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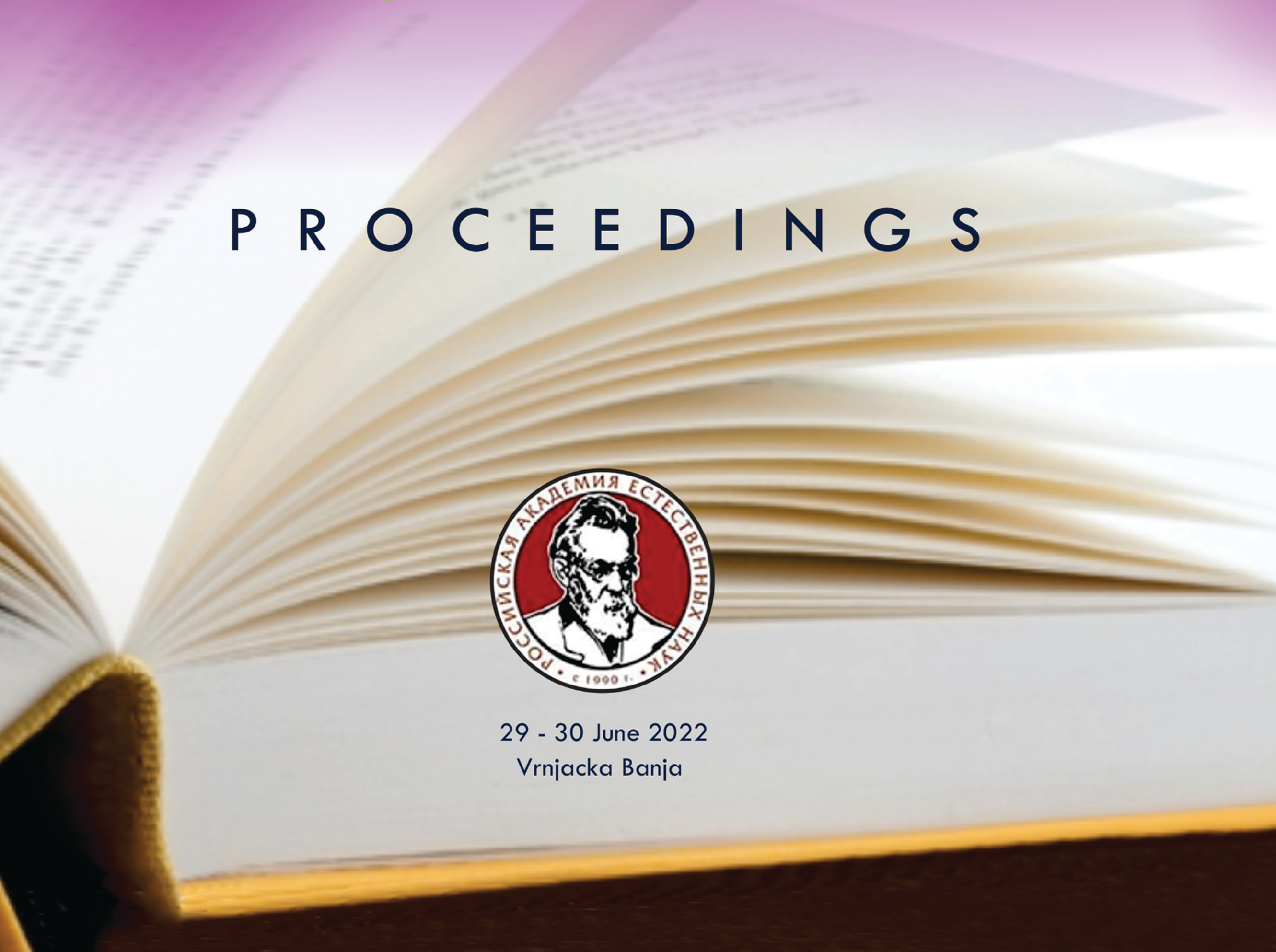

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INTEGRATED STRATEGIES FOR MANAGING FUSARIUM HEAD BLIGHT AND DEOXYNIVALENOL CONTAMINATION IN WHEAT

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Review paper

Abstract

Fusarium head blight (FHB) is economically the most important wheat disease, causing yield and quality losses. Fungal species from the genus Fusarium are the main causative agents of FHB, with Fusarium graminearum as the predominant species. F. graminearum synthesizes more different secondary metabolites (mycotoxins). In wheat, the most studied mycotoxins are trichothecenes and zearalenone produced by F. graminearum. Trichothecene deoxynivalenol (DON) and its acetylated forms 3-acetyl-deoxynivalenol (3-ADON) and 15-acetyl-deoxynivalenol (15-ADON) are the most detected in wheat grains. Strategies for controlling FHB and DON in wheat include different preharvest and postharvest measures, emphasizing integrated approaches. The main aim of this review was to present some preharvest and postharvest strategies for integrated FHB management in wheat production.

Keywords: *integrated pest management, Fusarium head blight, deoxynivalenol, wheat*

Introduction

Among main cereal crops (rice, wheat, maize), wheat is the second most important cereal crop worldwide, after rice. In 2020, Serbia harvested an area of wheat was 600,000 ha, producing 2,873,503 tons of wheat grains (Statistical Yearbook of the Republic of Serbia, 2021). The average yield was 4.9 tons per hectare. It is one of the major staple foods for humans. The wheat grain consists of 80-85% starch and proteins, 9-20% dietary fibres, and minor contents of lipids, vitamins, minerals, and bioactive compounds (Prasadi and Joye, 2020).

Fusarium head blight (FHB) is one of the most devastating diseases of small grains (wheat, barley, rye) caused by various fungal species of the *Fusarium* genus, of which *F. graminearum* Schwabe (sexual stage – *Giberrella zeae* (Schwein.) Petch) is the most common in temperate climatic regions Europe, America and Asia (Wegulo et al., 2011; Krnjaja et al., 2011a,b; Župunski et al., 2019). *Fusarium* species that cause FHB infect wheat crops during the anthesis stage under favorable weather conditions, such as high temperatures, humidity, and abundant rain. Maize, wheat, and barley residues are usually the primary inoculum for the initial FHB infection (Shah et al., 2018). Cereal grains infected by *Fusarium* species often contain high concentrations of mycotoxins causing harm to humans and animals. Mycotoxins are secondary metabolites produced by fungal species. Food contaminated with mycotoxin can cause diseases in humans and animals (mycotoxicoses) (Zain, 2011).

F. graminearum, as the predominant FHB pathogen in the asexual cycle, produces macroconidia which are transported from soil or infected leaves to flowering spikes by rain and wind and proliferated to spikelets. FHB symptoms manifest as necrosis and bleaching of the spike with shriveled kernels. Orange sporodochia, which comprise macroconidia, are formed on infected spikelets. In the sexual cycle, *F. graminearum* produces abundant perithecia in the crop residues. Ascospores (sexual spores) are released from perithecia, which mature during warm and humid weather in spring and spread by wind, rain, or insects, causing initial FHB infection (Shah et al., 2018; Francesconi et al., 2019).

F. graminearum synthesizes more different mycotoxins, mainly trichothecenes and zearalenone. Trichothecenes are of sesquiterpenoid mycotoxins. They are divided into four groups, types A, B, C, and D. Mycotoxins from types A and B are the most important in cereal crops. B-type trichothecenes include the mycotoxins deoxynivalenol (DON), its derivatives (3-acetyl-deoxynivalenol (3-ADON) and 15-acetyl-deoxynivalenol (15-ADON)), and nivalenol (NIV). DON represents the most frequently found mycotoxin in wheat grains worldwide (Piacentini et al., 2019). FHB symptoms can be improved by mycotoxin DON. DON can be a virulent factor in FHB pathogenesis (Tian et al., 2016; Krnjaja et al., 2021).

It is noticed that DON can contaminate straw and chaff, with higher levels in chaff than in the grains (Cowger and Arellano, 2013). It is very important in pig and turkey husbandry on a litter of straw and chaff. Wheat straw provides 12% of weaner pig's feed intake in straw-based systems. In dairy production, wheat straw and chaff are used as roughage feed. Additionally, wheat grains are integrally part of ensiled forage for dairy and beef cattle. Mycotoxins also survive in ensiled grains and present a risk to animal health (Cowger and Arellano, 2013). Consumption of contaminated feed, DON causes intoxication of animals, inhibiting protein synthesis (Pestka, 2010). DON is a neurotoxin and immunotoxin, which can cause lower feed intake (anorexia), emesis, and feed refusal because it is called vomitoxin (Haidukowski et al., 2005).

The occurrence and development of FHB and DON contamination depend on many factors such as climatic, agroecological, and environmental conditions, especially during flowering stages, and also agricultural practices (crop rotation, tillage, cultivar susceptibility, fungicide applications, etc.) Fungal growth and DON synthesis in wheat grains can appear during preharvest and postharvest. Preharvest contamination of grains is influenced by environmental conditions (moisture, temperature, humidity, droughts, insects) and agronomic practices. In addition, some preventive measures such as drying and different types of decontamination are applied during storage and processing (Blandino et al., 2012; Los et al., 2018). Based on mentioned, the main aim of this research was to review and consider some of the sustainable control strategies in integrated management of FHB and DON in wheat grains, focusing on preharvest and postharvest preventive measures for mitigation of these contaminants in wheat grains.

Preharvest strategies for the control of FHB and DON

Agronomic measures for preharvest wheat protection from FHB and DON contamination include tillage, crop rotation, early sowing, optimal fertilization, choosing resistant cultivars, and chemical and biological control. Integrated approaches are recommended as a more effective way to reduce FHB and DON occurrences. Likewise, the effectiveness of these measures individually or in combination depends on climatic and environmental conditions during the growing period, especially during the flowering wheat stages.

Tillage, crop rotation, sowing time, nitrogen fertilization, resistant cultivars

F. graminearum survives and overwinters as a saprophyte on cereal residues that are the major source of inoculum for the next season. Tillage to bury crop residues and crop rotation with non-hosts are used as effective agronomic measures to reduce inoculum potential of pathogen and DON accumulation in wheat-growing (Dill-Macky and Jones, 2000). Sowing time is an important preventive measure for controlling FHB severity and DON in wheat crops. The most risk of FHB infection is in 10-20 days from anthesis of wheat. Compared to late sowing time, early sowing time can contribute to avoiding favorable weather conditions for FHB infection during wheat flowering. However, this measure is recommended depending on the climatic conditions in which the crop is grown, especially during the anthesis and grain filling wheat stages (Shah et al., 2018). The effect of nitrogen fertilization on the development of FHB and DON synthesis is inconsistent. There are reports of a significant effect of increased N rates on FHB development and the level of DON (Lemmens et al., 2004), as well as reports that weather conditions affect FHB severity and DON synthesis more than N rates (Krnjaja et al., 2015). Additionally, Subedi et al. (2007) have reported small and inconsistent differences among nitrogen treatments and concluded that the effects of nitrogen on FHB incidence and severity were not of practical significance in spring wheat.

High yields of wheat are provided by sowing quality and healthy seeds. The main aim of the seed industry should also be to improve host resistance. There are several types of FHB resistance: type I - resistance to initial infection, type II - resistance to spread of *Fusarium* spp. within the spike, type III - resistance to seed infection, type IV - tolerance to FHB and DON, and type V - resistance to DON accumulation. Types I and II FHB resistance are the most described (Mesterházy, 1995; Boutigny et al., 2008). Cultivation of resistant cultivars reduces the occurrence of *Fusarium* species and the concentration of their mycotoxins. One of the ways to achieve this aim is to find sources of resistance to FHB and to determine quantitative trait loci (QTL) (genes) in a segregating population. This is a lengthy procedure because FHB resistance is determined by several genes which are influenced by the environment. An additional challenge in the breeding of wheat cultivars is the need to combine FHB resistance with exceptional agronomic and qualitative characteristics (Miedaner et al., 2017). However, knowledge of wheat genetic resistance to FHB has increased in recent years based on numerous studies of genetic resources in wheat relatives, cultivars, and breeding lines. There are numerous discovered and reported germplasms (FHB-resistant loci) available for breeding, for example, wheat genotypes from East Asia (Buerstmayr et al., 2020; Góral et al., 2021). Plant height significantly affects FHB. Buerstmayr et al. (2020) have established a significant dependence between FHB resistance and plant height, with taller plants as more resistant to FHB than shorter plants. Generally, there is a high risk of FHB infection for shorter plants because the distance from the inoculum source in plant residues on the soil to the spike is shorter than for taller plants. Furthermore, parameters such as the presence of awns and the percentage of flower opening at the flowering stage also contribute to the incidence and severity of FHB (Shah et al., 2018).

Chemical and biological control

The application of fungicides is another important preharvest measure for controlling FHB and DON. The most commonly used fungicides are demethylation inhibitor (DMI) fungicides (metconazole, propiconazole, prothioconazole, tebuconazole, epoxiconazole), showing significant effectiveness in suppressing FHB and DON (Krnjaja et al., 2014; Wegulo et al., 2015). Additionally, to be effective, fungicides must be sprayed during flowering time. During anthesis, warm and wet climatic conditions intensify FHB symptoms, as the conidia infect spikelets during a short period at anthesis. Therefore, the timing of fungicide application is a key factor for successful FHB control. However, growers often have trouble doing fungicide treatment on time, because of the unfavorable weather conditions for crop spraying (Shah et al., 2018).

Biological agents (bio-fungicides) are also used in the FHB control strategy. Their application is especially useful in organic wheat production. Bio-fungicides can be many beneficial fungi, bacteria, and yeasts, which infect and control the development of plant pathogens. Bacteria from the genera *Bacillus*, *Pseudomonas,* and *Streptomyces* have already been used in the field with successful results in the reduction of FHB severity (Legrand et al., 2017). In addition, *in vitro* tested strains of *Lactobacillus plantarum* and *Bacillus amyloliquefaciens* have also shown antimicrobial activity against tested strains of *F. graminearum* and *F. culmorum* isolated from wheat (Baffoni et al., 2015). The strain of *Bacillus subtilis* isolated from wheat anthers has shown an antagonistic effect against *F. graminearum* (Palazzini et al., 2016). Furthermore, the yeast species *Aureobasidium pullulans* reduced FHB severity by 20% on winter wheat in greenhouse conditions (Sarrocco and Vannacci, 2018). Then, fungal species from the genus *Trichoderma* are used in biological control against *Fusarium* spp., with *T. harzianum* as the most researched species (Filizola et al., 2019). However, *T. games* can also significantly reduce FHB severity and DON production. Mycoparasitic species *Clonostachys rosea* is used as a beneficial fungus against FHB, reducing perithecial production. Co-culture of *Cryptococcus flavescens* and *C. aureus* reduced FHB severity in wheat greenhouse trials (Sarrocco and Vannacci, 2018). Metabolites produced by plants (phenolic compounds and essential oils) are effective inhibitors of *F. graminearum* infections. Likewise, essential oils (EOs) or plant extracts are used as bio-fungicides (Grahovac et al., 2009). Due to the negative impact of pesticides on the environment and human health, EOs are used as biocontrol products. The steam distillation method is used for their obtaining from different plant organs. The chemical composition of EOs varies, it depends on the plant organ from which the EO is extracted (Raveau et al., 2020). By testing the efficiency of different EOs to reduce DON accumulation, such as extracts from cinnamon, clove, lemongrass, oregano, and palmarosa, the EO extract of clove was the most effective to reduce the accumulation of DON in wheat grain infected by *F. graminearum*. However, the mycotoxigenic activity of EOs affected by environmental factors (temperature and water activity) (Shah et al., 2018).

Postharvest strategies for the control of FHB and DON

Protection of wheat grains from fungal contaminants is also necessary during the postharvest period. Due to fungal postharvest contamination, the grains lose nutritive and qualitative values and become unusable for human and animal consumption. Therefore, physical, biological, and chemical methods are recommended as post-harvest management strategies for wheat grains protection.

Physical methods are based on preventive approaches. The moisture content of wheat grains should be 13.5% or lower during harvest and storage (Wegulo et al., 2015). Storage temperature and humidity must be adequate to prevent fungal growth and mycotoxin synthesis. Aeration of storage can also reduce the risk of fungal development (Mielniczuk and Skwaryło-Bednarz, 2020). Since insects can be fungal vectors, it is important to protect storage wheat grains from insects by using synthetic (methyl bromide and phosphine) and natural insecticides (plant essential oils), traps, and sticky taps (Kumar and Kalita, 2017; Kljajić et al., 2021). Ozonation prevents fungal development during storage and reduces DON in wheat grains. DON degradation is positively correlated with ozone concentration and the time of grain exposure to ozone (Li et al., 2015). In contaminated cereals, mycotoxins can be reduced by using adsorbents such as aluminosilicate minerals (zeolite, clay minerals) (Krnjaja et al., 2009).

Biological methods include the application of microorganisms for the neutralization of mycotoxins in wheat grain after harvest. Lactic acid bacteria (LAB), from the genera *Lactobacillus* and *Pediococcus*, reduced DON levels in malting wheat grains by adsorption mechanisms or microbiological binding. Modified glucomannan obtained from *Saccharomyces cerevisiae* yeast cell walls successfully reduces certain individual and combined harmful effects of mycotoxins. Another biological method based on the reduction of mycotoxins is the application of microorganisms that degrade mycotoxins into lower toxic compounds than the initial substance. Trichothecene mycotoxins are degraded by *Curtobacterium* spp. (Krnjaja et al., 2009; Mielniczuk and Skwaryło-Bednarz, 2020).

Chemical methods are based on detoxification by different chemical compounds. Organic acids such as citric and lactic acid are used for reducing DON and its derivatives in feed (Humer et al., 2016). Chlorine, hydrogen sulfates and ammonium hydroxide are also used for inactivating one or more mycotoxins and microorganisms. However, the use of any chemical compounds for conversing or disrupting mycotoxins may have negative effects on the sensory and nutritional properties of wheat and its products (Los et al., 2018; Mielniczuk and Skwaryło-Bednarz, 2020).

Conclusion

Individual preharvest and postharvest measures can be usefully for reducing FHB incidence, but integrated control strategies for FHB are more efficient, especially under favorable environmental conditions for *Fusarium* infection. The selection of resistant cultivars to FHB is the most effective preventive measure in wheat protection. However, the complexity of creating resistant cultivars leads to applying multiple strategies in FHB management, including the combination of measures such as fungicides and other agronomic practices. After harvest, grains should be stored in adequate storage with increased aeration capacity. Implementation of postharvest strategies is used to protect wheat grains from fungal contaminants and DON accumulation, of which all physical and biological methods are especially recommended.

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Интегралне мере у заштити пшенице од фузариоза класа и деоксиниваленола

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Ревијални рад

Апстракт

Фузариоза класа (ФХБ) је економски најважнија болест пшенице која проузрокује губитке у приносу и квалитету. Врсте гљива из рода Fusarium су главни проузроковачи ФХБ, са Fusarium graminearum као примарном врстом. F. graminearum синтетише више различитих секундарних метаболита (микотоксина). У пшеници, највише проучавани микотоксини су трихотецени и зеараленон продуковани од F. graminearum. Трихотецен деоксиниваленол (ДОН) и његови ацетиловани облици 3-ацетил-деоксиниваленол (3-АДОН) и 15-ацетил-деоксиниваленол (15-АДОН) су најчешће детектовани микотоксини у зрну пшенице. Стратегије за контролу ФХБ и ДОН у пшеници укључују коришћење различитих мера заштите пре и после жетве, наглашавајући интегралне приступе. Главни циљ овог прегледног рада био је да представи неке стратегије заштите пре и после жетве, као део интегралног концепта управљања фузариозама у производњи пшенице.

Кључне речи: интегралне мере заштите, фузариоза класа, деоксиниваленол, пшеница

Integralne mere u zaštiti pšenice od fuzarioza klasa i deoksinivalenola

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Apstrakt

Fuzarioza klasa (FHB) je ekonomski najvažnija bolest pšenice koja prouzrokuje gubitke u prinosu i kvalitetu. Vrste gljiva iz roda Fusarium su glavni prouzrokovači FHB, sa Fusarium graminearum kao primarnom vrstom. F. graminearum sintetiše više različitih sekundarnih metabolita (mikotoksina).U pšenici, najviše proučavani mikotoksini su trihoteceni i zearalenon produkovani od F. graminearum. Trihotecen deoksinivalenol (DON) i njegovi acetilovani oblici 3-*acetil-deoksinivalenol (3-ADON) i 15-acetil-deoksinivalenol (15-ADON) su najčešće detektovani mikotoksini u zrnu pšenice. Strategije za kontrolu FHB i DON u pšenici uključuju korišćenje različitih mera zaštite pre i posle žetve, naglašavajući integralne pristupe. Glavni cilj ovog preglednog rada bio je da predstavi neke strategije zaštite pre i posle žetve, kao deo integralnog koncepta upravljanja fuzariozoma u proizvodnji pšenice.*

Ključne reči: integralne mere zaštite, fuzarioza klasa, deoksinivalenol, pšenica

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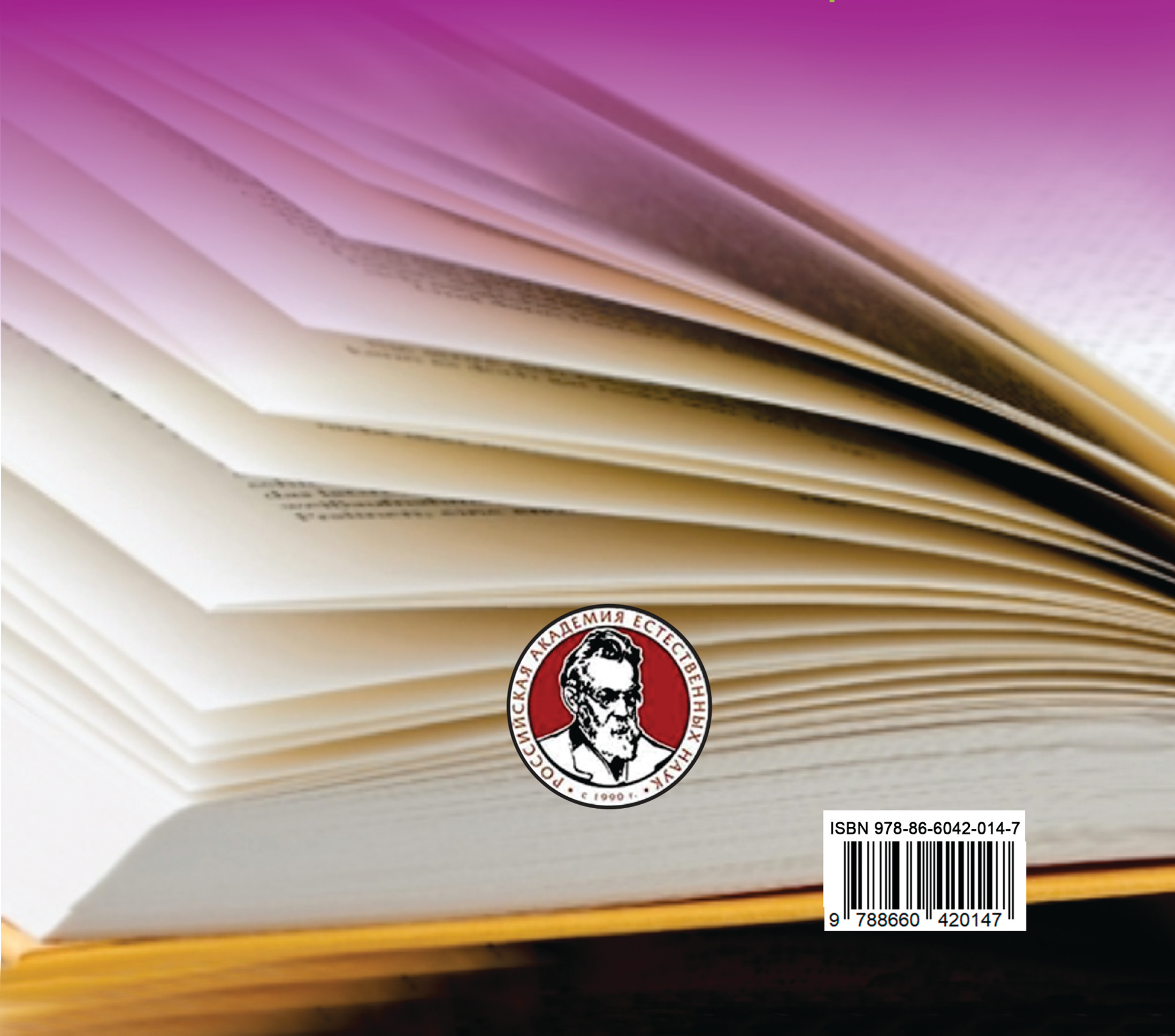

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