a valuable raw material for medications, such as capillary strengtheners, immunomodulators, anticancerogenes and cholagogues.

One of the taxa containing flavonoids is the species of *Polygonum L.* genus of the *Polygonaceae* Juss. family. 300 species of the *Polygonum L.* genus of the *Polygonaceae* Juss. family are known to spread in the temperate zone of the world (Svlyev, 1996; Wang et al., 2005). Most of them are grown as decorative, technical plants and fodder (Svlyev, 1996). *Polygonum* species are used in the traditional medicine of many nations in the treatment of cardiovascular diseases (Yim et al., 2000), as an anti-inflammatory agent (Bralley et al., 2008), neuroprotector (Wang et al., 2009), age-related Alzheimer (Um et al., 2006), Parkinson (Li et al., 2005) diseases.

Various species of the genus, especially *P. aviculare L.* included in the pharmacopeia of many countries are used as a raw material for developing medical preparations. As they are rich in polyphenols of plant origin, especially flavonoids. One of the tasks of scientific and practical importance when using a plant as a raw material is to determine in which organ of the plant and during which phase of the growth active substances are accumulated as much as possible.

The main purpose of the work was to determine the spread of flavonoids in plant (*P. aviculare L.* and *P. patulum L.*) organs, and the pattern of accumulation depending on the growth phases, biomass productivity, flavonoid yield and optimal time period for collecting a plant raw material.

MATERIALS AND METHODS

Various organs of *P. aviculare L.* and *P. patulum L.* species were used as plant materials. Plant materials were collected at the beginning of vegetation, during the periods of the development of buds, before flowering (25-35% of buds were mature), flowering and fruit development in the botanical-geographical region of the Guba region of Greater Caucasus, in the north-eastern part of the Urva village of the Gusar region, around the forest and in the Susay village of the Guba region in 2014-2016.

Whole model plants were taken in various phases of the development. Roots were cleaned, plants were weighed and dried. Vegetative (leaf, stem, root) and generative (bud, flower, fruit) organs of each plant were detached and prepared

for analysis. Analysis was always performed with the material of the same population. Productivity of the above-ground part was established. Fresh and dry weights of plants collected from 4x1 m² field separated from the 100m² field were found. The density of *P. aviculare* and *P. patulum* species in 1 m² field was 15 plants and 16 plants, respectively. For the analysis of the raw material, plants were dried in the air and cut into 1mm slices. Amount of dry matter was determined using MX-50 moisture analyzer. To found dynamics of the changes in the flavonoid content and productivity of the above-ground part, 30 plants were taken for each sample. Sum of the flavanoids was determined in various plant organs spectrophotometrically (Gosfar 1989). Total amount of flavonoids was estimated based on avicularin according to the following formula:

$$x = \frac{D * 100 * 100 * 25}{330 * m * (100 - w)}$$

D – optic density; 330 - absorption index of avicularin with AlCl₃ at 410 nm; m-mass of the material, w- lost weight upon drying (%).

Each analysis was performed in 3 replicates and the mean values were estimated. The relative error of the methodology was ± 1.4%.

RESULTS AND DISCUSSION

The study of the accumulation dynamics of flavonoids in various organs of *P. aviculare* and *P. patulum* species belonging to the *Polygonum* L. genus depending on growth phases showed pronounced changes in flavonoid contents during the vegetative period (Table 1). In generative organs of *P. aviculare* and *P. patulum* species maximum amounts of flavonoids were accumulated in flowers (7.11 and 5.7%, respectively), and minimum amounts in green fruit (1.91 and 2.83%, respectively). In vegetative organs maximum amounts were found in leaves (4.85; 4.44%) and minimum amounts in roots (0.41 and 0.31%, respectively) and stem (0.71-0.65%, respectively).

In both species flavonoid content was found to change sharply depending on the growth stage of the plant. Maximum flavonoids (4.85%) were accumulated in leaves of the *P. aviculare* L. species before flowering, while in *P. patulum* L. maximum accumulation (4.44%) occurred during the flowering phase.

In both species flavonoid contents in the leaves of the studied species were found to be maximum in the phase of fruit development (2.83 and 3.03, respectively). Compared to other vegetative organs minimum flavonoids were accumulated in roots. In roots of *P. aviculare* L. and *P. patulum* L. maximum flavonoids were accumulated during the de-

velopment of buds (0.82%), and before flowering (0.67%), respectively. In above-ground organs of the studied species minimum flavonoids were detected in stems. Maximum flavonoids (1.34%) were found in the stem of *P. aviculare* L. during the initial phase of vegetation. But in *P. patulum* L. maximum amount was observed in the phase of bud development (1.13%), and minimum amount in the fruit development (0.71%) phase and the initial vegetation period (0.65%).

Flavonoid contents in the above-ground organs of the studied species changed in the range of 2.21-3.81%. In above-ground parts of *P. aviculare* L. maximum flavonoid contents were found during mass-flowering period (3.81%), while in *P. patulum* L. the highest quantity was detected before flowering (4.08%).

The study of the productivity of plant parts used as raw materials is of great practical importance. *P. aviculare* L. is a known medicinal plant. The study of the flavonoid content in the above-ground parts of *P. patulum* L. confirmed that the flavonoid content of this plant met the demands of pharmacopeia and could be used as a raw material. Therefore, dynamics of the increase in above-ground mass of both species has been studied throughout phenological phases. Data on biomass productivity are presented in Table 2. The results show that depending on the growth phases both fresh and dry mass production of the plant changed in a large range. So, in *P. aviculare* L. fresh and dry masses changed in the ranges of 2.85-25.0g and 0.31-4.62 g, respectively. While in *P. patulum* L. these changes were 2.23-28.49 g and 0.25-5.44 g, respectively.

Maximum weight per a plant for *P. aviculare* L. based on fresh weight was found during mass-flowering (24.7 g) and based on dry weight during the development of fruit (5.12g). While in *P. patulum* L. the same values were 26.3 and 5.39 g, respectively. The obtained results showed that it was advisable to collect plant materials when using both species as raw materials during mass-flowering. But the optimum period of plant collecting should be established to produce flavonoids in a high quantity. This was established based on the plant density per a certain field (1 m²) and flavonoid amounts in plant mass in 100 m² field.

According to Tables 1 and 2 productivity of flavonoids in 100 m² and 1ha was calculated and the results were presented in Table 3. As seen in the Table maximum amounts of flavonoids from above-ground parts of both species can be obtained during the complete flowering phase (240 g/100 m² and 335.9 g/100 m²). The obtained results confirmed the practical importance of the studied species and showed that both species can be used as raw materials for producing flavonoids.

Table 1. Dynamics of the accumulation of flavonoids in various organs of the *Polygonum* species throughout growth phases (based on dry weight, %)

Analyzed organ	Years	Phases of growth				
		Beginning of vegetation	Bud development	Before flowering	Mass-flowering	Fruit development
<i>P. aviculare L.</i>						
Stem	2014	1.15	0.99	0.96	0.71	0.61
	2015	1.53	1.32	1.28	0.94	0.82
	2016	1.31	1.16	1.13	0.83	0.71
	orta	1.34	1.21	1.12	0.82	0.71
Leaf	2014	2.75	4.06	4.15	3.70	2.45
	2015	3.66	5.32	5.53	4.93	3.27
	2016	3.22	4.44	4.87	4.34	2.77
	orta	3.21	4.61	4.85	4.32	2.83
Generative organ	2014	-	5.66	6.08	5.55	1.57
	2015	-	7.55	8.11	7.40	2.35
	2016	-	6.64	7.14	6.51	1.83
	orta	-	6.62	7.11	6.48	1.91
Above-ground part	2014	2.07	2.55	3.38	3.26	1.92
	2015	2.95	3.45	4.17	4.35	2.55
	2016	2.60	3.09	3.67	3.83	2.24
	orta	2.54	3.02	3.74	3.81	2.23
Root	2014	0.49	0.72	0.63	0.59	0.37
	2015	0.65	0.95	0.84	0.78	0.45
	2016	0.55	0.80	0.71	0.66	0.40
	orta	0.56	0.82	0.72	0.68	0.41
<i>P. patulum L.</i>						
Stem	2014	0.74	0.98	0.91	0.84	0.56
	2015	0.98	1.31	1.21	1.12	0.75
	2016	0.82	1.16	1.02	0.94	0.63
	orta	0.85	1.13	1.05	0.97	0.65
Leaf	2014	2.93	3.51	3.62	3.85	2.65
	2015	3.91	4.68	4.83	5.14	3.51
	2016	3.29	3.83	4.06	4.32	2.93
	orta	3.38	4.00	4.17	4.44	3.03
Generative organ	2014	-	4.27	4.85	4.48	2.46
	2015	-	5.58	6.47	5.88	3.28
	2016	-	4.67	5.43	5.02	2.76
	orta	-	4.84	5.58	5.13	2.83
Above-ground part	2014	1.93	2.90	3.37	3.66	2.14
	2015	2.54	3.96	4.69	4.48	2.85
	2016	2.16	3.38	3.97	3.75	2.51
	orta	2.21	3.41	4.08	3.86	2.50
Root	2014	0.34	0.46	0.58	0.37	0.27
	2015	0.46	0.55	0.79	0.49	0.36
	2016	0.39	0.47	0.65	0.41	0.30
	orta	0.39	0.49	0.67	0.42	0.31

Note: Deviation: $\pm 0.1 \div 0.2$ **Table 2.** Dynamics of the increase in the above-ground part of the *Polygonum L. species* (per a plant)

Species \ Phases	Beginning of vegetation	Bud development	Before flowering	Mass-flowering	Fruit development
<i>P. aviculare L.</i>					
Fresh weight	2.85	10.8	13.68	24.7	21.8
Dry weight	0.31	1.23	1.68	4.62	5.12
<i>P. patulum L.</i>					
Fresh weight	2.23	13.32	18.1	26.3	22.6
Dry weight	0.25	1.49	2.59	5.39	4.92

Table 3. Amounts of flavonoids obtained from *Polygonum* L. species during various phases of growth in 100 m² field. (mean values for 2014-2016)

Species	Phase of growth	Dry mass in 100 m ² , g	Flavonoid amount, g/100 m ²	Flavonoid amount (kg) in 1 ha
1	2	3	4	5
<i>P. aviculare</i> L.	Beginning of vegetation	465.0	11.81	1.18
	Bud development	1849.0	55.83	5.58
<i>P. aviculare</i> L.	Before flowering	2520.0	96.01	9.60
	Mass-flowering	16870	240.06	24.0
	Fruit development	6930.0	150.3	15.0
<i>P. patulum</i> L.	Beginning of vegetation	6739.0	8.84	0.88
	Bud development	2384.2	81.29	8.13
	Before flowering	4144.0	169.0	16.9
	Mass-flowering	8704.0	335.9	33.59
	Fruit development	8144.0	277.7	27.77

CONCLUSION

The study of the dynamics of the flavonoid accumulation in various organs of *P. aviculare* L. and *P. patulum* L. species of *Polygonum* L. genus showed that maximum accumulation occurred in reproductive organs (7.11-5.58%), less in leaves (4.85-4.44%) and minimum in roots (0.41-0.31%). Flavonoid contents were found to change sharply depending on the growth phase of the plant. Maximum flavonoids were accumulated in leaves of the *P. aviculare* species before flowering (4.85%), while in the *P. patulum* species it was observed during mass-flowering phase (4.44%). During the vegetative period the quantity of flavonoids changed in above-ground parts of the plants in the range of 2.21-3.84%. Maximum accumulation occurred in the *P. aviculare* L. and *P. patulum* L. species during the mass-flowering phase (3.81%), and before flowering (4.08%), respectively. Thus, the accumulation of flavonoids in plants is a dynamic process. The uneven distribution of flavonoids in plant organs and changes of their contents during various phases of the plant growth are related to their biological functions. The highest productivity of above-ground mass was detected during mass-flowering phase of both species (24.7 and 26.3 g/per a plant). It was established that both plants can be used as raw materials for obtaining flavonoids.

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***Polygonum L.* Növlərində Flavonoidlərin Toplanma Dinamikası**

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Qırxbuğumkimilər *Polygonaceae* Juss. fəsiləsinin qırxbuğum *Polygonum L.* cinsinin dünyanın mülayim qurşağında yayılmış 300 növü vardır. Onların bəziləri rəsmi dərman bitkisi olub, müxtəlif xəstəliklərin müalicəsində və dərman vasitələrinin alınmasında xammal kimi istifadə olunurlar. Cinsə daxil olan növlərin əsas təsiredici maddəsi flavonoidlərdir. Məqalədə *P. aviculare* və *P. patulum L.* növlərinin müxtəlif orqanlarında flavonoidlərin miqdarı, paylanması, inkişaf fazaları üzrə toplanma dinamikası, yerüstü hissə məhsuldarlığı öyrənilmişdir. Müəyyən edilmişdir ki, flavonoidlər orqanlar üzrə qeyri bərabər paylanır. Generativ orqanlardan maksimum miqdar qönçələrdə, vegetativ orqanlardan isə yarpaqlarda toplanır. Hər iki növün bioloji kütlə məhsuldarlığı və flavonoidlərin bitkiyə görə maksimum miqdarı çiçəkləmə fazasıdır.

Açar sözlər: *Polygonum*, flavonoid, toplanma dinamikası, vegetativ, generativ orqanlar, biokütlə

Динамика Накопления Флавоноидов У Видов Рода *Polygonum L.*

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В умеренном климатическом поясе обнаружено 300 видов рода *Polygonum L.* семейства *Polygonaceae* Juss. Некоторые из них являются лекарственными растениями, которые используются для лечения заболеваний или в качестве сырья для приготовления лекарств. Флавоноиды являются активными веществами вида, принадлежащего к роду *Polygonum L.* Содержание флавоноидов, их распределение и динамика накопления во всех фазах развития, а также продуктивность надземных частей изучались в различных органах видов *P. aviculare* и *P. patulum L.* Выявлено, что в различных органах растений распределение флавоноидов было неравномерным. Из генеративных органов максимальное накопление флавоноидов наблюдалось в бутонах, а из вегетативных органов - в листьях. Для обоих видов максимальные продуктивность биомассы и содержание флавоноидов отмечены в фазе цветения.

Ключевые слова: *Polygonum*, флавоноид, динамика накопления, вегетативные, генеративные органы, биомасса