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PHYSIOLOGICAL AND BIOCHEMICAL RESPONSE OF THE *NOSTOC COMMUNE* ASSOCIATION TO THE EFFECT OF IMIDAZOLINONE HERBICIDES

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The features of the physiological and biochemical response of the Nostoc commune algal-bacterial association to the toxic effect of an imidazolinone herbicide (active ingredients: imazamox and imazapyr) were investigated. The relevance of the study is driven by the need for a comprehensive assessment of the ecotoxicological risks associated with the application of these pesticides to photosynthetic microorganisms in aquatic ecosystems, as well as the search for effective bioagents for the phytoremediation of contaminated aquatic environments.

The cultivation of the N. commune association was carried out using the batch culture method in liquid BG-11 nutrient medium for 28 days. Herbicide exposure was modeled within an imazamox concentration gradient ranging from 0.01 to 5.0 mg/L. During the experiment, growth dynamics (assessed by culture optical density), the state of the photosynthetic pigment apparatus, the macromolecular biochemical composition of the biomass, and the cellular amino acid profile were analyzed.

The study revealed a biphasic character of the growth response of microorganisms to herbicide exposure. Low imazamox concentrations (0.01–0.1 mg/L) induced a stimulatory effect on growth processes, whereas an increase in herbicide content to 0.5–5.0 mg/L caused a dose-dependent inhibition of culture viability. A structural reconfiguration of the pigment complex was established, manifested by a significant decrease in chlorophyll a and phycobiliprotein contents at high pesticide concentrations, alongside the preservation of elevated carotenoid levels. Toxic exposure was found to be accompanied by a concentration-dependent reduction in the proportion of total protein in the biomass (from 47% to 19%), with a compensatory increase in the lipid-carbohydrate fraction. Among the analyzed spectrum of amino acids, leucine exhibited the highest sensitivity, with its content decreasing by 46% relative to the control even at the minimum imazamox concentration.

The obtained experimental data demonstrate a high adaptive potential of the N. commune association under moderate pesticide load and confirm the feasibility of using the studied biochemical markers for diagnosing toxic damage to aquatic microbiocenoses caused by imidazolinone herbicides.

Keywords: Nostoc commune, algal-bacterial association, imazamox, imidazolinone herbicides, proteins, lipids, carbohydrates, photosynthetic pigments, amino acids

Introduction. The intensification of agricultural production is accompanied by an increasing pesticide burden on aquatic ecosystems due to surface runoff and drainage from treated agricultural lands. The entry of agrochemical residues into surface and groundwater poses a threat to non-target aquatic organisms, including autotrophic and heterotrophic microorganisms responsible for primary production, the transformation of essential nutrients, and the self-purification of aquatic environments. Disruption of the functional structure of microbial communities under the influence of xenobiotics may potentially reduce the ecological stability of the entire aquatic ecosystem (Amaro et al., 2023; Ahmed et al., 2022; Touliabah et al., 2022; Chai et al., 2021).

Herbicides belonging to the imidazolinone class (imazapyr, imazamox, imazethapyr, imazapic, etc.) represent a particularly important group of ecotoxicants and are widely used to control unwanted vegetation. Their mode of action involves the inhibition of acetolactate synthase (ALS/AHAS, EC 2.2.1.6), a key enzyme in the biosynthesis of essential branched-chain amino acids (valine, leucine, and isoleucine). Inhibition of this metabolic pathway results in growth arrest in susceptible organisms (Xie et al., 2018; Rojano-Delgado et al., 2015; Tan et al., 2005). Imidazolinones are characterized by high amphiphilicity, stability in aquatic environments, and relatively long half-lives, which increase the risk of their prolonged migration within ecosystems. The natural self-purification of water bodies from these compounds is limited by the rate of microbial degradation, which depends on temperature, hydrological conditions, pH, nutrient availability, and the composition of the indigenous microflora (Touloupakis et al., 2023; Touliabah et al., 2022).

In this context, the development of biotechnological approaches to water treatment

(bioremediation) based on the metabolic potential of microorganisms is of particular relevance (Amaro et al., 2023; Ahmed et al., 2022). Unlike physicochemical methods, microbial systems can not only remove contaminants from the aqueous phase through sorption but also facilitate their enzymatic biotransformation (Ho et al., 2024; Verasoundarapandian et al., 2022). Particular attention has been drawn to algal-bacterial associations, in which trophic and metabolic synergy occurs between photoautotrophic cyanobacteria and heterotrophic bacteria. The photosynthetic component acts as a source of oxygen and exometabolites (organic carbon), which support the metabolic activity of bacterial degraders (León-Miranda and Tejada-Jiménez, 2023; Park et al., 2022). In turn, bacterial partners contribute to the degradation of complex xenobiotics and the breakdown of intermediate products of their metabolism, thereby increasing the overall resistance of the biosystem to toxic stress (Ho et al., 2024; Fuentes et al., 2016; Cooper et al., 2015).

The filamentous cyanobacterium *Nostoc commune* is a promising biological agent for the development of such biotechnological systems. This species is characterized by considerable ecological plasticity, the ability to fix atmospheric nitrogen, and active production of extracellular polymeric substances (EPS), which form a well-developed mucilaginous matrix (Temina et al., 2007; Tamaru et al., 2005). The extracellular polysaccharide-protein matrix serves a dual function: it facilitates the initial biosorption of xenobiotics through its functional groups (amino, carboxyl, hydroxyl, and phosphate groups) and provides a protective microenvironment for cell immobilization and the formation of stable biofilms (Alvarez et al., 2021; Cruz et al., 2020). The retention of biomass in the form of structured colonies or aggregates is a critical factor for the practical application of *N. commune* in flow-through bioreactors (Huang et al., 2022; Atoku et al., 2021).

However, the effectiveness of using *Nostoc commune*-based associations in bioremediation technologies is determined by the limits of their physiological tolerance to ecotoxicants. Under herbicide exposure, cyanobacterial cells undergo complex changes in growth parameters, the functional state of the photosynthetic apparatus, and the antioxidant defense system (Zahra et al., 2020). Assessing chlorophyll *a*, carotenoids, and total protein content makes it possible to determine the extent of inhibition of primary metabolic processes and the maintenance of the functional activity of the pigment complex (Cui et al., 2021; Milošević and Govedarica, 2002).

Despite the availability of studies addressing pesticide behavior in aquatic environments and general aspects of xenobiotic biodegradation by cyanobacteria (Ikioukenigha et al., 2024; Verasoundarapandian et al., 2022), the response of the *Nostoc commune* algal-bacterial association to the specific effects of imidazolinone herbicides remains insufficiently understood. In particular, the relationship between the microbial profile of the association, growth dynamics, the functional state of the photosynthetic apparatus, and the antioxidant response of the biomass at different concentrations of the toxicant requires further investigation.

The aim of this study is to elucidate the nature of physiological and biochemical changes in the *Nostoc commune* association under the influence of imidazolinone herbicides in order to assess its tolerance to herbicide stress.

Materials and Methods. The object of the study was the algal-bacterial association *Nostoc commune*, maintained in the Culture Collection of the Department of Biochemistry and Biotechnology at Yuriy Fedkovych Chernivtsi National University.

Nostoc commune is a typical representative of filamentous cyanobacteria (phylum Cyanobacteria), whose trichomes consist of uniseriate chains of spherical or barrel-shaped vegetative cells (Onyeaka et al., 2025). This species is characterized by the formation of macroscopic colonies, ranging from spherical to plate-like mucilaginous thalli, embedded in an extracellular polymeric substance (EPS)-rich matrix. This matrix provides resistance to severe desiccation and UV stress, while also performing protective and structural-aggregative functions.

The functional morphology of *N. commune* is based on cell differentiation into vegetative cells, which perform oxygenic photosynthesis, and specialized cells called heterocysts (intercalary or terminal), in which the nitrogenase enzyme complex functions under anaerobic conditions, ensuring biological nitrogen fixation. Under unfavorable environmental conditions, such as prolonged drought, nutrient depletion, or temperature stress, trichome cells can differentiate into spore-like structures known as akinetes. These are characterized by additional cell wall layers (exospore) and the accumulation of storage metabolites, including cyanophycin, volutin/polyphosphates, and glycogen, which ensure the long-term viability of the population (Tamaru et al., 2005).

The initial culture of the *N. commune* algal-bacterial association was grown under batch conditions in liquid BG-11 nutrient medium under controlled abiotic parameters: a temperature of 22 °C, a 16:8 h light:dark photoperiod, and a light intensity of 2000 lx. An exponentially growing culture, characterized by maximum specific growth rate and

biosynthetic activity, was used for all experiments.

The systemic herbicide formulation Euro-Lightning® (imidazolinone class) was used as a model chemical stressor. The formulation contains two active ingredients: imazamox (33 g/L) and imazapyr (15 g/L). The molecular mechanism of action of both compounds involves the inhibition of acetolactate synthase (ALS, EC 2.2.1.6), a key enzyme in the biosynthesis of branched-chain amino acids (valine, leucine, and isoleucine) (Rojano-Delgado et al., 2015). The formulation exhibits pronounced systemic phytotoxicity due to its rapid translocation through xylem and phloem, ensuring high efficacy against a broad spectrum of weed species. According to the WHO hazard classification, Euro-Lightning belongs to Class III (slightly hazardous compounds). However, owing to the high biological activity and physicochemical stability of imazamox and imazapyr, these compounds may persist in soil and aquatic environments for extended periods, posing a toxic threat to non-target aquatic organisms, particularly photoautotrophic and heterotrophic microorganisms (Cepoi et al., 2022).

To investigate the toxic response, the *N. commune* association was cultivated in media containing a gradient of Euro-Lightning concentrations (expressed as active ingredient equivalent): 0.01, 0.05, 0.1, 0.5, 1.0, and 5.0 mg/L. The control consisted of an *N. commune* culture grown in BG-11 medium without herbicide supplementation. The experiment lasted for 28 days. Every three days, the pH of the culture medium and the optical density OD 680 of the culture were monitored. In addition, light microscopy was performed to assess the morphological condition of cells and trichomes using a Micromed Evolution ES-4120 microscope.

Water-soluble cellular components were extracted using phosphate buffer. Cell disruption was achieved by ultrasonication. Following disruption, the samples were centrifuged for 15 min at 4000 rpm (2200 g). The resulting supernatant was used to determine total protein content by the Lowry method, carbohydrate content using the anthrone reagent, and phycobiliprotein pigment content based on their characteristic absorption spectra.

The concentrations of valine, leucine, and isoleucine in the cyanobacterial biomass were determined by ascending thin-layer chromatography (TLC) using an n-butanol–acetic acid–water solvent system (4:1:1, v/v). Following chromatographic separation, the corresponding amino acid spots were eluted from the adsorbent, and their concentrations were determined spectrophotometrically based on the colorimetric reaction with ninhydrin.

Lipophilic compounds were extracted using a chloroform–methanol mixture (2:1, v/v). The resulting extracts were used to determine total lipid content using the phosphovanillin reagent, as well as chlorophyll *a* and carotenoids contents by spectrophotometry at their characteristic absorption wavelengths using a Cary 60 spectrophotometer. Pigment concentrations were calculated using standard equations.

The experimental results are presented as the mean pm standard error of the mean (M±m). Statistical analysis of the experimental data was performed using Microsoft Excel. The significance of differences between the measured parameters was assessed using Student's t-test, with a significance threshold of 0.05.

Results and Discussion. Optical density is a convenient parameter for evaluating the effect of herbicides on cyanobacterial growth, as it reflects the rate of biomass accumulation. Monitoring changes in this parameter allows for assessing culture resistance or sensitivity to the toxicant and tracking adaptive responses throughout the experiment. The growth dynamics of the *Nostoc commune* association, evaluated by culture optical density, revealed a clear dose-dependent response (Fig.1.).

The growth dynamics of the control culture followed a typical sigmoidal curve, characterized by a lag phase, exponential growth up to day 13, and a transition to the stationary phase on days 19–22. By day 28, a natural decline in optical density to 0.35 OD units was observed, presumably due to nutrient depletion, metabolite accumulation, and self-shading effects.

The effect of imazamox on cyanobacterial growth exhibited a pronounced biphasic (hormetic) dose–response relationship depending on the duration of exposure. Low concentrations (0.01–0.1 mg/L) induced a stimulatory effect (hormesis). Specifically, exposure to 0.01 mg/L consistently maintained optical density values above those of the control throughout the experiment, reaching a maximum on day 22 of incubation and preserving high culture viability up to day 28. The 0.05 mg/L dose induced the highest peak in optical density on day 22, exceeding control values by 33%; however, this was followed by a sharp decline to 0.29 OD units. Increasing the imazamox concentration to 0.1 mg/L shifted the growth peak to day 19, followed by culture deterioration by day 28.

We hypothesize that this adaptive response resulted from two interconnected processes: the gradual degradation of the herbicide in the aquatic medium and the metabolic activity of the *Nostoc commune* association and its microflora.

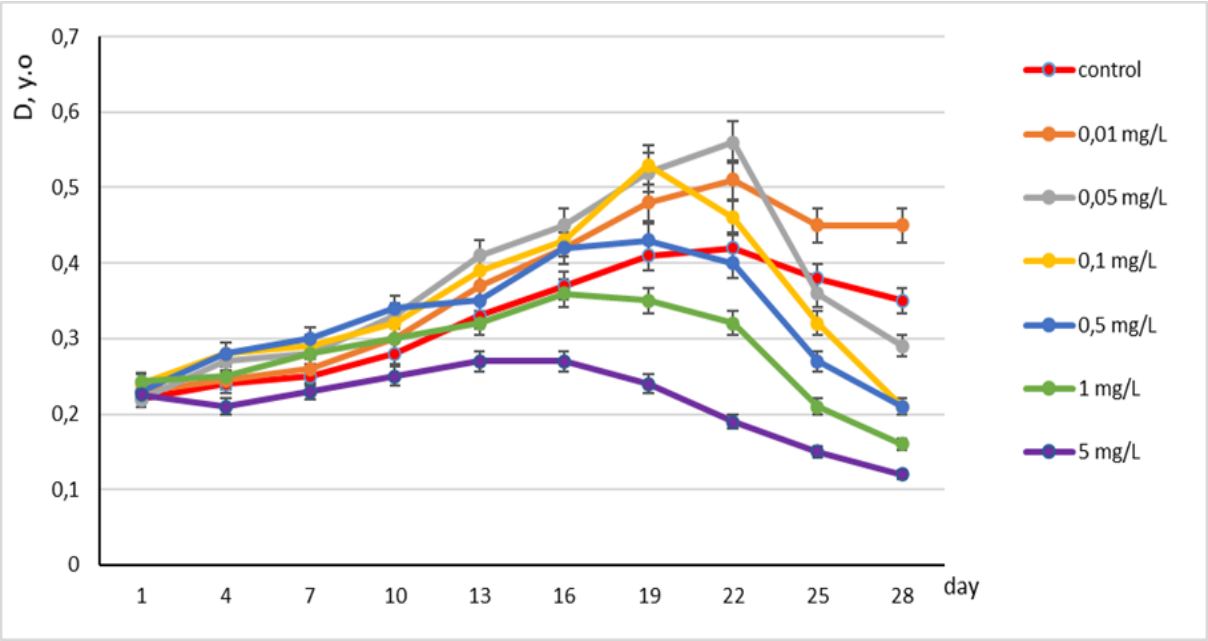


Fig. 1. Growth dynamics of the Nostoc commune association under the influence of imazamox

The polysaccharide sheath surrounding the trichomes of the *N. commune* thalli plays a key protective role, as its functional groups are capable of binding organic pollutants and facilitating their subsequent biotransformation. The periplasmic space may also contribute to xenobiotic detoxification by temporarily localizing toxic compounds prior to cellular uptake, enabling partial enzymatic degradation. Furthermore, the large specific surface area of the *N. commune* mucilaginous matrix promotes these physical and biochemical interactions.

Preliminary analysis of the associated microflora revealed the presence of bacteria belonging to the genera *Pseudomonas*, *Sphingomonas*, and *Acinetobacter*, which may actively participate in herbicide degradation, thereby mitigating toxic stress within the culture medium.

Conversely, exposure to medium and high concentrations of imazamox (0.5–5.0 mg/L) suppressed the physiological processes of *N. commune*. At 0.5 mg/L imazamox, temporary adaptation persisted until days 16–19, after which a rapid decrease in culture optical density occurred. Concentrations of 1.0 and 5.0 mg/L caused severe growth inhibition starting from the early stages of cultivation. At the maximum dose (5.0 mg/L), the culture reached only a minor growth peak on days 13–16, followed by a decline in optical density to 0.12 OD units by day 28, indicating profound toxic damage and cell lysis.

Notably, time-dependent differences between the experimental groups became apparent only after 13–16 days of cultivation. This observation highlights the limited diagnostic value of short-term assays (such as rapid oxygen evolution or acute growth inhibition tests) when assessing the ecological impacts of this herbicide class. Imazamox acts as an inhibitor of acetolactate synthase (ALS), targeting a key enzyme required for the biosynthesis of essential branched-chain amino acids (valine, leucine, and isoleucine). The presence of ALS in cyanobacteria explains their high sensitivity to this compound.

Growth inhibition at high doses (1.0–5.0 mg/L) is likely associated with the impairment of protein biosynthetic pathways, degradation of the photosynthetic pigment complex (chlorophyll *a* and phycobiliproteins), and induction of severe oxidative stress, accompanied by membrane lipid peroxidation.

Consequently, changes in pigment composition were analyzed during the final stage of *N. commune* incubation with imazamox (Fig. 2), as the state of the pigment apparatus serves as a sensitive bioindicator of photosynthetic efficiency under xenobiotic stress.

The response of the cyanobacterial pigment apparatus to increasing herbicide concentrations exhibited a clearly pronounced biphasic (hormetic) pattern: low concentrations induced a gradual increase in pigment content, whereas high concentrations resulted in a dose-dependent inhibition of pigment accumulation.

Chlorophyll *a* was found to be the most sensitive pigment to imazamox exposure. Its content increased moderately in the experimental variants treated with 0.01–0.1 mg/L imazamox. However, at concentrations 0.5 mg/L, a rapid decline was observed, with chlorophyll *a* content decreasing to 7.3 mg/g at 1.0 mg/L and 6.6 mg/g at 5.0 mg/L imazamox, corresponding to a 40.5% reduction relative to the control.

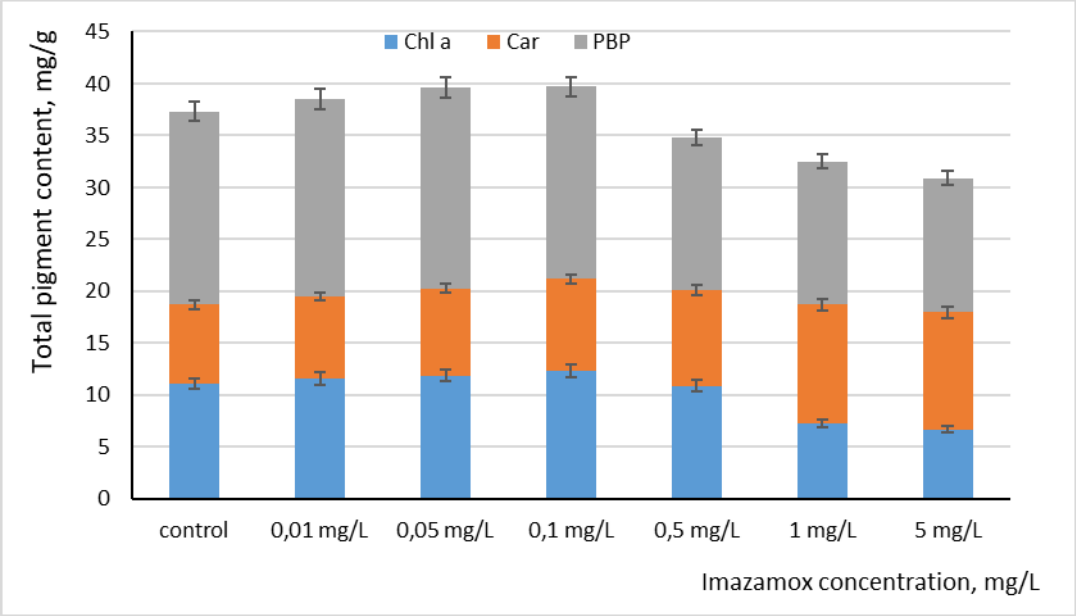


Fig. 2. Pigment content in the biomass of the Nostoc commune association under imazamox exposure

Carotenoid content demonstrated an adaptive response pattern. Under mild and moderate stress conditions (0.01–0.5 mg/L), carotenoid levels consistently increased from 7.6 mg/g in the control to a maximum of 9.3 mg/g dry biomass at imazamox concentrations of 0.1 and 0.5 mg/L. Even at the highest toxic concentrations (1.0–5.0 mg/L), carotenoid levels remained elevated, indicating a shift in their relative proportion within the total pigment pool.

Phycobiliproteins, the primary light-harvesting pigment complex in cyanobacteria, accumulated in response to imazamox concentrations of 0.01–0.1 mg/L, whereas their content in the biomass of the *Nostoc commune* association decreased significantly at higher herbicide doses (1.0–5.0 mg/L).

Low concentrations of imazamox may act as mild metabolic stressors, triggering compensatory responses in cyanobacteria, particularly an increase in light-harvesting pigment synthesis to maintain photosynthetic activity at a relatively high level. Conversely, the marked increase in the carotenoid-to-chlorophyll *a* ratio (Car/Chl *a*) observed with increasing imazamox concentrations (0.5–5.0 mg/L) reflects a physiological response to oxidative stress. Carotenoids function as key antioxidants and photoprotective agents by quenching reactive oxygen species (ROS) and shielding photosystems from damage under growth-inhibited conditions.

High herbicide concentrations inhibit acetolactate synthase, disrupting cellular protein biosynthesis and interfering with the assembly of proteins incorporated into reaction centers and pigment-protein complexes. These metabolic disturbances promote the degradation of chlorophyll *a* and phycobilisomes, leading to an overall reduction in the photosynthetic potential of the culture.

Therefore, the biochemical profile of the *Nostoc commune* association biomass under imazamox exposure was further investigated to evaluate potential alterations in the distribution of its major macromolecular components (Fig. 3).

Proteins constitute the predominant fraction of the biomass, which is characteristic of cyanobacteria during active exponential growth under non-stressed conditions. A moderate but consistent decrease in the protein fraction of the *Nostoc commune* association biomass was observed with increasing imazamox concentrations, declining from 47% in the control to 19% at the maximum herbicide concentration (5.0 mg/L). This shift inevitably led to a redistribution of the overall macromolecular composition of the biomass. The decrease in the protein content was accompanied by a compensatory increase in the combined proportion of lipids and carbohydrates (Lip+Carb), which rose from 53% in the control to 81% under exposure to 5.0 mg/L imazamox.

Imazamox acts as an inhibitor of acetolactate synthase (ALS), a key enzyme in the biosynthetic pathway of essential branched-chain amino acids (valine, leucine, and isoleucine). The inhibition of ALS directly impairs the synthesis of new protein molecules, leading to a marked reduction in the cellular protein fraction.

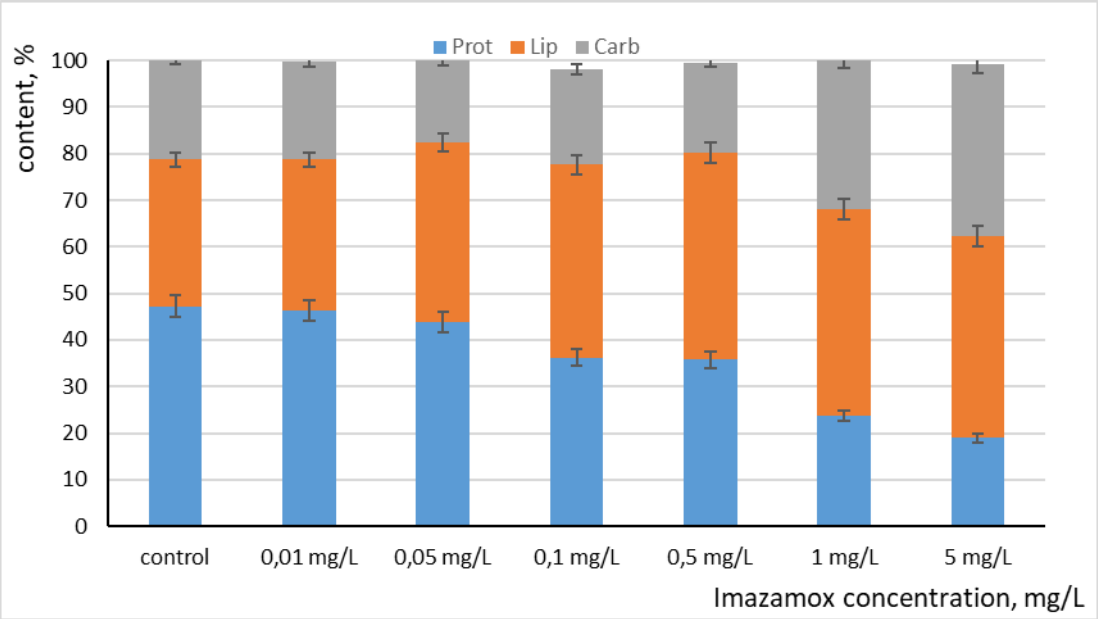


Fig. 3. Protein, lipid, and carbohydrate contents in the biomass of the Nostoc commune association under imazamox exposure

When protein biosynthesis and cell division are suppressed, primary photosynthetic assimilation products (carbon skeletons generated during CO_2 fixation) can no longer be efficiently funneled into growth and structural protein assembly. Consequently, cyanobacterial cells reroute excess carbon flux and reducing equivalents (NADPH) toward the synthesis of energy-dense storage compounds, primarily neutral lipids and storage polysaccharides, including glycogen.

Since the primary biochemical target of imidazolinone herbicides is the biosynthesis of valine, leucine, and isoleucine, the specific levels of these free branched-chain amino acids in the biomass of the *Nostoc commune* association were subsequently evaluated (Fig. 4).

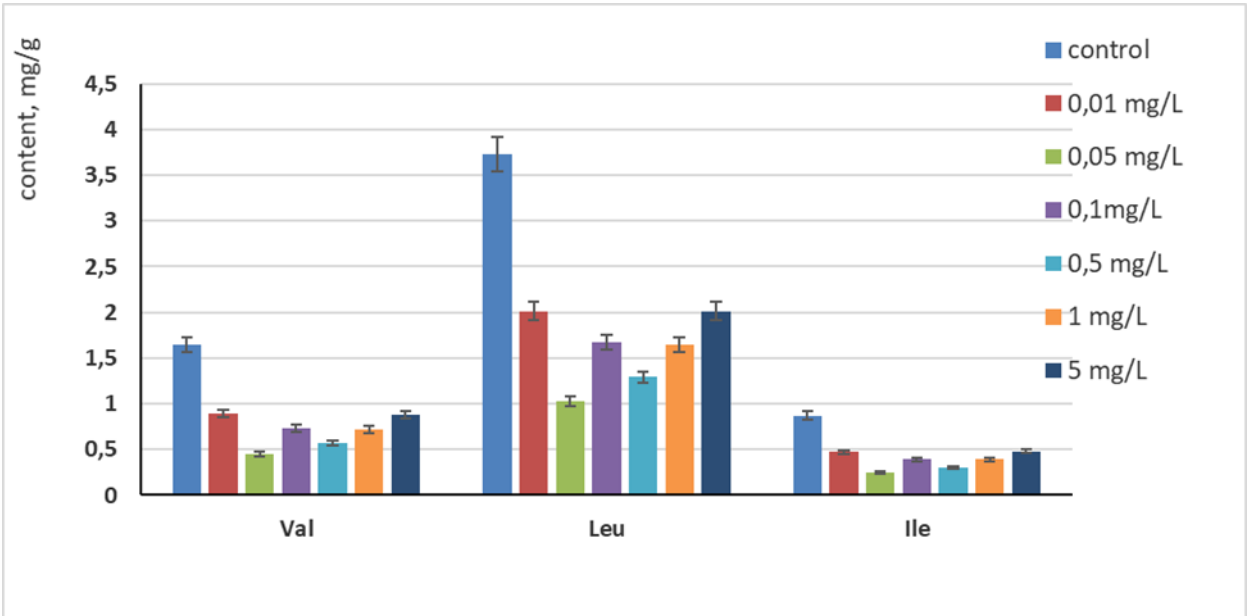


Fig. 4. Valine, leucine, and isoleucine contents in the biomass of the Nostoc commune association under imazamox exposure

All three amino acids exhibited a fundamentally similar pattern of content dynamics in response to increasing imazamox concentrations; however, leucine proved to be the most sensitive to herbicide exposure. Even at the lowest imazamox concentration (0.01 mg/L), a sharp decrease in leucine (Leu) content was observed, declining to 2.01 mg/g dry biomass, which corresponds to a 46% reduction relative to the

control. In cyanobacteria, as in prokaryotes in general, leucine is one of the most abundant amino acids in structural and photosynthetic proteins. Therefore, even partial ALS inhibition can rapidly deplete the available free leucine pool.

At low herbicide concentrations, cyanobacterial cells remain metabolically active and continue intensive protein synthesis and cell division. Because ALS activity is partially inhibited by imazamox, the rate of *de novo* synthesis of valine (Val), Leu, and isoleucine (Ile) becomes insufficient to meet the demand of the protein biosynthetic machinery, leading to localized amino acid pool depletion.

Conversely, the observed secondary increase in free amino acid content at high imazamox concentrations (1.0–5.0 mg/L) may be attributed to two main factors: profound inhibition of overall protein synthesis and cell division, resulting in the accumulation of unconsumed amino acid precursors, or cellular damage and protein degradation accompanied by cell lysis.

These findings demonstrate the complex and multifaceted nature of the response of the *Nostoc commune* association to imazamox-induced xenobiotic stress. The observed biphasic response-ranging from hormetic stimulation at low concentrations to pronounced toxicity at high doses-indicates that cyanobacterial communities possess substantial compensatory potential. Physical and biological protective barriers, including the extracellular polysaccharide sheath, periplasmic enzymatic systems, and metabolic cooperation within the associated microbiome, contribute to the temporary mitigation of toxic effects under low-exposure conditions.

However, direct inhibition of acetolactate synthase, the molecular target of imazamox, triggers a cascade of metabolic disturbances. This cascade initially manifests as rapid depletion of the leucine pool required for protein assembly. Impairment of protein biosynthesis induces a major reconfiguration of carbon and nitrogen metabolism: vegetative growth is halted, and excess photosynthetic assimilation products are redirected toward the synthesis of storage lipids and carbohydrates. These changes are accompanied by photosystem degradation and an adaptive increase in the relative proportion of photoprotective carotenoids.

The high sensitivity of leucine levels and chlorophyll *a* content to imazamox exposure indicates that these biochemical parameters can serve as potential biomarkers for the early detection of pesticide contamination in aquatic environments, before visible signs of biomass inhibition become apparent.

Furthermore, the duration of the experimental observation period proved to be crucial for an objective evaluation of growth activity. Time-dependent physiological differences between the control and treated groups became clearly distinguishable only after 13–16 days of cultivation. This finding highlights the limited diagnostic value of conventional short-term (acute) oxygen evolution or rapid growth assays when evaluating herbicides with this specific mode of action, underscoring the necessity of long-term monitoring for accurate ecological risk assessments of ALS inhibitors in cyanobacterial communities.

Conflict of Interest*. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.*

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ФІЗІОЛОГО-БІОХІМІЧНИЙ ВІДГУК АСОЦІАЦІЇ *NOSTOC COMMUNE* НА ВПЛИВ ІМІДАЗОЛІНОНОВИХ ГЕРБІЦИДІВ

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Досліджено особливості фізіолого-біохімічної реакції альгобактеріальної асоціації Nostoc commune на токсичну дію імідазолінонового гербіциду (діючі речовини - імазамокс та імазапір). Актуальність роботи зумовлена необхідністю комплексної оцінки екотоксикологічних ризиків застосування зазначених пестицидів для фотосинтезувальних мікроорганізмів у водних екосистемах, а також пошуком ефективних біоагентів для фіторемедіації забруднених водних середовищ.

Культивування асоціації N. commune здійснювали методом накопичувальної культури на живильному середовищі BG-11 протягом 28 діб. Вплив гербіцидного навантаження моделювали в діапазоні концентрацій імазамоксу 0,01–5,0 мг/л. У процесі експерименту проаналізовано динаміку росту (за оптичною щільністю культури), стан пігментного апарату, компонентний біохімічний склад біомаси та амінокислотний профіль клітин.

У результаті проведених досліджень виявлено двофазний характер ростової відповіді мікроорганізмів на дію гербіциду. За умов низьких концентрацій імазамоксу (0,01–0,1 мг/л) спостерігався стимулювальний ефект щодо ростових процесів, тоді як підвищення вмісту речовини до 0,5–5,0 мг/л викликало дозозалежне пригнічення життєдіяльності культури. Встановлено структурну перебудову пігментного комплексу, що проявлялася вірогідним зниженням вмісту хлорофілу a та фікобіліпротеїнів за високих концентрацій пестициду при одночасному збереженні високого рівня каротиноїдів. З'ясовано, що токсична дія супроводжується концентраційно залежним зменшенням частки загального білка в біомасі (з 47 % до 19 %) із компенсаторним зростанням вмісту ліпідно-вуглеводної фракції. Серед дослідженого спектра амінокислот найбільшу чутливість виявив лейцин, вміст якого за мінімальної концентрації імазамоксу знижувався на 46 % порівняно з контролем.

Отримані експериментальні дані свідчать про високий адаптаційний потенціал асоціації N. commune за умови помірного пестицидного навантаження, а також підтверджують доцільність використання вивчених біохімічних маркерів для діагностики токсичного ураження водних мікробіоценозів імідазоліноновими гербіцидами.

Ключові слова: Nostoc commune, альгобактеріальна асоціація, імазамокс, імідазолінонові гербіциди, білки, ліпіди, вуглеводи, фотосинтетичні пігменти, амінокислоти

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