UDK: 638.1 | DOI:10.5937/etp243-2082P
Datum prijema rada: 29.10.2024.
Datum korekcije rada: 12.11.2024.
Datum prihvatanja rada: 14.11.2024.
PREGLEDNI RAD

EKONOMIJA
TEORIJA I PRAKSA
Special Edition / 2024
str. 82–103

THE ROLE OF BEES IN GREEN AGRICULTURE

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Abstract: *The decline of bee populations worldwide poses a significant threat to global agriculture and ecosystem stability. Bees play a vital role in pollination, contributing to the reproduction of numerous flowering plants, including many crops essential for human consumption. This paper examines the indispensable role of bees in promoting green agriculture practices, emphasizing their profound impact on biodiversity, food security, and environmental sustainability. Through a comprehensive review of existing literature, this paper elucidates the intricate relationship between bees and agriculture. It explores the mechanisms of bee-mediated pollination and highlights the critical role of diverse bee species in ensuring crop yield and quality. Furthermore, the paper discusses the detrimental effects of bee population decline on agricultural productivity and ecosystem health, emphasizing the urgent need for conservation efforts. The paper underscores the importance of collaboration among policymakers, farmers, scientists, and conservationists to implement effective measures*

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for safeguarding bee populations and promoting sustainable agriculture. Furthermore, the paper discusses the economic benefits of preserving bee populations, such as increased crop yields and enhanced ecosystem services. It also examines the potential risks associated with the widespread use of pesticides and other agrochemicals, emphasizing the importance of adopting alternative approaches that minimize harm to bee populations while maintaining agricultural productivity. In conclusion, this paper underscores the indispensable role of bees in green agriculture and calls for concerted efforts to protect and preserve bee populations for the benefit of both ecosystems and human societies. By adopting bee-friendly agricultural practices, we can promote sustainable food production systems that ensure the well-being of both bees and humans alike.

Keywords: *honeybees, honey, sustainability, organic, agriculture.*

INTRODUCTION

In the intricate tapestry of agricultural ecosystems, bees emerge as unsung heroes, weaving threads of biodiversity, food security, and environmental sustainability. Their pivotal role transcends mere pollination; it forms the bedrock of a flourishing agricultural landscape.

As prolific pollinators, bees facilitate the reproduction of countless plant species, thereby sustaining diverse ecosystems (Silva et al., 2021). From orchards to meadows, their diligent foraging activities ensure the proliferation of fruits, vegetables, and flowering plants, enriching habitats and supporting myriad organisms dependent on these resources. By promoting genetic diversity within plant populations, bees contribute to resilience against environmental stresses, safeguarding against the threats posed by climate change and habitat loss (Baguette et al., 2020).

Moreover, bees are linchpins of global food security, underpinning agricultural productivity and crop yield. Their pollination services are indispensable for the cultivation of a substantial portion of the world's food supply, including fruits, nuts, and vegetables. Studies estimate that approximately 75% of leading global food crops rely on pollinators, with

bees alone contributing to the production of over 90 commercially grown crops (Prodanović et al., 2024). Without their diligent pollination efforts, agricultural yields would plummet, exacerbating food shortages and compromising nutritional diversity, particularly in regions heavily reliant on small-scale farming (Lika et al., 2021).

The symbiotic relationship between bees and agriculture is palpable, as both entities are mutually interdependent. While bees are indispensable for crop pollination, agriculture provides bees with essential forage and nesting resources. However, this intricate balance is increasingly imperilled by modern agricultural practices, characterized by the widespread use of pesticides and agrochemicals (Hendlin, 2021). The indiscriminate application of these chemicals poses a grave threat to bee populations, disrupting their reproductive cycles, impairing their foraging behaviour, and compromising their immune systems. Consequently, declines in bee populations have been reported worldwide, with alarming implications for agricultural sustainability and food security (Stevanović et al., 2024).

Beyond their ecological significance, bees confer substantial economic benefits, underpinning agricultural economies and livelihoods. The commercial value of their pollination services is estimated in the billions of dollars annually, contributing significantly to agricultural output and rural incomes. Moreover, bees play a pivotal role in supporting biodiversity-based tourism and ecotourism ventures, attracting visitors keen to witness the splendour of pollinator-dependent ecosystems (Gajić et al., 2024). Thus, the preservation of bee populations is not only an ecological imperative but also an economic necessity, with far-reaching implications for sustainable development and poverty alleviation.

However, the burgeoning risks associated with pesticide use threaten to unravel the intricate web of ecological and economic benefits derived from bees. The indiscriminate use of neonicotinoids, in particular, has been implicated in the widespread decline of bee populations, prompting calls for stringent regulations and sustainable alternatives (Olorunsogo et al., 2024). As agriculture grapples with the imperative to feed a burgeoning global population, the conservation of bees emerges as a linchpin of sustainable agricultural development. Efforts to mitigate the impacts of pesticides must be complemented by broader

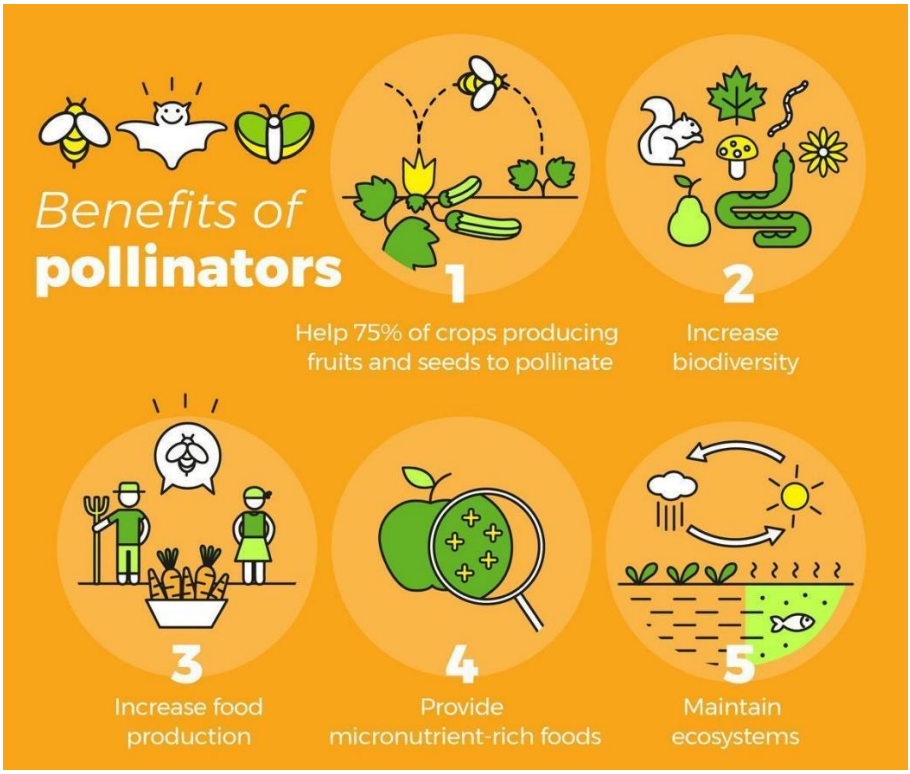
strategies aimed at enhancing habitat diversity, promoting agroecological practices, and fostering community-led initiatives for bee conservation (Decourtye et al., 2019; Drivdal & van der Sluijs, 2021; Sponsler et al., 2019).

The aim of this review is to delve into the multifaceted significance of bees in green agriculture, exploring their profound impact on biodiversity conservation, food production, and ecological balance. Furthermore, the aim is to present the intricate relationship between bees and agriculture, elucidating the economic benefits derived from their preservation and the potential risks posed by the widespread use of pesticides and agrochemicals in apiculture production.

ROLE OF BEES IN BIODIVERSITY, FOOD SECURITY, AND ENVIRONMENTAL SUSTAINABILITY

The role of bees in biodiversity, food security, and environmental sustainability is multifaceted and indispensable, underscoring their significance in ecological systems and agricultural landscapes worldwide. Bees play a critical role in biodiversity conservation, food security, and environmental sustainability (Richardson, 2023; Toledo & Burlingame, 2006). As pollinators, they are essential for the reproduction of flowering plants, the production of food crops, and the maintenance of ecosystem services (Figure 1) (Prodanović et al., 2021). Their decline poses significant risks to agricultural productivity, ecosystem stability, and human well-being (Stevanović et al., 2024). Therefore, concerted efforts are needed to conserve bee populations, mitigate threats such as habitat loss and pesticide use, and promote sustainable land management practices that support bee habitats and forage resources. By safeguarding bees, we can foster resilient ecosystems, ensure food security, and advance environmental sustainability for future generations (Marshman et al., 2019).

Figure 1. *Importance of pollinators in the global ecosystem.*



Biodiversity

Bees are keystone species in terrestrial ecosystems, playing a pivotal role in maintaining biodiversity. As pollinators, they facilitate the reproduction of numerous plant species, contributing to the genetic diversity of plant populations. This, in turn, sustains diverse habitats and supports a myriad of organisms dependent on these resources. Bees exhibit remarkable specialization in their foraging behaviours, forming intricate relationships with specific plant species (Easton-Calabria et al., 2019). Through their pollination activities, bees promote the proliferation of flowering plants, ensuring the abundance of food and habitat for a wide array of animals, including insects, birds, and mammals. Thus, bees are instrumental in shaping the structure and

function of ecosystems, fostering resilience against environmental stresses such as climate change and habitat loss (Durazzo et al., 2021).

Food Security

The role of bees in food security is unparalleled, underpinning global agricultural productivity and crop yield. Approximately 75% of leading global food crops rely on pollinators, with bees being the most effective and efficient pollinators among them. From fruits and vegetables to nuts and oilseeds, bees contribute to the production of a diverse array of food items essential for human nutrition. Without their diligent pollination services, agricultural yields would plummet, leading to food shortages, decreased nutritional diversity, and economic instability. Moreover, bees play a crucial role in supporting small-scale and subsistence farming systems, particularly in developing countries, where reliance on pollinator-dependent crops is high. Thus, the conservation of bee populations is essential for ensuring food security at local, national, and global scales (Dhankher & Foyer, 2018).

Environmental Sustainability

Bees are integral to environmental sustainability, embodying principles of ecological balance and resilience (Patel et al., 2021). Their pollination services are vital for maintaining the productivity and stability of natural and agricultural ecosystems. By promoting the reproduction of plant species, bees contribute to soil fertility, water retention, and carbon sequestration, enhancing ecosystem services essential for human well-being. Moreover, bees are indicators of environmental health, with declines in bee populations serving as early warning signals of ecosystem degradation and biodiversity loss (Bargańska et al., 2016). As such, efforts to conserve bees are intrinsically linked to broader initiatives aimed at promoting sustainable land management practices, preserving habitat diversity, and mitigating the impacts of climate change. Furthermore, the ecological services provided by bees extend beyond pollination, encompassing pest control, nutrient cycling, and seed dispersal, further highlighting their role in maintaining ecological balance and functionality (Melin et al., 2018).

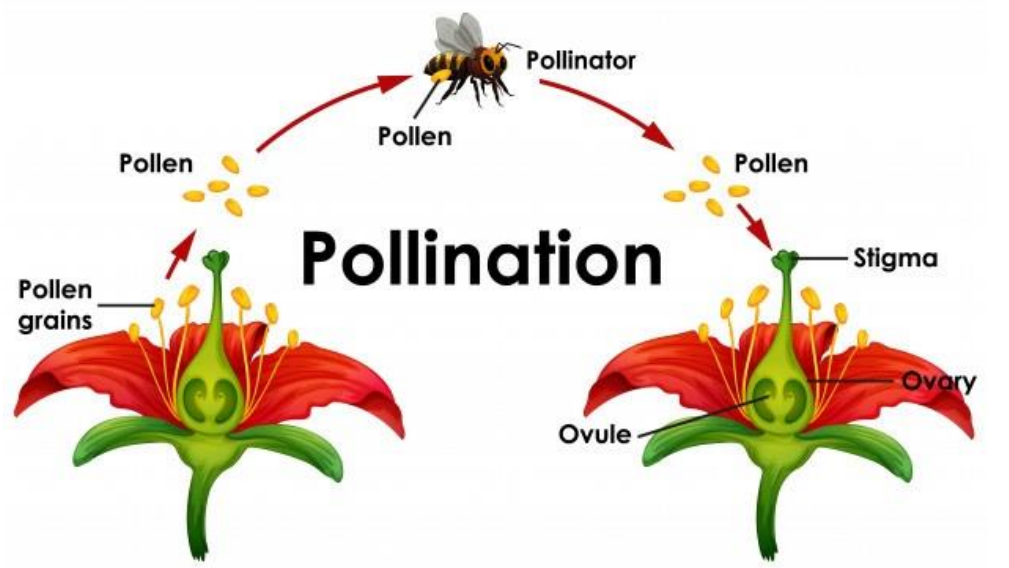
THE RELATIONSHIP BETWEEN BEES AND AGRICULTURE

The relationship between bees and agriculture is symbiotic and indispensable, characterized by mutual dependence and profound ecological significance. Bees play a critical role in agricultural systems worldwide, contributing to crop pollination, yield enhancement, and ecosystem resilience. Conversely, agriculture provides bees with essential forage resources and nesting habitats, fostering their survival and reproductive success (Sharma et al., 2023). The relationship between bees and agriculture is a cornerstone of global food production, economic prosperity, and environmental sustainability. Bees provide invaluable pollination services essential for crop yield and diversity, while agriculture offers bees essential resources and habitats for survival. However, this relationship is increasingly threatened by anthropogenic factors such as pesticide use, habitat loss, and climate change. To ensure the continued resilience of agricultural systems and the conservation of bee populations, concerted efforts are needed to mitigate these threats, promote sustainable land management practices, and foster collaboration between beekeepers, farmers, policymakers, and researchers (Grozinger & Patch, 2023). By safeguarding bees and their vital role in agriculture, we can build a more sustainable and resilient food system for future generations.

Pollination Services

At the heart of the relationship between bees and agriculture lies the vital ecosystem service of pollination. Bees, among other pollinators, are responsible for pollinating a substantial portion of the world's food crops, including fruits, vegetables, nuts, and oilseeds. Their foraging activities facilitate the transfer of pollen from male to female flower reproductive organs, initiating fertilization and fruit or seed development (Abrol, 2012). This process is essential for crop yield and quality, with many plant species exhibiting increased fruit sets and larger fruit sizes when adequately pollinated by bees (Figure 2). Consequently, the presence of healthy bee populations is crucial for ensuring agricultural productivity and food security.

Figure 2. *Bees pollination process.*



Crop Diversity and Genetic Variation

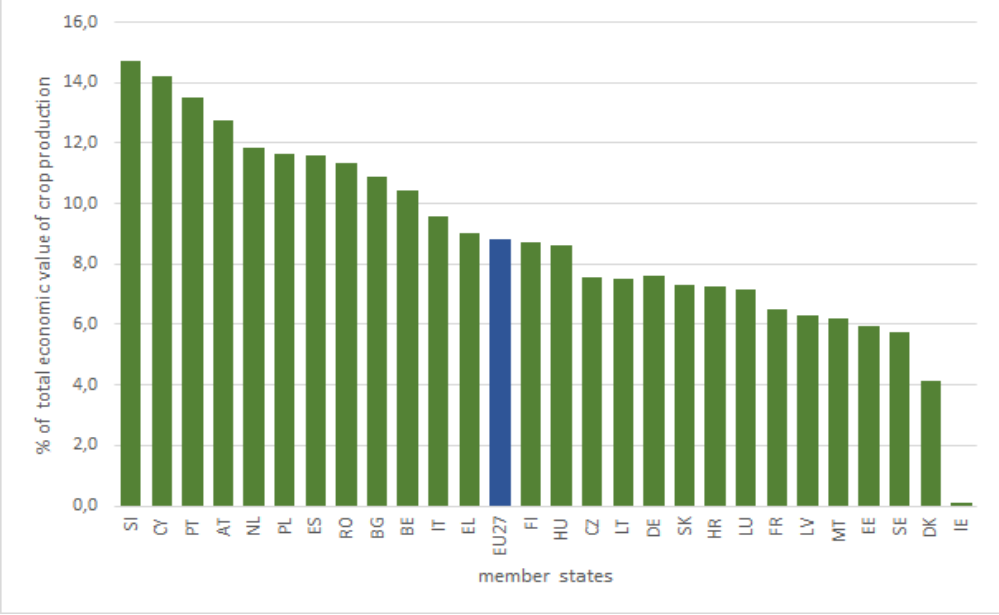
Bees contribute to agricultural diversity by facilitating the reproduction of diverse plant species. Through their pollination services, bees support the cultivation of a wide array of crops, including both traditional and specialty varieties. This diversity is essential for maintaining genetic variation within plant populations, which enhances resilience to environmental stresses such as pests, diseases, and climate change (Sutter et al., 2017). Moreover, bees play a role in promoting biodiversity within agricultural landscapes by supporting the growth of wildflowers and other non-crop plants. These floral resources provide essential forage for bees and other pollinators, contributing to ecosystem health and stability (Vaudo et al., 2015).

Economic Importance

The economic importance of bees in agriculture cannot be overstated. The commercial value of bee pollination services is estimated in the billions of dollars annually, contributing significantly to agricultural

output and rural economies (Melathopoulos et al., 2015). In addition to direct pollination services, bees also support agricultural livelihoods through honey production, beeswax harvesting, and the sale of bee-related products such as royal jelly and propolis (Figure 3). Furthermore, bees play a crucial role in supporting agro ecotourism ventures, attracting visitors keen to experience the beauty of pollinator-dependent ecosystems (Breeze et al., 2014). Thus, the preservation of bee populations is not only an ecological imperative but also an economic necessity, with far-reaching implications for sustainable development and rural livelihoods (Prodanović et al., 2024).

Figure 3. *Average relative economic value of crop pollination for EU member states.*



Challenges and Risks

Despite the mutual benefits derived from their relationship, bees, and agriculture face numerous challenges and risks. The widespread use of pesticides and agrochemicals poses a significant threat to bee populations, leading to declines in abundance, diversity, and reproductive success (Av et al., 2023). Pesticides such as neonicotinoids have been implicated in bee

mortality and sublethal effects, impairing their foraging behavior, navigation abilities, and immune systems. Furthermore, habitat loss and degradation due to agricultural intensification, urbanization, and land-use change threaten the availability of suitable nesting sites and forage resources for bees. Climate change also poses challenges, altering flowering patterns and phenology, which may desynchronize bee emergence and floral availability (Pervez & Manzoor, 2023).

THE ECONOMIC BENEFITS OF PRESERVING BEE POPULATIONS

The economic benefits of preserving bee populations are vast and far-reaching, encompassing agricultural productivity, rural livelihoods, commercial beekeeping enterprises, pollination services industries, and ecosystem services (Kevan & Phillips, 2001). By conserving bee populations, we can ensure the sustainability of global food production systems, support rural economies, and promote environmental stewardship. Therefore, concerted efforts are needed to mitigate the threats facing bee populations, including habitat loss, pesticide use, diseases, and climate change, and to promote policies and practices that prioritize bee conservation and sustainable beekeeping practices. By safeguarding bees and their vital contributions to agriculture and ecosystems, we can build a more resilient and sustainable future for generations to come (Abrol et al., 2016).

Agricultural Productivity and Crop Yields

The primary economic benefit of preserving bee populations lies in their indispensable role as pollinators of crops (Khalifa et al., 2021). Bees, along with other pollinators, are responsible for pollinating a substantial portion of the world's food crops, including fruits, vegetables, nuts, and oilseeds. Their foraging activities facilitate the transfer of pollen from male to female flower reproductive organs, initiating fertilization and fruit or seed development. This process is essential for crop yield and quality, with many plant species exhibiting increased fruit sets and larger fruit sizes when adequately pollinated by bees. Consequently, the presence of healthy bee populations is crucial for ensuring agricultural productivity, reducing yield variability, and mitigating economic losses due to poor pollination (Isaacs et al., 2017).

Genetic Diversity and Crop Resilience

Preserving bee populations contributes to the maintenance of genetic diversity within plant populations, enhancing crop resilience to environmental stresses such as pests, diseases, and climate change. Bees facilitate the reproduction of diverse plant species through their pollination services, supporting the cultivation of traditional and specialty crop varieties (Nicholls & Altieri, 2013). This genetic diversity provides a reservoir of adaptive traits that can confer resistance to pests and diseases, improve crop yields, and enhance agricultural sustainability. Additionally, bees contribute to the conservation of wild plant species and native vegetation, which serve as important genetic resources for crop breeding and agricultural development (Puvača, Halfawi, et al., 2022).

Commercial Beekeeping and Honey Production

The preservation of bee populations supports the viability of commercial beekeeping enterprises and the honey production industry, generating significant revenue streams and economic opportunities. Beekeepers rely on healthy bee populations to produce honey, beeswax, royal jelly, propolis, and other hive products that are in demand by consumers worldwide (Vapa-Tankosić et al., 2020). Honey, in particular, is valued for its unique flavor, nutritional properties, and medicinal benefits, making it a sought-after commodity in domestic and international markets. Furthermore, beekeepers provide essential pollination services to agricultural producers, renting out their beehives to farmers for crop pollination, thereby generating additional income and supporting rural livelihoods.

Pollination Services Industry

The preservation of bee populations sustains the pollination services industry, which provides essential pollination services to agricultural producers and growers. Commercial pollination services involve the rental of beehives to farmers and orchardists during the flowering period

of crops, ensuring adequate pollination and maximizing crop yields (Nicholls & Altieri, 2013). This industry plays a critical role in supporting the production of high-value crops such as almonds, apples, blueberries, cherries, and melons, which are heavily dependent on bee pollination. Consequently, the preservation of bee populations is essential for maintaining the viability and profitability of the pollination services industry, which contributes significantly to agricultural output and rural economies (Khalifa et al., 2021).

Ecosystem Services and Environmental Benefits

Beyond their direct economic contributions, preserving bee populations delivers a range of ecosystem services and environmental benefits that are essential for human well-being and economic prosperity (Klein et al., 2018). Bees contribute to soil fertility, water retention, and carbon sequestration through their pollination activities, enhancing ecosystem resilience and mitigating the impacts of climate change. Additionally, bees support biodiversity conservation by facilitating the reproduction of flowering plants and wildflowers, which provide essential habitat and food resources for a wide range of wildlife species. By preserving bee populations, we can maintain the integrity of ecosystems, promote biodiversity, and safeguard essential ecosystem services that underpin agricultural productivity and human livelihoods (Puvača et al., 2022).

POTENTIAL RISKS ASSOCIATED WITH THE WIDESPREAD USE OF PESTICIDES AND AGROCHEMICALS IN APICULTURE PRODUCTION

The widespread use of pesticides and agrochemicals in apiculture production poses significant risks to bee populations, ecosystem health, and agricultural sustainability (Agarski et al., 2023). Acute and chronic toxicity, sublethal effects, colony collapse disorder, residue accumulation in hive products, and indirect effects on ecosystems and food chains are among the key risks associated with pesticide use in beekeeping. To mitigate these risks, integrated pest management (IPM) strategies, organic farming practices, and alternative pest control methods should be prioritized to reduce reliance on chemical inputs and promote ecological resilience. Furthermore, regulatory measures, pesticide risk

assessments, and public education efforts are needed to raise awareness about the impacts of pesticide use on bees and promote sustainable agricultural practices that safeguard pollinator populations and ecosystem health (Rortais et al., 2017). By addressing the risks associated with pesticide use in apiculture production, we can protect bees, preserve biodiversity, and ensure the sustainability of global food production systems for future generations.

Acute and Chronic Toxicity

Pesticides and agrochemicals can exert acute and chronic toxic effects on bees, impairing their physiological functions, behaviour, and survival. Many insecticides, fungicides, and herbicides used in agriculture are toxic to bees, either directly through contact or ingestion or indirectly through contaminated nectar, pollen, and water sources (DiBartolomeis et al., 2019). Acute exposure to high concentrations of pesticides can lead to immediate mortality among bees, while chronic exposure to sublethal doses can cause behavioral abnormalities, reduced foraging efficiency, impaired navigation abilities, and compromised immune systems. These effects can weaken bee colonies, making them more susceptible to diseases, parasites, and environmental stresses (Wang et al., 2020).

Sublethal Effects and Colony Collapse Disorder

The sublethal effects of pesticides pose significant risks to bee populations, contributing to phenomena such as colony collapse disorder (CCD) and widespread declines in bee abundance and health. While individual bees may survive acute pesticide exposure, sublethal doses can impair their cognitive functions, learning abilities, and social interactions within the colony (Desneux et al., 2007). These sublethal effects can disrupt hive dynamics, reduce brood production, and compromise the reproductive success of queen bees, ultimately leading to colony depopulation and collapse. CCD, characterized by the sudden disappearance of worker bees from hives, has been linked to multiple stressors, including pesticide exposure, pathogens, nutritional deficiencies, and habitat loss (van Engelsdorp et al., 2017).

Residue Accumulation in Hive Products

Pesticide residues can accumulate in hive products such as honey, beeswax, and pollen, posing risks to human health and food safety (Zafeiraki et al., 2022). Bees collect nectar and pollen from flowering plants treated with pesticides, which can contain residues of insecticides, fungicides, and herbicides. These residues can be transferred to hive products during the honey production process, resulting in contaminated products that may exceed regulatory safety limits for pesticide residues (Pohorecka et al., 2017). Consumption of contaminated honey and hive products can pose risks to human health, particularly for sensitive populations such as children, pregnant women, and individuals with compromised immune systems.

Indirect Effects on Ecosystems and Food Chains

The widespread use of pesticides and agrochemicals in agriculture can have indirect effects on ecosystems and food chains, disrupting ecological processes and community dynamics (Sánchez-Bayo, 2021). Pesticides can harm non-target organisms such as beneficial insects, birds, and mammals that play critical roles in ecosystem functioning, including pest control, pollination, and nutrient cycling. Moreover, pesticide runoff from agricultural fields can contaminate soil, water bodies, and adjacent habitats, leading to ecosystem degradation, biodiversity loss, and habitat fragmentation (Brühl et al., 2023). These indirect effects can have cascading impacts on ecosystem services, agricultural productivity, and human well-being.

CONCLUSIONS

In conclusion, the pivotal role of bees in green agriculture cannot be overstated. From biodiversity conservation to food security and economic prosperity, bees are indispensable agents of ecological balance and agricultural sustainability. However, their future hangs in the balance, imperilled by the perils of pesticide use and habitat degradation. Urgent action is needed to preserve bee populations and safeguard the myriad benefits they confer upon agricultural ecosystems and human societies alike. Only through concerted efforts can we ensure a future

where bees continue to thrive, pollinating the path to a greener, more sustainable agricultural future.

ACKNOWLEDGEMENT

This research was supported by grant No. 142-451 "Improving the competitiveness of organic food products in functions of sustainable development of AP Vojvodina", provided by the Provincial Secretariat for Higher Education and Scientific Research of the Autonomous Province of Vojvodina.

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ULOGA PČELA U ZELENOJ POLJOPRIVREDI

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Sažetak: *Opadanje populacije pčela širom sveta predstavlja značajnu pretnju globalnoj poljoprivredi i stabilnosti ekosistema. Pčele igraju vitalnu ulogu u oprašivanju, doprinoseći reprodukciji brojnih cvetnica, uključujući mnoge useve neophodne za ljudsku ishranu. Ovaj rad istražuje nezamenljiivu ulogu pčela u promovisanju praksi zelene poljoprivrede, naglašavajući njihov značajan uticaj na biodiverzitet, bezbednost hrane i ekološku održivost. Kroz sveobuhvatni pregled postojeće literature, ovaj rad objašnjava složeni odnos između pčela i poljoprivrede. Istražuje mehanizme oprašivanja i ističe ključnu ulogu različitih vrsta pčela u osiguravanju prinosa i kvaliteta useva. Takođe, rad razmatra štetne efekte opadanja populacije pčela na poljoprivrednu produktivnost i zdravlje ekosistema. Rad ističe važnost saradnje između donosilaca politika, poljoprivrednika, naučnika i zaštitara prirode radi sprovođenja efikasnih mera zaštite populacija pčela i promovisanja održive poljoprivrede. Takođe, rad razmatra ekonomske koristi čuvanja populacija pčela, kao što su povećani prinosi useva i unapređene ekosistematske usluge. Takođe se ispituju potencijalni rizici povezani sa širokom upotrebom pesticida i drugih agrohemijskih sredstava, naglašavajući važnost usvajanja alternativnih pristupa koji smanjuju štetu populacijama pčela uz očuvanje poljoprivredne proizvodnje. Na kraju, ovaj rad ističe ključnu ulogu pčela u zelenoj poljoprivredi i poziva na zajedničke napore za zaštitu i*

očuvanje populacija pčela u korist kako ekosistema, tako i društva. Usvajanjem dobrih poljoprivrednih praksi možemo promovisati održive sisteme proizvodnje hrane koji osiguravaju dobrobit kako pčela, tako i ljudi.

Ključne reči: *pčele, med, održivost, organski, poljoprivreda.*