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Formation of pale purple coneflower *(Echinacea pallida* (Nutt.) Nutt.) seed productivity in the conditions of the Left-Bank Forest-Steppe of Ukraine

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The study results of seed productivity of pale purple coneflower (*Echinacea pallida* (Nutt.) Nutt.), a promising medicinal and honey crop are presented. The research was conducted in the conditions of production plantations of Poltava region. It was established that at the early stages of ontogenesis, pale purple coneflower developed slowly: the first sprouts appeared 11–15 days after sowing and this period extended to 20–25 days. The cotyledon leaf phase lasted about for 7–9 days, and the first true leaf was formed during 25–32 days. The above-ground part and root system grew slowly in the first two months, their development accelerated from July. By the end of the vegetation, the plant formed a rosette of leaves and a fleshy vertically thickened rhizome. The generative period of pale purple coneflower began from the second year of growing season. Flowering lasted on the average for 46–52 days, starting in June. Plants reached a height of 85 cm, forming from 1 to 9 generative stems (on the average – 5.4). The average number of seeds per plant made 2770 pieces, and thousand-seed weight varied within 2.3–3.55 g. The morphometric study of the parameters of different orders' inflorescences on the shoot shows that the anthodia of the first-fourth orders were characterized by the largest diameter (3.02–3.60 cm) and the height of the inflorescences (2.44–3.25 cm). The first three inflorescences provided 68 % of the total seeds' weight from the plant, which indicates their highest productivity and value. It is emphasized that the sowing qualities of pale purple coneflower seeds are limited by a long period of organic dormancy. Laboratory germination of freshly harvested seeds from inflorescences of the first order did not exceed 60%, but of inflorescences of the second and third orders was 75–78 %. Infectious structures of five fungi genera (*Alternaria, Cladosporium, Fusarium, Mucor, Stachybotrys*) were found on the achenia. To increase germination, it is recommended to conduct stratification at a temperature of +4–5°C for at least 60 days. It was concluded that seed crops of pale purple coneflower can be used more rationally by harvesting inflorescences of the fourth and higher orders for pharmaceutical needs. Taking into account the biological characteristics of the crop will contribute to increasing the yield and ensuring the stable cultivation of this promising plant.

Keywords: Pale purple coneflower, *Echinacea pallida*, seed productivity, medicinal plants.

Формування насіннєвої продуктивності ехінацеї блідої (*Echinacea pallida* (Nutt.) Nutt.) в умовах Лівобережного Лісостепу України

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Наведені результати досліджень насіннєвої продуктивності перспективної лікарської та медоносної культури ехінацеї блідої (*Echinacea pallida* (Nutt.) Nutt.), проведених в умовах виробничих плантацій Полтавської області. Встановлено, що на ранніх етапах онтогенезу ехінацея бліда розвивалась повільно: перші сходи з'являлись через 11–15 діб після сівби і цей період подовжуватись до 20–25 днів. Фаза сім'ядольних листків тривала близько 7–9 діб, а перший справжній листок формувався протягом 25–32 діб. Надземна частина і коренева система в перші два місяці росли повільно, їх розвиток прискорювався з липня. До кінця вегетації рослина утворювала розетку листків та м'ясисте вертикально потовщене кореневище. Генеративний період ехінацеї блідої наставав з другого року вегетації. Цвітіння тривало в середньому 46–52 діб, починаючись у червні. Рослини сягали висоти 85 см, утворюючи від 1 до 9 генеративних пагонів (у середньому – 5,4). Середня кількість насіння на одну рослину становила 2770 штук, а маса 1000 насінин варіювала в межах 2,3–3,55 г. Морфометричне дослідження параметрів суцвіть різних порядків на пагоні свідчать, що кошики перших–четвертих порядків характеризувалися найбільшим діаметром (3,02–3,60 см) та висотою суцвіть (2,44–3,25 см). Перші три суцвіття забезпечували 68 % загальної маси насіння з рослини, що вказує на їхню найбільшу продуктивність і значення. Наголошується, що посівні якості насіння ехінацеї блідої обмежуються тривалим періодом органічного спокою. Лабораторна схожість свіжозібраного насіння суцвіть першого порядку не перевищувала 60 %, проте з суцвіть другого та третього порядку становила 75–78 %. На сім'янках виявлені інфекційні структури п'яти родів грибів (*Alternaria, Cladosporium, Fusarium, Mucor, Stachybotrys*). Для підвищення схожості рекомендовано проводити стратифікацію при температурі +4–5°C протягом не менше 60 діб. Зроблений висновок, що насіннєві посіви ехінацеї блідої можна більш раціонально використовувати за рахунок збирання суцвіть четвертого і більше порядків для фармацевтичних потреб. Врахування біологічних особливостей культури сприятиме підвищенню врожайності та забезпеченню стабільного вирощування цієї перспективної рослини.

Ключові слова: Ехінацея бліда, *Echinacea pallida*, насіннєва продуктивність, лікарські рослини.

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Introduction

The demand for medicinal plants as pharmaceutical raw materials in the world is constantly growing and correlates with the trend of using natural components for the production of medical preparations [4, 13, 19]. Despite the decline of medicinal plant growing as an industry, Ukraine has a strong potential in the form of scientific personnel, varieties, experience in cultivating and procuring medicinal raw materials. After creating economic and social conditions for development, the industry can make a significant contribution to the post-war recovery of Ukraine.

The representatives of Echinacea (Echinacea Moench.) genus have been successfully introduced to Ukraine and are popular not only as medicinal plants, but also as honey-bearing, fodder, and ornamental crops [14, 15]. This is facilitated by the unique phyto-chemistry of plants: the aerial part and root system contain a complex of natural compounds [1, 9], the content of which can be influenced by growing conditions and environmental factors [18, 5, 10]; they have antibacterial, antiviral, antioxidant activity, etc. [20, 21]. Among them, pale purple coneflower (*Echinacea pallida* (Nutt.) Nutt.) is not as well-known as purple coneflower, but has great prospects and needs to be widely popularized [6, 11].

Among its advantages, it is worth mentioning its drought resistance. The vertically thickened rhizome penetrates deeply into the soil and is able to use moisture from the lower layers, and the dense leaves and stems' pubescence contributes to the economical use of water by the plant [8]. Positive characteristics also include the rapid formation of reproduction organs in spring and the beginning of flowering in June. The combination of pale purple coneflower and purple coneflower, which begins to bloom in July, allows create a truly unique honey-bearing conveyor [15].

However, there are certain biological peculiarities that somewhat impede the cultivation of pale purple coneflower. The main one is low field germination [6]. At the beginning of introductory research, in the 90s of the past century, the seeds of samples obtained from the prairies of the USA had the laboratory germination of up to 32 %. The result of acclimatization and selection was a significant increase in the indicator to 60–70 %. However, in field conditions, low germination leads to thinning of crops [7].

The ways to overcome this problem are to propagate pale purple coneflower by seedlings and to use methods to stimulate seed germination [17]. In America and Europe, there is already a positive experience, especially in growing seedlings, but this does not apply to large areas and requires special infrastructure and technical potential, which is problematic for Ukraine. The physiological dormancy of seeds can also be overcome by treating them with growth regulators, chemicals, by applying physical factors such as irradiation, low temperatures, etc. [16, 23].

Among the technological peculiarities of cultivation, it is worth mentioning a low competition of first-year plants with segetal vegetation, which requires manual weeding and loosening [8]. For the seed production of pale purple coneflower, the choice of harvesting dates is important, which is connected with the non-simultaneity of ripening the anthodia of different orders. During the harvesting of coneflower seeds, the fruits are easily damaged, which affects further storage. The seed productivity of pale purple coneflower in production conditions has not been sufficiently studied, which is primarily due to the low volumes of cultivating this species not only in Ukraine, but also abroad. We believe that the issue is relevant for modern medicinal plant growing and requires profound study.

The aim of the study

The research objective is to investigate the peculiarities of the formation of pale purple coneflower (*Echinacea pallida* (Nutt.) Nutt.) seed productivity.

The task of the study is to assess the seed productivity of anthodia of different orders and their share in the total productivity; to determine the seeds' sowing properties depending on the order of inflorescences' arrangement on the shoot.

Materials and methods

The studies of pale purple coneflower (*Echinacea pallida* (Nutt.) Nutt.) seed productivity of were conducted in 2023–2024 in Radianskyi Agricultural Complex of Kremenchuk district in Poltava region. The soils are black residually deeply slightly saline, located on loess terraces. The humus content is 2.1–2.4 %, pH = 5.9–6.8. The climate is moderately continental with unstable moistening. In 2023, regular precipitation in the first period of the vegetation made it possible to obtain sprouts and form a rosette of leaves, which provided developed plants by the end of the growing season. In 2024, the combination of atmospheric drought and unproductive precipitation did not allow the maximum implementation of the seed potential of pale purple coneflower.

The cultivation technology included sowing with a precision seeder at a width of 45 cm and a sowing rate of 10–12 kg/ha, inter-row loosening, fertilizer application, and manual weeding in the first year of vegetation.

Experiment 1. During the growing season in the first year of vegetation and from the moment of plant re-growing in the second year, samples (15 plants) were taken, determining the morphometric characteristics of the above-ground part and root system. Among the indicators of the above-ground mass development, the weight of stems, leaves, inflorescences and their morphological parameters (the length and width of leaves, diameter of inflorescences, and height of stems) were determined. Also, the number of leaves, inflorescences, stems, anthodia and seeds were calculated.

Experiment 2. The study of seed productivity. The most typical model plants of pale purple coneflower were cut and the structure of the above-ground mass and seed productivity were determined: inflorescence parameters, number of seeds and their weight in inflorescences, the assessment of productivity by inflorescence orders. Biological yield was assessed by threshing pale purple coneflower plants harvested from an area of one square meter in five replicates.

Experiment 3. The determination of pale purple coneflower seeds sowing properties. 100 seeds in triplicate were placed in Petri dishes on filter paper, then 5 ml of distilled water was added and the seeds were germinated at a temperature of 22–24°C. Germination energy was determined on the seventh day, laboratory germination – on the 14th day [7].

The statistical assessment of the obtained results was conducted using the method of variance analysis in the MS OFFICE program package.

Results and discussion

We have established that pale purple coneflower at the initial stage of ontogenesis, namely in its virginal period, develops slowly. After sowing, the sprouts began to appear only on the 11th–18th day. In some years, especially dry ones, the period of shoots can be extended to 20-25 days. At the stage of cotyledonary leaves, pale purple coneflower shoots were on average 7–9 days (***Fig. 1***). After that, the first true leaf began to develop. This process, depending on weather conditions, extended to 25–32 days from the moment of sprouts emergence.

Our studies indicate that during the first two months of vegetation, the above-ground part and root system of pale purple coneflower developed much more slowly than in the following months. During the growing period of the first vegetation year, the plants formed a developed rosette of leaves and a fleshy vertically thickened rhizome. This distinguishes pale purple coneflower f rom other species of this genus. Taking it into account, we note that this biological peculiarity gives it great advantages both in ecological and technological terms. The transition to the generative period was accompanied by the formation of the shoot with inflorescences. This period in pale purple coneflower began from the second year of vegetation.

Fig. 1. Pale purple coneflower plants: sprouts, the first year of vegetation, the second year of vegetation, before seed cropping

Starting from the re-vegetation, the plants quickly went through the stages of organogenesis and flowering began in June. As our observations show, pale purple coneflower plants bloom for an average of 46 days. In this case, inflorescences of the first to fourth orders bloom almost simultaneously, the following ones are formed and bloom later depending on the existing soil and climatic conditions [22].

Pale purple coneflower plants at the time of seed cropping were characterized by a number of morphometric indicators reflecting their biomass (***Table 1***). The average plant height made 85.4 cm, and the number of shoots per plant was 5.4 pcs. The stems weight reached 81.6 g, and the number of stem leaves made 68.5 pcs. with a total weight of 42.3 g. Besides, an average of 18.4 rosette leaves were formed on one plant weighing 15.6 g. The plants formed an average of 21.4 inflorescences, which ensured their productivity, and the total weight of anthodia made 32.3 g.

It was established that one plant in the second year of life produced an average of 2770 seeds, with a total weight of 9.84 g. The laboratory germination of freshly cropped seeds did not exceed 60%, which corresponded to the data of other researchers [12]. Moreover, the attention has to be paid to the fact that this species has a fairly long period of its achenia organic dormancy. This should be taken into account when growing pale purple coneflower and methods of regulating seed dormancy should be used [16]. According to our previous observations, the dry stratification method deserves attention, while its duration at a temperature of +4–5°C must not be less than 60 days.

Table 1
The indicators of pale purple coneflower plant development at the time of seed cropping

Indicators	Value
Plant height, cm.	85.4
Number of shoots per plant, pcs.	5.4
Stems weight, g.	81.6
Number of stem leaves, pcs.	68.5
Weight of stem leaves, g.	42.3
Number of rosette leaves, pcs.	18.4
Weight of rosette leaves, g.	15.6
Number of inflorescences, pcs.	21.4
Weight of inflorescences, g.	32.3
Weight of the above-ground part, g.	171.8
Weight of raw root, g.	41.5

The analysis of morphometric characteristics of pale purple coneflower inflorescences shows that the anthodia sizes of the first four orders gradually decreased (***Table 2***). For example, the inflorescences diameter varied from 3.60 cm (the first order) to 3.02 cm (the fourth order). A similar trend was observed as to the inflorescences height (from 3.25 cm to 2.44 cm) and the stem diameter under the inflorescence (from 0.71 cm to 0.54 cm). The indicators of the inflorescences of subsequent orders did not have a clear pattern.

Table 2
The parameters of pale purple coneflower inflorescences according to the order of their arrangement

Inflorescence order	Inflorescence diameter, cm	Inflorescence height, cm	Stem diameter under inflorescence, cm
1st order	3.60	3.25	0.71
2nd order	3.12	2.61	0.56
3rd order	3.09	2.51	0.55
4th order	3.02	2.44	0.54
5th order	3.21	2.71	0.59
6th order	2.97	2.92	0.58
7th order	3.07	2.27	0.51

The analysis of the number of achenia in one inflorescence (***Fig. 2***) shows that the conditions of fruit formation significantly influenced the indicator, which proves the possibility of regulating this process by ensuring the optimal soil moistening during flowering. On the average, from 148 to 186 fruits were formed in one inflorescence. At the same time, the number of fruits gradually decreased from the first to the third order, and then increased again to 153.1 pieces. However, the first inflorescence in our experiments formed 93–95 more fruits than the inflorescences of other orders.

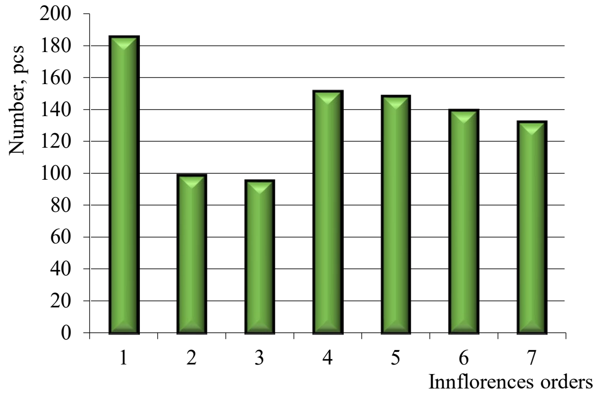

Fig. 2. The number of achenia in inflorescences of pale purple coneflower of different orders, pcs.

Concerning the fruits weight in the inflorescence, a similar trend is observed as to the number of achenia. This is explained by a significant correlation between the number of achenia and their weight. The largest fruits weight was observed in the inflorescences of the first order – 0.66 g (***Fig. 3***). This indicator gradually decreased to the 3rd order (0.29 g). In subsequent orders, the weight grew to 0.45 g (4th order) and decreased again to 0.3 g.

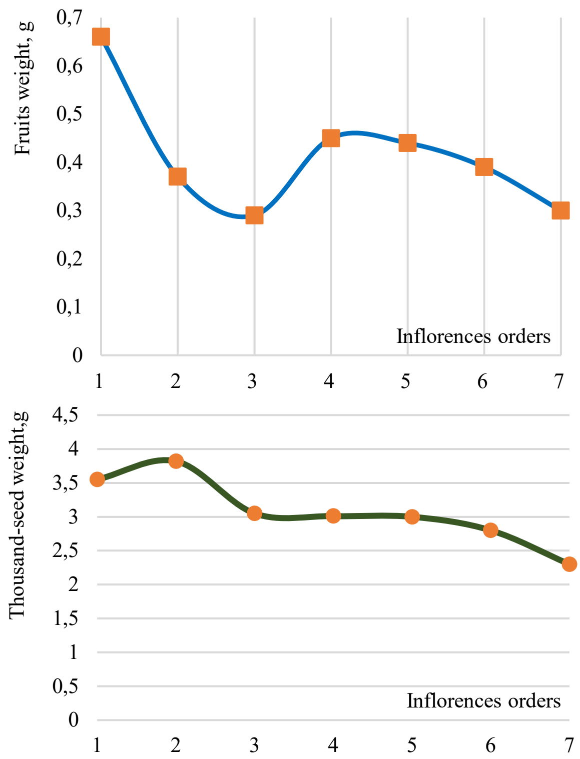

Fig. 3. Fruits weight in inflorescences and thousand-seed weight in inflorescences of different orders of pale purple coneflower, g.

Thousand-seed weight in the experiments fluctuated less. In the anthodia of the first order it was the largest and amounted to 3.55 g (***Fig. 3***). It is worth mentioning that there was no high dependence of thousand-seed weight on the fruits weight in inflorescences (R = 0.48). The amplitude of thousand-seed weight was in the range from 2.30 to 3.82 g.

The calculations show that the main share of the obtained harvest falls on the first 3 inflorescences (***Fig. 4***). It amounted to 68% of the total achenia weight, and the other inflorescences of the 4th-7th orders provided only 32 % of the harvest. Taking into account the above-mentioned, the question of the rational use of seed crops arises. It is quite realistic to introduce the technology when inflorescences of the 4th and higher orders can be used as pharmaceutical raw materials. On the one hand, this will allow improve the seeds' sowing qualities, and on the other hand, to use the plantation more effectively.

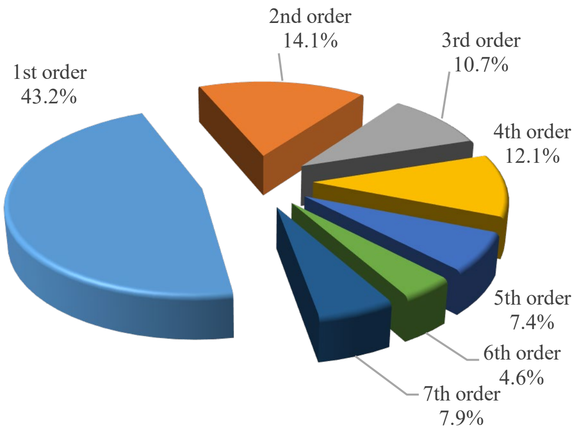

Fig. 4. The analysis of the yield structure by the orders of pale purple coneflower inflorescences

Taking into account the above-mentioned peculiarities, the assessment of pale purple coneflower biological yield was conducted (***Table 3***). According to the yield structure, on the average, 4 inflorescences were formed on one shoot, in which 98.1 pcs. of seeds weighing 0.35 grams were formed. One plant on the average formed 5.4 shoots. Considering that thousand-seed weight amounted to 3.55 g, one plant formed 7.56 grams of seeds. If we take into account that 90 thousand plants are grown on one hectare, the biological potential of seed productivity in pale purple coneflower in Kobeliaky district was 0.68 t/ha. It is worth noting that in the conditions of production sown areas, the yield is much lower, which is explained by the uneven ripening of anthodia, significant losses during harvesting and subsequent seed cleaning. In our opinion, the issue of coneflower seed production has been little studied, and therefore it is a broad field of activity for agronomists, physiologists, and seed scientists to search for levers to improve the fruit formation of this crop.

Table 3

The structure of the biological yield of pale purple coneflower seeds

Indicators	Research results
Number of stems per plant, pcs.	5.40
Number of inflorescences per 1 stem, pcs.	4.00
Number of fruits in the inflorescence, pcs.	98.10
Fruit weight in 1 inflorescence, g.	0.35
Thousand-seed weight	3.55
Fruit weight per plant, g.	7.56
Number of plants per 1 ha, pcs.	90000
Yield from 1 hectare, tons.	0.68

In laboratory conditions, studies were conducted of the sowing qualities of freshly harvested pale purple coneflower seeds collected from inflorescences of different orders (***Fig. 5***). At the same time, germination energy and laboratory germination were determined. The dynamics of seed germination shows that, regardless of the inflorescence order, the largest number of achenia germinated on the 4th–7th day. After the seventh day, the number of germinated seeds significantly decreased, and on the 12th–14th day the germination process stopped.

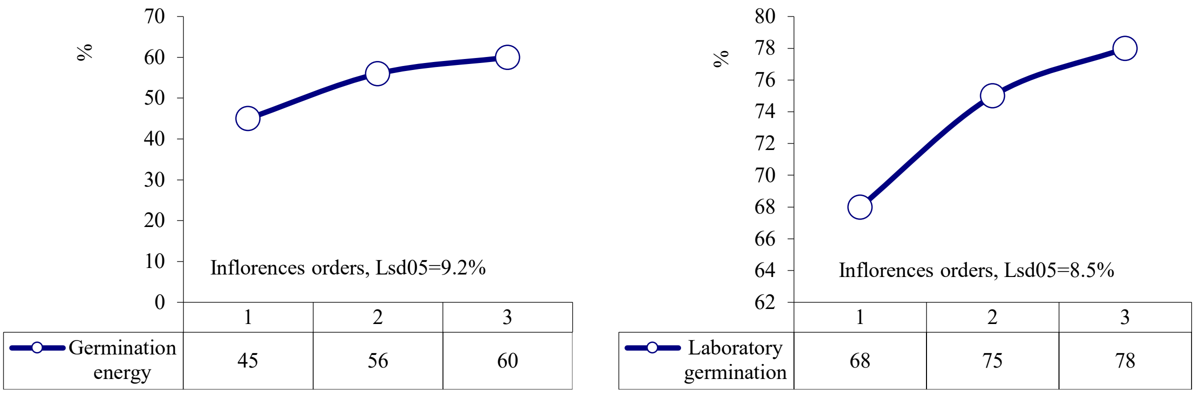

Fig. 5. Germination energy and laboratory germination of pale purple coneflower seeds

The seed germination energy was the highest in fruits of the second and third orders, and amounted to 56–60 %. This indicator was somewhat lower in fruits of the first order – 45 %. As for laboratory germination, i n the seeds of the first order inflorescences it was minimal – 68 % and higher – in the seeds of the second and third order inflorescences – 75–78 %.

Phyto-pathological expert examination of seeds showed the presence on the achenia of five fungi genera infectious structures: *Alternaria, Cladosporium, Fusarium, Mucor, and Stachybotrys*. The representatives of the primary infection of *Alternaria and Fusarium* genera dominated, the level of contamination by which reached 36% of the analyzed material. The obtained results coincided in regularities with the studies of other authors and are explained by the peculiarities of the crop biology [7].

Conclusions

The conducted studies on the seed productivity of pale purple coneflower allow us to draw the following conclusions:

1. The formation of plant productivity in the first year of vegetation occurs slowly. After sowing, the sprouts appear after 11–18 days, and in dry weather the period is extended to 20–25 days. In the cotyledon leaf phase, the sprouts remain for about 7–9 days, after which the development of the first true leaf begins, which lasts for 25–32 days. The above-ground part and the root system grow slowly in the first two months, but from July the growth accelerates significantly. Pale purple coneflower forms a fleshy vertically thickened rhizome, which is a distinctive feature of this species.

2. On the second year of vegetation, flowering begins in June and lasts on the average for 46 days, which makes pale purple coneflower a promising honey-bearing crop. At the time of seed harvesting, the plant height reaches 85.4 cm, and the number of generative shoots varies from 1 to 9, on the average – 5.4 shoots. The average number of seeds per plant is 2770 pieces with a total weight of 9.84 g, and thousand-seed weight varies within 2.30–3.55 g.

3. It was found that the largest share of seed productivity is provided by the first three inflorescences, which form 68 % of the total seed mass. 148–185 fruits were formed in one anthodium. The first inflorescences on the shoot formed 93-95 fruits more than the inflorescences of other orders. The fruits weight in the inflorescences of the first–third orders amounted to 0.29–0.66 g, and thousand-seed weight was 3.05–3.85 grams. It is suggested to harvest inflorescences on the areas sown for seeds below the third order for pharmaceutical needs, which will improve the quality of seed material.

4. According to the assessment of biological yield, one plant formed 5.4 shoots, on which 7.56 grams of seeds were formed, which calculated per hectare (90 thousand plants) made 0.68 t/ha. The germination energy of freshly harvested seeds did not exceed 60 %, which is explained by a long period of organic dormancy. The highest germination rates were observed in the seeds of the second and third order inflorescences (75–78 %).

Conflict of interest

The authors state that there is no conflict of interest.

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