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Research Article

Features of polysaccharide accumulation in *Althaea officinalis* L. raw material under various technological methods

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Abstract: Based on the conducted research, the influence of mineral fertilizers, drip irrigation, growth regulators, and harvest times on the polysaccharide content in *Althaea officinalis* L. raw material was determined. The study utilized field, laboratory, and computational methods. A trend was observed where increasing the dose of mineral fertilizers resulted in higher polysaccharide content in the dry raw material. Drip irrigation slightly reduced the polysaccharide content in the grass and leaves of *A. officinalis* but increased their content in the roots. When examining the effect of foliar application of growth regulators on the total polysaccharide content in *A. officinalis* raw material, it was found that growth regulators can either increase or decrease the content of biologically active substances compared to the control. The highest polysaccharide content in the grass and leaves was obtained with the application of $N_{120}P_{120}K_{120}$, and in the roots with $N_{180}P_{180}K_{180}$. Among the studied growth regulators, Potassium Humate and Sodium Humate were found to be the most effective. The optimal time for harvesting the aerial parts of *A. officinalis* to achieve the highest polysaccharide content is during the flowering phase, where the dry grass collected in this phase contained 9.11% polysaccharides, the leaves contained 11.21%, and the stems contained 6.18%. To obtain high-quality *A. officinalis* raw material, timely preventive measures against the pathogen *Puccinia malvacearum* Mont and the spread of the pest *Podagrica fuscicornis* L.

INTRODUCTION

Althaea officinalis L., commonly known as marshmallow, is a plant whose underground organs, herb, leaves, and flowers are used in traditional, official, and veterinary medicine in many countries around the world (Al-Snafi, 2013; Koleva *et al*., 1986; Mahboubi, 2020). The chemical composition of *A. officinalis* is remarkably rich, including pectins, starch, monosaccharides, disaccharides, mucilage, flavonoids, coumarins, scopoletin, tannins, asparagines, and amino acids (Akbar, 2020; Deters *et al*., 2010).

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Despite its long history of use, *A. officinalis* plays a significant role in modern systems for the prevention and treatment of various diseases (Al-Snafi, 2013; Deters *et al*., 2010). Studies using new methods have determined that the root of *A. officinalis* contains 51-1% water-soluble polysaccharides, which are composed of galacturonorhamnans, glucans, arabinans, and other carbohydrates, including arabinogalactans (Dawid-Pać, 2013; Karimi *et al*., 2021). This unique chemical composition accounts for the anti-inflammatory, antiulcerogenic, and antimicrobial activities not only of the roots but also of other parts of *A. officinalis* (Rezaei *et al*., 2015).

Clinical studies have shown that plant polysaccharides, particularly those derived from the herb and leaves of *A. officinalis*, enhance the action of internal antioxidant enzymes, demonstrating their immunomodulatory effects (Banaee *et al*., 2017). The aqueous extract and isolated polysaccharide complexes from the herb and leaves of *A. officinalis* effectively stimulate physiological processes in epithelial cells. Additionally, due to the passive mucilage-strengthening effect on connective tissue cells, extracts from the roots of *A. officinalis* can accelerate wound healing processes (Deters *et al*., 2010). Extracts obtained from the underground organs and flowers of *A. officinalis* have experimentally confirmed antibacterial (effective against both gram-positive and gram-negative bacteria), antifungal, anti-inflammatory, antibacterial, and antitussive properties. Phytopreparations based on *A. officinalis* also exhibit proven antiviral and antioxidant activities (Bonaterra *et al*., 2020).

Until recently, only dried roots were used for the production of *A. officinalis-based* medications (Andruszczak & Wisniewski, 2007; Kianitalaei *et al*., 2019; Shah *et al*., 2011). Consequently, most agronomic studies focused on achieving high yields of underground organs. However, over the past 20-30 years, pharmaceutical companies have begun actively using the aerial parts - herb, leaves, and flowers of *A. officinalis* as alternative, ecologically sustainable raw materials. Given the widespread use of *A. officinalis* aerial parts, there is a need to improve cultivation technology to ensure stable yields of not only roots but also high-quality herbs. The application of mineral fertilizers, drip irrigation, and growth regulators are effective means of increasing the yield of medicinal plants, as demonstrated by several studies (Shatkovskyi *et al*., 2021). These methods have also proven highly effective for *A. officinalis* (Pryvedeniuk *et al*., 2021).

Research conducted by Iranian scientists on the effects of nitrogen and phosphorus on the yield of *A. officinalis* has shown that nitrogen significantly increases plant height, leaf area, and chlorophyll content, while phosphorus only affects plant height. The most effective fertilizer application rates were found to be 150 kg/ha of nitrogen and 90 kg/ha of phosphorus (Meyghan & Moradi, 2018). During the years 2012-2013, studies in Iran investigated the impact of organic and mineral fertilizers on the productivity of *A. officinalis*. The highest raw material yield was achieved through the application of mineral fertilizers in combination with Thiobacillus and sulfur (Khorramdel *et al*, 2018).

Polish scientists focused on improving methods of propagating *A. officinalis*. The highest crop yield was obtained by establishing plantations using seedling methods with cassette systems. The highest quality roots were achieved when *A. officinalis* was grown under polypropylene film (Andruszczak & Wisniewski, 2007). The application of irrigation on medicinal plants significantly increases their yield but can also substantially affect the accumulation of biologically active substances, either increasing or decreasing their content (Asadzadeh *et al*., 2023; Baudoin *et al*., 2022; Rioba *et al*., 2015). The quality of medicinal plant raw materials is significantly influenced by mineral fertilizer use (Luta *et al*., 2022; Sugier *et al*., 2023).

Studies examining innovative cultivation approaches for medicinal plants suggest that while beneficial for growth and development, certain practices may unintentionally promote disease spread and affect material quality (Pryvedeniuk *et al*, 2020). Given the high therapeutic efficacy of medicinal products made from various raw parts of *A. officinalis*, and considering the principles of sustainability and reproducibility of its composition, the quality of the starting raw material becomes crucial. Therefore, all production processes of raw materials, including new varieties, technological practices, and technologies, undergo rigorous efficiency evaluation

through quality assessment of the resulting product—medicinal plant raw materials (World Health Organization, 2003).

Considering that the application of mineral fertilizers, growth regulators, and drip irrigation during the cultivation of medicinal plants may impact the quality of the obtained raw materials, the Research Station of Medicinal Plants of the IAP NAAS conducted a series of studies from 2019 to 2021 to determine the patterns of polysaccharide accumulation in *A. officinalis* raw materials under various technological practices.

MATERIAL and METHODS

Research Objectives

To evaluate how mineral fertilizers, drip irrigation, and growth regulators affect polysaccharide content in *A. officinalis*. To determine the best harvest time for maximum quality and identify quality-reducing harmful organisms.

Research Location

Research Station of Medicinal Plants of the Institute of Agroecology and Environmental Management of the National Academy of Agrarian Sciences of Ukraine (NAAS) is located in the village of Berezotocha, Lubny district, Poltava region, on the territory of the Left-Bank Forest-Steppe of Ukraine, at an altitude of 160 m above sea level, on the second terrace of the left bank of the Sula River (Dnipro River basin) (50°50' N and 30°11' E).

Weather Conditions During the Research Period

The research area has a moderately continental climate. Data from 2019–2021 from the Lubensky meteorological station showed an average annual temperature of 9.9°C and 517.9 mm of precipitation. June was the warmest (22.0°C), January coldest (-2.7°C). August was driest (14.3 mm), and May 2020 was the wettest month (176.3 mm). Conditions favored *A. officinalis* growth (Table 1).

Table 1. Meteorological Conditions 2019–2021.

Climate factors	Years	Month												
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Average temperature (°C)	2019	-5.4	-0.6	3.8	10.4	17.3	23.4	19.9	20.4	15.6	10.5	4.1	2.0	10.1
	2020	0.2	1.3	6.6	8.9	12.9	22.1	21.2	20.7	17.9	12.4	3.3	1.6	10.8
	2021	-2.8	-5.6	1.8	7.6	14.7	20.6	24.2	21.6	13.1	7.6	4.2	-1.5	8.8
	Per years	-2.7	-1.6	4.1	9.0	15.0	22.0	21.8	20.9	15.5	10.2	3.9	0.7	9.9
														Average
Precipitations (mm)	2019	57.7	28.7	36.4	28.0	63.4	29.5	22.5	7.1	17.3	27.	39.6	43.1	400.3
	2020	36.4	59.3	11.4	18.0	176.3	38.1	67.7	7.9	30.5	20.9	22.4	44.0	532.9
	2021	73.8	64.0	26.6	25.0	75.1	75.7	31.0	28.0	62.6	30.1	45.4	83.2	620.5
	Per years	56.0	50.7	24.8	23.7	104.9	47.8	40.4	14.3	36.8	26.0	35.8	56.8	517.9

Methodology – Field Studies

The soil is deep, low-humus chernozem with light loam: moderate humus (2.43%, horizon 80–90 cm), low easily hydrolyzable nitrogen (103.6 mg/kg), very high mobile phosphorus (384.4 mg/kg), and elevated mobile potassium (110.4 mg/kg).

Research utilized methods common in medicinal plant cultivation. Experiment schemes followed Dospekhov and Goryansky (Goryansky, 1970; Dospekhov, 1985). Biometrics, phenology, and yield used Brykin A.I.'s methodology (Brykin, 1981).

The predecessor was clean fallow. Fall plowing (28-30 cm) was followed by spring moisture retention and pre-sowing cultivation (6-8 cm). Mineral fertilizer (nitroammophoska $N_{16}P_{16}K_{16}$) was applied pre-tillage at $N_{60}P_{60}K_{60}$, $N_{120}P_{120}K_{120}$, $N_{180}P_{180}K_{180}$, with an unfertilized control. *A. officinalis* (var. Malvina) was sown at 7 kg/ha (1 cm depth, 60 cm row spacing). During growth, soil moisture (0-0.4 m layer) was maintained at 80-90% of minimum capacity via drip irrigation (well source), monitored by VTT-II tensiometers (Romaschenko *et al*., 2014).

Growth regulators were sprayed thrice: stem elongation, bud formation, and flowering initiation. Preparations (300 l/ha): Vympel, Emistin, Zircon, Ivin, Potassium humate (30%), Sodium humate (30%). Cultivation occurred without protection agents.

Identification of Harmful Organisms

Disease prevalence was assessed by systematic inspection using 10 plots (1 m each), counting healthy/infected plants. Prevalence calculated by formula P = (n/N)*100. Infection severity is determined by a 6-point scale. Disease development was assessed with a standard formula involving plant counts and severity scores (Tribel, 2001).

Laboratory Studies

A. officinalis samples (herbs, leaves, roots) were harvested during flowering and dried at 35–45°C. Polysaccharide content determined per the State Pharmacopoeia of Ukraine (St. Ph. Ukr.). Extraction included refluxing, centrifugation, filtration, drying, and final weighing. Content calculated using standard formula and compared against pharmacopeia benchmarks: ≥5.0% in herbs, ≥14.0% in roots.

Statistical Analysis

The statistical processing of the experimental results was conducted using analysis of variance (ANOVA), correlation, and regression methods with the software Statistica version 6.0 (TIBCO Software Inc.).

RESULTS

Traditionally, Ukrainian pharmaceutical companies use the dried herbs (aerial parts) and dried roots of *A. officinalis* for the production of medicinal products (St. Ph. Ukr.). European pharmaceutical companies primarily use dried leaves (separated leaves with inflorescences from the stems) and dried roots (Ph. Eur.). Recently, Ukrainian enterprises have also started using the leaves of *A. officinalis* (without stems) in production. Therefore, quality control of the content of biologically active substances – polysaccharides – was performed not only in the herbs and roots but also separately in the leaves. The main quality criterion for medicinal plant raw materials is the content of biologically active substances; the higher their content, the more valuable the raw material.

In the studies on the effect of basic mineral fertilizer application and drip irrigation on the chemical composition of *A. officinalis* raw material, a pattern of increasing polysaccharide content in dry raw material with increasing doses of mineral fertilizer application was observed. The use of drip irrigation slightly reduced the polysaccharide content in the herbs and leaves of *A. officinalis* but increased their content in the roots.

In the variants with $N_{60}P_{60}K_{60}$ application without irrigation, the polysaccharide content increased relative to the control (no fertilizer, no irrigation) by 0.19% in the herbs, 1.07% in the leaves, and 0.16% in the roots. The highest polysaccharide content in the aerial parts of *A. officinalis* was obtained in the variants with $N_{120}P_{120}K_{120}$ fertilizer application, where the content exceeded the control by 1.23% in the herbs, 1.4% in the leaves without irrigation, and 0.26% in the grass, 2.13% in the leaves under irrigation conditions. Further increasing the fertilizer dose slightly reduced the polysaccharide content in the herbs and leaves of *A.*

officinalis but increased it in the roots. In the variants with $N_{180}P_{180}K_{180}$ fertilizer application, the dry roots of *A. officinalis* contained 20.49% polysaccharides without irrigation, exceeding the control variant by 2.88%, and 22.19% under irrigation, exceeding the control variant by 3.34% (Table 2).

Table 2. Effects of irrigation and mineral fertilizers on the polysaccharide content in dry raw materials of *A. officinalis* (2019-2021).

Variants		Polysaccharide content, %		
Factor A	Factor B	Herbs	Leaves	Roots
Without irrigation	$N_0P_0K_0$	8.75	10.47	17.61
	$N_{60}P_{60}K_{60}$	8.94	11.54	17.77
	$N_{120}P_{120}K_{120}$	9.98	11.87	18.07
	$N_{180}P_{180}K_{180}$	8.93	10.29	20.49
On irrigation	$N_0P_0K_0$	8.76	9.52	18.85
	$N_{60}P_{60}K_{60}$	8.85	9.95	20.98
	$N_{120}P_{120}K_{120}$	9.02	11.65	21.76
	$N_{180}P_{180}K_{180}$	8.23	10.12	22.19
$LSD_{0,5\ main\ effects\ factor\ A}$		*0.07*	*0.11*	*0.86*
$LSD_{0,5\ main\ effects\ factor\ B}$		*0.13*	*0.18*	*0.57*
$LSD_{0,5\ partial\ differences\ factor\ A}$		*0.15*	*0.19*	*1.14*
$LSD_{0,5\ partial\ differences\ factor\ B}$		*0.24*	*0.28*	*1.25*

In the study of the effects of foliar application of growth regulators on the polysaccharide content in *A. officinalis* raw material, it was established that they can both increase and decrease their content relative to the control.

The application of Vympel reduced the polysaccharide content in the herbs by 0.76% and in the leaves by 0.44% of *A. officinalis* compared to the control (no growth regulators applied), but simultaneously increased their content in the roots by 2.32%. Foliar application of the growth regulator Emistin increased the polysaccharide content in the dry raw material of *A. officinalis* in the herbs by 0.17%, in the leaves by 0.33%, and in the roots by 1.95%. The use of the preparation Zircon negatively impacted polysaccharide accumulation, reducing their content in all types of studied raw materials. The growth stimulant Ivin did not significantly affect the polysaccharide content in the dry raw material of *A. officinalis*. With foliar application of Potassium Humate, among the studied variants, the highest polysaccharide content in the aerial parts of *A. officinalis* was obtained, exceeding the control by 0.41% in the herbs and leaves. The highest polysaccharide content in the roots – 21.94% – was obtained with the application of Sodium Humate, exceeding the control by 4.11% (Table 3).

To determine the optimal harvesting periods for *A. officinalis* raw materials, studies were conducted to establish the dynamics of polysaccharide accumulation. In this experiment, *A. officinalis* was grown without irrigation, mineral fertilizers, or growth regulators. Their content was determined in the aerial part – herbs, and separately in leaves and stems (Figure 1).

The conducted studies indicate that for dry *A. officinalis* raw material, high polysaccharide content is characteristic during the intensive growth phase, with values of 8.92% in herbs, 10.70% in leaves, and 6.27% in stems. The transition of plants to the budding phase was accompanied by a decrease in polysaccharide content, amounting to 6.72% in dry grass, 8.91% in leaves, and 4.31% in stems. The beginning of flowering was associated with an increase in polysaccharide content, reaching its maximum during the mass flowering phase, with values of 9.11% in herbs, 11.21% in leaves, and 6.18% in stems (Figure 1). During further plant growth and development, the polysaccharide content decreased and was the lowest in the fruiting phase, with values of 6.44% in herbs, 7.33% in leaves, and 4.02% in stems. Given this fact, this phase of plant development can be recommended as the most optimal period for harvesting the crop.

Table 3. Effects of foliar application of growth regulators on the polysaccharide content in dry raw materials of *A. officinalis* (2019-2021).

Variants	Polysaccharide content, %		
	Herbs	Leaves	Roots
Control	8.72	10.51	17.83
Vympel	7.96	10.07	20.15
Emistin	8.89	10.84	19.78
Zircon	8.16	9.82	17.20
Ivin	8.53	10.65	17.61
Potassium Humate	9.13	10.92	20.22
Sodium Humate	8.55	10.64	21.94
LSD $_{0,5}$	*0.16*	*0.12*	*0.21*

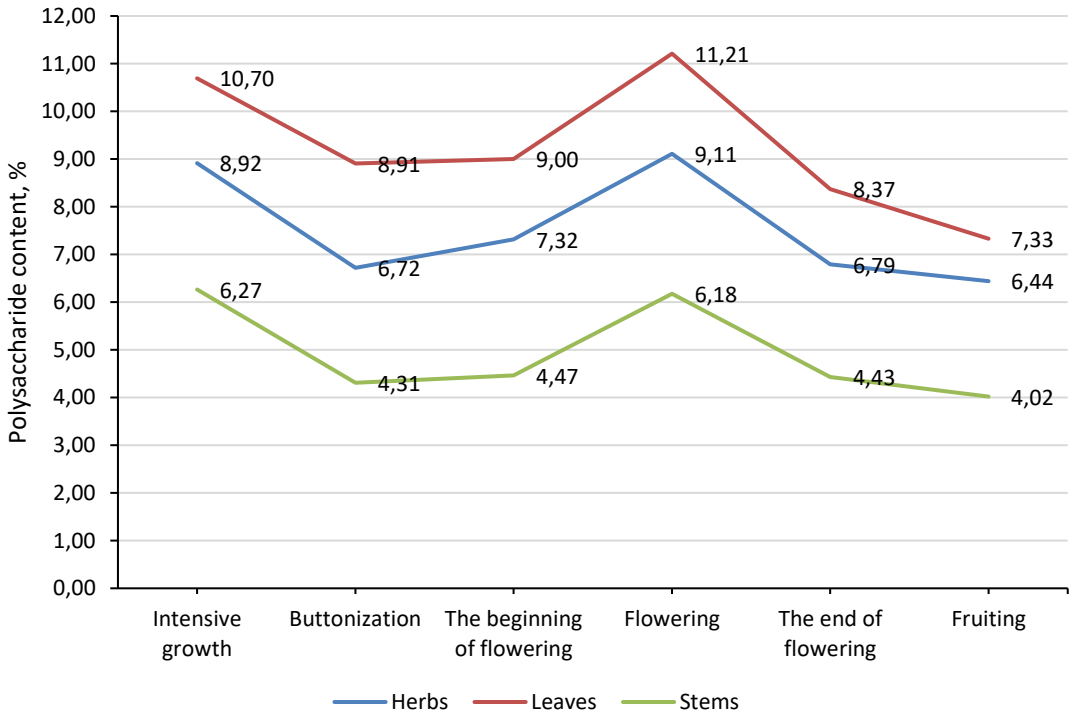


Figure 1. Dynamics of polysaccharide accumulation in dry raw materials of *A. officinalis* (2019-2021).

Additionally, pests and plant pathogens can significantly reduce medicinal plant raw material quality (Mishshenko *et al*, 2015). Studies of *A. officinalis* crops documented infections by rust (*Puccinia malvacearum* Mont), root rot (*Fusarium, Alternaria*), and infestations of the mallow flea beetle (*Podagrica fuscicornis* L.).

It is known that diseases under the general name "root rot" are caused by fungi and oomycetes of the genera *Fusarium*, *Helminthosporium*, *Alternaria*, *Pythium*, and some bacteria (Hlushchenko, 2013). The manifestation of the disease is quite uniform. Root tissues rapidly macerate, leaves turn yellow, dry out, and fall off. When the disease spreads during the pre-harvest period of herbs, in the budding and early flowering phases, the manifestation of root rot visually appears as ordinary wilting. Leaves turn yellow and wilt along the stem, dry out, and fall off, and the tops droop, which is often associated with soil drought in production conditions. The raw materials of infected plants have well-visible signs – the tissues of the stems are dark.

During the research period, in wet and warm weather, especially under irrigation conditions, the affected areas of the *A. officinalis* stems were covered with white or pink (*Fusarium*), dark gray, or greenish-olive (*Alternaria*) coatings. Damage to underground organs also manifested as darkening, with cross-sections showing brown or reddish hues. The surface of the roots

cracked, the bark broke down, and small roots and root hairs rotted. The spread of the disease was not widespread. A specialized pathogen causing rust in *A. officinalis* is the specialized fungus of the class Urediniomycetes – *Puccinia malvacearum* Mont.., which causes mass plant infections and easily spreads through air currents (Borcean *et al*, 2016).

During the research period, the mass spread of rust disease in *A. officinalis* was recorded in July-August 2022. On the ventral side of the leaves, along the veins, bright orange or golden-yellow aecia pustules with a diameter of up to 2 mm formed. Later, light brown uredinia pustules with urediniospores appeared, causing re-infection of plants during the vegetation period. The incubation period lasted from 7 to 10 days. The development of the disease was facilitated by the presence of droplet-liquid moisture and a temperature of 24-26°C. Under favorable conditions, several generations of urediniospores form during the plant's vegetation period (Figure 2).

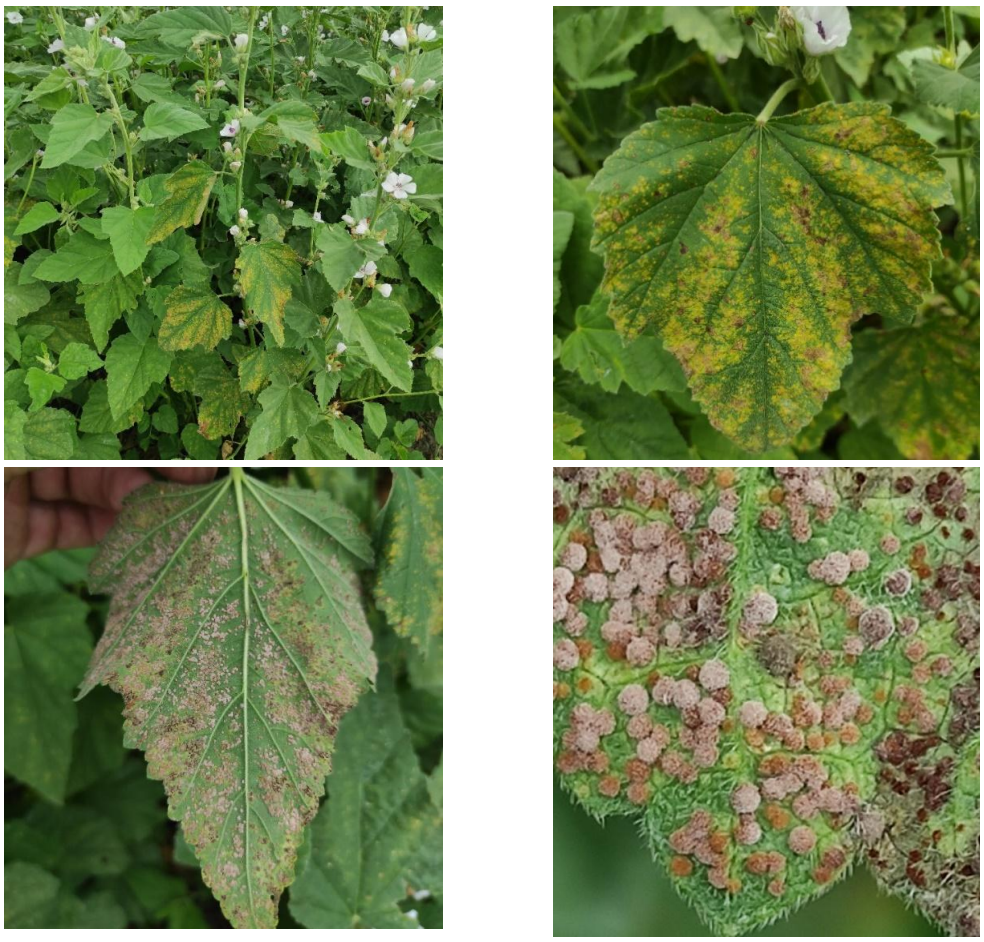


Figure 2. Infection of *A. officinalis* with rust (*Puccinia malvacearum* Mont.)

At the end of the vegetation period, the final manifestation of the disease becomes noticeable – small, round spots with a reddish edge of 1-2 mm appear on the dorsal surface of the leaf. At the same time, dark brown, almost black, telia pustules with teliospores, the wintering stage of the fungus, are formed. In spring, they germinate into basidia, on which basidiospores form, causing primary plant infection. Therefore, perennial plantations of *A. officinalis* require special attention. The impact on raw material quality is due to a decrease in the content of biologically active compounds, especially in the leaves. Quality control of raw materials involves normalizing the content of rust-infected organs – no more than 4% of leaves infected with *Puccinia malvacearum* with red spots (St. Ph. Ukr.).

Among the pests that impact the quality of raw materials, the most significant damage to *A. officinalis* during the research period was caused by *Podagrica fuscicornis* L., which belongs

to the herbivorous oligophagous and feeds on plants of the genera *Althaea* L., *Malva* L., and *Lavatera* L. (Bohinc *et al*., 2011).

In transitional crops of *A. officinalis*, the pest appeared in early spring, at the end of March and the beginning of April, during clear weather at temperatures of +6, +8 °C, and in cloudy weather at +15 °C. *Podagrica fuscicornis* (Linnaeus,1767) migrates in groups of varying numbers and feeds throughout the entire growing season. The imagines eat the soft parts of the leaf blade in the form of small, round spots of irregular shape, which subsequently increase significantly in size. The insects predominantly damage young leaves, and in cases of very severe damage to the leaf surface—more than 75% (damage level 9 points)—it appears as a lattice and dries up. During the research period, the most widespread occurrence and the highest degree of plant damage were recorded in August, with 51-75% of the leaf surface damaged (damage level 7 points) (Figure 3).



Figure 3. Damage to the leaves *A. officinalis* by *Podagrica fuscicornis* L.

During flowering, the beetles actively damaged the generative organs—flowers and buds. At the end of May and the beginning of June, fertilized females laid small groups (up to 20) of pinkish-colored eggs on the surface of the leaves. The larvae hatched from the eggs and, after 3-4 molts, turned into pupae. The duration of each phase of the life cycle depends on weather conditions and other environmental factors. Generally, after 1-2 weeks, adult individuals appeared, which overwintered in the soil at a depth of 10-12 cm or in crop residues of the host plant, avoiding open soil surfaces. Damage to plants by *Podagrica fuscicornis* sharply reduces the commercial characteristics of the raw materials, and the content of polysaccharides in the aerial parts *A. officinalis* plants is directly dependent on the degree of plant damage. Considering the guidelines "Medicinal Products. Good Agricultural and Collection Practice for Herbal Starting Materials," damaged and infected plants or parts of plants were removed from the research, leading to the loss of collected plant raw materials and a decrease in polysaccharide content to 4.47% when more than 75% of the leaf surface was damaged (damage level 9 points).

DISCUSSION

It is known that the use of certain technological practices in medicinal plant cultivation can increase production productivity. At the same time, their application can significantly affect the qualitative characteristics of the obtained plant products, particularly the content of biologically active substances.

The use of various types of fertilizers allows for the management of both the process of forming the yield of medicinal plants and their quality (Khorramdel *et al*., 2018; Luta *et al*., 2022). For example, it has been proven that the use of nitrogen fertilizers in the cultivation of Arnica

montana positively affects the quality of raw materials—the dry flower—but only in certain doses. Thus, the content of sesquiterpene lactones, flavonoids, and essential oils increased with the increase in nitrogen doses up to 60 kg N ha−1. However, further increasing the nitrogen dose led to a decrease in the content of biologically active compounds (Sugier *et al*., 2023). In Meyghan's studies (Meyghan & Moradi, 2018), the use of nitrogen and phosphorus mineral fertilizers significantly increased the yield of *A. officinalis* flowers and the quality of this raw material. According to our research, the use of mineral fertilizers containing nitrogen, phosphorus, and potassium at a dose of $N_{120}P_{120}K_{120}$ promotes an increase in the polysaccharide content in the herbs and leaves of *A. officinalis* to 9.02-9.98% and 11.65-11.87%, respectively. The application of fertilizers at a dose of $N_{180}P_{180}K_{180}$ promotes an increase in the polysaccharide content in the roots to 20.49-22.19%.

To manage the accumulation of biologically active substances in the roots of *A. officinalis*, mulching materials can be used in addition to mineral fertilizers. In the studies of Polish scientists, the highest polysaccharide content was found in the roots obtained when grown under polypropylene film (Andruszczak & Wisniewski, 2007).

It is well known that water is one of the most important factors affecting plant growth and yield. On the other hand, water resources must be used efficiently due to the growing competition for limited water resources between domestic, industrial, and agricultural consumption, as well as due to global warming (Ekren *et al*., 2012). Various types of irrigation are used for growing medicinal plants, a priority sector, in many regions of the world (Filipovic & Kljajić, 2015). The use of drip irrigation in the cultivation of *A. officinalis* is an effective means of increasing its productivity. However, according to our research results, the use of irrigation led to a decrease in the content of biologically active substances in the plant products of *A. officinalis*, but the quality of the obtained raw materials remained in accordance with current domestic requirements for medicinal raw materials.

The application of growth regulators on medicinal plants can also be an effective factor in managing the quality and productivity of the obtained raw materials. A number of studies have shown that the use of growth regulators can significantly improve the quality of medicinal plant raw materials (Assaf *et al*., 2022; Sharafzadeh & Zare, 2011). The growth regulators used in our experiments on *A. officinalis* changed the quality of the obtained raw materials in different ways. For example, Emistim and potassium humate increased the polysaccharide content in the herbs and leaves of *A. officinalis* by 0.17-0.41%, while the polysaccharide content in the roots increased only when the preparations Vympel, Sodium humate, and Potassium humate were applied by 2.32-4.11%.

For the cultivation of medicinal plants to obtain raw materials with a high content of biologically active substances, the timing of harvesting is also an important factor, ensuring both the highest crop yield and high quality of the harvested crop. Thus, research on the impact of various agronomic practices on the essential oil content in *Salvia officinalis* showed that the timing of raw material collection was the most influential factor (Mohammadi-Cheraghabadi *et al*., 2023). Most types of medicinal plants, for which the raw material is the aerial part, are harvested during flowering, and *A. officinalis* is no exception. In our studies, it was found that deviations in the harvesting time of the aerial part of *A. officinalis* from the flowering phase significantly reduce the polysaccharide content in the herb, leaves, and stems. A trend toward a decrease in the polysaccharide content during the bud stage of *A. officinalis* was noted, with 8.91% in the leaves, 6.72% in the herb, and 4.31% in the stems. With the onset of flowering, the polysaccharide content increases and reaches its peak during the mass flowering phase, with raw material collected at this phase containing 11.21% polysaccharides in the leaves, 9.11% in the herb, and 6.17% in the stems. With the onset of fruiting, the content of biologically active substances decreases to 7.33% in the leaves, 6.44% in the herb, and 4.02% in the stems. According to the current requirements of the State Pharmacopoeia of Ukraine, dried *A. officinalis* herb should contain at least 5% polysaccharides. The collected leaves and herb of *A.*

officinalis throughout the entire vegetative period meet these requirements and can be used in the pharmaceutical industry. The polysaccharide content in the stems, even when harvested at optimal times, does not meet these requirements.

Another factor affecting the presence and quantity of biologically active substances in medicinal plants is harmful organisms (Hlushchenko, 2012). Thus, the polysaccharide content in the raw materials of *Echinacea purpurea* (L.) Moench plants affected by diseases were 2% lower than in healthy ones, and the saponin content in the roots of infected Panax ginseng C.A. Meyer plants was 7.7%, almost half compared to the control healthy samples – 12.5% (Mishshenko *et al*., 2015). State quality control of *A. officinalis* raw materials requires the normalization of affected *Puccinia organs* – no more than 4% of leaves affected by *Puccinia malvacearum* with red spots, necessitating the control of this disease's spread (St. Ph. Ukr.). Damage to the aerial parts of the plants by *Podagrica fuscicornis* L. significantly reduces the commercial characteristics of the raw material and the polysaccharide content in it. Failure to comply with agronomic measures to control the pest population can significantly affect the quality of the obtained product. Our studies have shown that when more than 75% of the leaf surface (damage level of 9 points) is affected, the polysaccharide content in the leaves of *A. officinalis* decreases to 4.47%, which is below the current requirements.

CONCLUSION

It has been established that technological practices such as mineral fertilizers, growth regulators, and drip irrigation can be used as means to increase productivity and quality of *A. officinalis* raw materials, particularly the polysaccharide content. It has been proven that the primary application of mineral fertilizers when cultivating *A. officinalis* contributes to a reliable increase in the polysaccharide content in the dry raw material. There is a trend of increasing their content with increasing doses of fertilizers up to $N_{120}P_{120}K_{120}$ in the herb by 0.26 - 1.23% and in the leaves by 1.40 - 2.13%. In contrast, the polysaccharide content in the roots of plants increased by 2.82 - 3.34% only at a fertilizer dose of $N_{180}P_{180}K_{180}$.

The use of drip irrigation reduced the polysaccharide content in the dry raw material of the aerial parts – herb and leaves, but increased their content in the dry roots. The highest polysaccharide content in the herb – 9.98% and in the leaves – 11.87% was obtained with the application of $N_{120}P_{120}K_{120}$ without irrigation, while in the dry roots – 22.19% was obtained with the application of $N_{180}P_{180}K_{180}$ using drip irrigation.

It has been established that the use of growth regulators on *A. officinalis* can either increase or decrease the polysaccharide content in the raw material. Foliar application of Potassium Humate ensured the highest polysaccharide content in the dry herb and leaves of *A. officinalis*, which was 9.13% and 10.92%, respectively, exceeding the control by 0.41%. The highest polysaccharide content in the dry roots – 21.94% was obtained with the application of Sodium Humate (exceeding the control by 4.11%).

It has been established that the optimal harvesting time for the herb and leaves of *A. officinalis* is the flowering phase, as the raw material collected at this period contains the highest amount of biologically active substances – polysaccharides. During the research, periods of mass infestation of *A. officinalis* plants by *Puccinia malvacearum* Mont and damage by *Podagrica fuscicornis* L. were recorded. These harmful organisms can reduce the quality of *A. officinalis* raw materials; therefore, a pest control system should be established, considering the risks of their mass spread in industrial cultivation.

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Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in IJSM belongs to the authors.

Data Availability Statement

Research data is available and can be sent with e-mail upon request.

Authorship Contribution Statement

Nazar Pryvedeniuk: Investigation, Resources, Methodology, Experiment, Visualization, Formal Analysis, Writing. **Liudmyla Hlushchenko**: Investigation, Resources, Experiment, Visualization, Formal Analysis, Writing. **Oleksander Sereda:** Investigation, Experiment, Resources, Writing. **Andrii Shatkovskyi:** Investigation, Methodology, Experiment, Resources, Writing, Supervision, Writing. **Oleksandr Zhuravlov:** Investigation, Methodology, Experiment, Resources, Supervision, Writing. **Lidiia Mishchenko:** Investigation, Experiment, Resources, Writing. **Ivan Mishchenko:** Methodology, Experiment, Formal Analysis, Writing.

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REFERENCES

Akbar, S. (2020). *Althaea officinalis* L. (Malvaceae). In Handbook of 200 Medicinal Plants. Springer. 235-241.

Al-Snafi, A. (2013). The pharmaceutical importance of *Althaea officinalis* and *Althaea rosea*: a review. *International Journal of Pharm Tech Research, 5*, 1378-1385.

Andruszczak, S., & Wisniewski, J. (2007) Growth and development of marshmallow (*Althaea officinalis* L.) depending on the method of plantation establishment. *Herba Polonica, 53*(3), 63-69.

Asadzadeh, M., Ghavam, M., & Mirzaei, R. (2023). The effect of irrigation with treated and untreated wastewater on the yield and chemical composition of essential oil of Mentha spicata L. and *Rosmarinus officinalis* L. *Environmental Science and Pollution Research*, *30*(16), 46175-46184. https://doi.org/10.1007/s11356-023-25398-7

Assaf, M., Korkmaz, A., Karaman, Ş., & Kulak, M. (2022). Effect of plant growth regulators and salt stress on secondary metabolite composition in Lamiaceae species. *South African Journal of Botany*, *144*, 480-493. https://doi.org/10.1016/j.sajb.2021.10.030

Banaee, M., Soleimany, V., & Haghi, B.N. (2017). Therapeutic effects of marshmallow (*Althaea officinalis* L.) extract on plasma biochemical parameters of common carp infected with Aeromonas hydrophila. In *Veterinary Research Forum*, *8*(2), 145-153.

Baudoin, D.C., Bush, E., Gauthier, T., Hernandez, A.B., & Kirk-Ballard, H. (2022). Effects of irrigation and drought on growth and essential oil production in *O. vulgare* and *R. officinalis*. *American Journal of Plant Sciences*, *13*(5), 659-667. https://doi.org/10.4236/ajps.2022.135044

Bonaterra, G.A., Bronischewski, K., Hunold, P., Schwarzbach, H., Heinrich, E.U., Fink, C., Aziz-Kalbhenn, H., Müller, J., & Kinscherf, R. (2020). Anti-inflammatory and Anti-oxidative Effects of Phytohustil® and Root Extract of *Althaea officinalis* L. on Macrophages in vitro. *Front Pharmacol*, *11*, 290. https://DOI:10.3389/fphar.2020.00290

Borcean, A., Colcea, M., & David, G. (2016). Diseases of plants from Malvaceae family from spontaneous flora in the south western part of Romania. *Research Journal of Agricultural Science, 48*(1), 27-30.

Bohinc, T., Vidrih, M., & Trdan, S. (2011). Massive occurrence of Podagrica fuscicornis (L.) (Coleoptera, Chrysomelidae) on common marshmallow (*Althaea officinalis* L.) *Acta agriculturae Slovenica, 97*(3), 259-265. https://doi.org/10.2478/v10014-011-0020-x

Brykin A.I. (1981). *Field experiments with medicinal crops*. Moscow: CBNTIMP. Council of Europe. (2014). European Pharmacopoeia (8th ed.).

Dawid-Pać, R. (2013). Medicinal plants used in treatment of inflammatory skin diseases. *Postepy Dermatol Alergol, 30*(3), 170-177. https://doi.org/10.5114/pdia.2013.35620

Deters, A., Zippel, J., Hellenbrand, N., Pappai, D., Possemeyer, C., & Hensel, A., (2010). Aqueous extracts and polysaccharides from Marshmallow roots (*Althea officinalis* L.): Cellular internalisation and stimulation of cell physiology of human epithelial cells in vitro. *Journal of Ethnopharmacology, 127*(1), 62-69. https://doi.org/10.1016/j.jep.2009.09.050

Dospekhov, B.A. (1985). F*ield experiment technique (with the basics of statistical processing of research results)*. 5th ed., Rev. and add. Moscow: Agropromizdat.

Ekren, S., Sönmez, C., Özcakal, E., Kurttas, Y.S.K., Bayram, E., & Gürgülü, H. (2012) The effect of different irrigation water levels on yield and quality characteristics of purple basil (*Ocimum basilicum* L.). *Agric. Water Manag., 109*, 155–161. https://doi.org/10.1016/j.agwat.2012.03.004

Filipovic, V., & Kljajić, N. (2015). *Soil Moisture as One of the Limiting Factors in the Production of Medicinal Plants.* 119-137. https://doi.org/10.4018/978-1-4666-7521-6.ch006

Goryansky, M.M. (1970) *Methods of field experiments on irrigated lands*. Kyiv: Urozhay. Hlushchenko, L.A. (2013) Spread and harmfulness of diseases of Medicinal Plant. *Agroecologycal journal, 2*, 92-94.

Karimi, S., Ghanbarzadeh, B., Roufegarinejad, L., & Falcone, P.M. (2021). Polysaccharide extracted from *Althaea officinalis* L. root: New studies of structural, rheological and antioxidant properties. *Carbohydrate Research, 510*, 108438. https://doi.org/10.1016/j.carres.2021.108438

Khorramdel, S., Rezvani Moghaddam, P., Azizi, H., Shabahang, J., & Seyedi, M. (2018). Evaluation of the integrated effect of organic, chemical and biological fertilizers on yield of marshmallow (*Althaea officinalis* L.) as a medicinal plant. *Journal of Agroecology, 10*(3), 603-620. https://doi.org/10.22067/jag.v10i3.28104

Kianitalaei, A., Feyzabadi, Z., Hamedi, S., & Qaraaty, M. (2019). *Althaea officinalis* in traditional medicine and modern phytotherapy. *Journal of Advanced Pharmacy Education & Research, 9*(2), 154–161.

Koleva, M., Ninov, S., Daskalov, V., & Ilieva, S. (1986). Studies on the polyphenolic composition of the leaves of *Althaea officinalis* – cultivar "Rusalka". *Pharmacy (Bulgaria), 3*, 15–17.

Luța, E.A., Bița, A., Moroșan, A., Mihaiescu, D.E., Ghica, M., Mihai, D.P., Olaru, O.T., Deculescu-Ioniță, T., Duțu, L.E., Popescu, M.L., Costea, L., Nitulescu, G.M., Lupuliasa, D., Boscencu, R., & Gîrd, C.E. (2022). The influence of phytosociological cultivation and fertilization on polyphenolic content of *Menthae* and *Melissae folium* and evaluation of antioxidant properties through *in vitro* and *in silico* methods. *Plants, 11*(18), 2398. https://doi.org/10.3390/plants11182398

Mahboubi, M. (2020). Marsh mallow (*Althaea officinalis* L.) and its potency in the treatment of cough. *Complementary Medicine Research, 27*(3), 174–183. https://doi.org/10.1159/000503747

Meyghan, N., & Moradi, P. (2018). The effect of nitrogen and phosphorous fertilizers on morphophysiological properties of *Althaea officinalis*. *Iranian Journal of Plant Physiology, 8*(4), 2563–2571. https://doi.org/10.30495/IJPP.2018.543509

Mishchenko, L.T., Dunich, A.A., Dashchenko, A.V., & Polishchuk, V.P. (2015). *Viral diseases of medicinal plants*. Kyiv: Phytosociocentre. *(320 p.)* ISBN 978-966-306-175-4

Mohammadi-Cheraghabadi, M., Modarres-Sanavy, S.A., Sefidkon, F., Mokhtassi-Bidgoli, A., & Hazrati, S. (2023). Harvest time explains substantially more variance in yield, essential oil and quality performances of *Salvia officinalis* than irrigation and putrescine application. *Physiology and Molecular Biology of Plants, 29*, 109–120. https://doi.org/10.1007/s12298-022-01272-7

Shah, S.M., Akhtar, N., Akram, M., Shah, P.A., Saeed, T., Ahmed, K., & Asif, H.M. (2011). Pharmacological activity of *Althaea officinalis* L. *Journal of Medicinal Plants Research, 5*(24), 5662–5666.

Pryvedeniuk, N., Hlushchenko, L., & Trubka, V. (2021). Efficiency of mineral fertilizers for growing *Althaea officinalis* L. under conditions of irrigation. *Agroecological Journal, 1*, 134-139. https://doi.org/10.33730/2077-4893.1.2021.227251

Pryvedeniuk, N., Hlushchenko, L., Mishchenko, I., Dunich, A., & Mishchenko, L. (2020). New approaches in growing technology of *Valeriana officinalis* L. under the conditions of climate change. *Agriculture and Forestry*, *66*(4), 19–28. https://doi.org/10.17707/AgricultForest.66.4.02

Rezaei, M., Dadgar, Z., Noori-Zadeh, A., Mesbah-Namin, S.A., Pakzad, I., & Davodian, E. (2015). Evaluation of the antibacterial activity of the *Althaea officinalis* L. leaf extract and its wound healing potency in the rat model of excision wound creation. *Avicenna Journal of Phytomedicine*, *5*(2), 105–112.

Rioba, N.B., Itulya, F.M., Saidi, M., Dudai, N., & Bernstein, N. (2015). Effects of nitrogen, phosphorus and irrigation frequency on essential oil content and composition of sage (*Salvia officinalis* L.). *Journal of Applied Research on Medicinal and Aromatic Plants*, *2*(1), 21-29. https://doi.org/10.1016/j.jarmap.2015.01.003

Romaschenko, M.I., Shatkovskyi, A.P., & Usata, L.G. (2014). *Methodical recommendations for conducting field research under drip irrigation*. National Academy of Agrarian Sciences of Ukraine, Institute of Water Problems and Reclamation, NSC "Institute of Soil Science and Agrochemistry named after O. N. Sokolovsky", Institute of Irrigated Agriculture. Kyiv. *(46 p.)* ISBN 978-8700-15-14

Shatkovskyi, A., Pryvedeniuk, N., Hlushchenko, L. (2021). The effectiveness of agro-technological methods of medicinal crops growing on irrigation. *Land Reclamation and Water Management*, *2*, 166-176. https://doi.org/10.31073/mivg202102-299

Sharafzadeh, S., & Zare, M. (2011). Influence of Growth Regulators on Growth and Secondary Metabolites of Some Medicinal Plants from Lamiaceae Family. *Advances in Environmental Biology*, 2296-2303.

Sugier, D., Sugier, P., Jakubowicz-Gil, J., Gawlik-Dziki, U., Zając, A., Król, B., Chmiel, S., Kończak, M., Pięt, M., & Paduch, R. (2023). Nitrogen fertilization and solvents as factors modifying the antioxidant and anticancer potential of *Arnica montana* L. flower head extracts. *Plants*, *12*, 142. https://doi.org/10.3390/plants12010142

Ukrainian Scientific Pharmacopoeia Center for the Quality of Medicinal Products. (2014). State Pharmacopoeia of Ukraine: in 3 volumes (2nd ed.). (Vol. 3). ISBN 978-966-96478-9-4.

Tribel, S.O. (2001) *Test methods and application of pesticides*. Kyiv: Svit.

World Health Organization. (2003). WHO guidelines on good agricultural and collection practices (GACP) for medicinal plants. https://www.who.int/publications/i/item/9241546271