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MEETING THE CHALLENGE OF SUSTAINABLE AGRICULTURE: RECENT ADVANCES IN ORCHARD NUTRITION AND PROTECTION MANAGEMENT

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ABSTRACT

The demand for food is expected to increase by up to 70% by 2050 due to the projected population of over 10 billion people. Conventional agricultural methods, which imply the application of synthetic fertilizers and pesticides, are unlikely to meet this demand. Therefore, there is a need for the intensification of agricultural production. However, the excessive use of synthetic fertilizers and chemically synthesized pesticides can have adverse effects on the environment, soil fertility, crop yields, human health, and food quality.

Therefore, harmonizing plant nutrition and protection through sustainable principles in agriculture represents a major goal and challenge for agriculture in the 21st century. Innovative, sustainable, and environmentally safe solutions and bio-rational technologies such as the use of fertilizers and pesticides of biological origin need to be introduced.

This paper provides a review of recent achievements in orchard nutrition and protection management by introducing a new product based on liquid biofertilizer. This biofertilizer is derived from vermicompost and enriched with different strains of beneficial microorganisms from Azotobacter, Bacillus, Pseudomonas, and Trichoderma genera, which contribute to increasing productivity, quality characteristics, and economic efficiency of production while simultaneously respecting ecological and health safety standards. The new formula includes a complete technological procedure and has been developed at the Fruit Research Institute, Čačak in the Republic of Serbia.

Keywords: *Effective microorganisms, Vermicompost extracts, Sustainable orchard management, Bio-rational technologies, Ecological safety, Health safety*

INTRODUCTION

The imperative of modern agricultural production is to achieve high and stable yields of high-quality products. The projected population of over 10 billion by 2050 will result in up to a 70% increase in food demand, which cannot be met with conventional methods and a growth rate of 1.8% annually. Therefore, there is an urgent need to intensify agricultural production. However, this intensification is often achieved through the excessive and continuous use of synthetic fertilizers containing essential nutrients such as nitrogen, potassium, and phosphorus. Unfortunately, research in this area tends to focus on increasing yields, neglecting the cumulative effects of abovementioned chemicals on the biological and chemical properties of soil, water, and air, the quality of the obtained products, and human health.

Although nitrogen is a vital nutrient that enhances and promotes plant growth and is essential for high crop yields and optimum fruit quality (Leghari, et al., 2016), its overuse may have adverse effects on plants (Jeppsson, 2000). Namely, its excessive use is closely

related to reduction in soil fertility, yields and nutritional value of crops, increased risk of environmental pollution and human diseases. High nitrogen levels in plant tissues can decrease resistance, increase susceptibility to herbivore attack, and adversely affect the feeding preference, food consumption, growth, reproduction, and population density of insects. Moreover, the frequent and improper use of nitrates in agriculture has proven to be harmful to the environment. More than 50% of the applied synthetic fertilizers are not absorbed by plants, but are consequently lost in different ways, causing not only economic inefficiency but also damage to the environment. In certain situations, high nitrogen levels can harm both the plants and humans who consume them. The use of nitrates in organic and chemical fertilizers is a major source of water pollution in Europe (Ju et al., 2006, Singh et al., 2012). Generally, agriculture is responsible for over 50% of the total nitrogen discharge into surface waters. Therefore, 30 years ago, the EU issued the Nitrates Directive, aimed to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices. Apart from that, the evaporation of volatile nitrogen compounds causes damage to the ozone, resulting in serious human health problems and greenhouse effects. Also, the leaching of nitrates may lead to their uptake and accumulation above the allowable level in cultivated plants, their subsequent entry into the human body and, consequently, health problems in humans (Hord et al., 2009). National policies related to the reduction of nutrient losses to the environment are generally implemented in European directives.

In addition, the intensification of agriculture is related to the use of chemically synthesized pesticides. Pesticide products as chemically synthesized agents are chemical compounds with diversified toxicological properties and persistency effects, and are highly risky potential pollutants in the environment and human population. According to the WHO's estimate, three million cases of pesticide poisoning occur every year, resulting in more than 250 000 deaths, mostly due to inexpert handling and application or intentional poisoning (Stoytcheva, 2011). A number of epidemiological studies have been carried out to evaluate the association between exposure to pesticides and cancer. Stoytcheva (2011) reported that pesticides can play a role in the cancer process by either non-genotoxic mechanism such as promotion, peroxisome proliferation, and hormone imbalance, or by affecting the carcinogenic process in a variety of ways, of which both can alter the genome and provide a growth advantage for neoplastic cells. Besides, a direct negative effect of active substances of synthetic pesticides on human and animal health, excessive or improper use of insecticides is also associated with: pesticide resistance in some pests, water, soil and air contamination that transfers chemical residues along the food chain, reduction of biodiversity and nitrogen fixation, destruction of marine and bird life and/or contributing genetic defects in subsequent generations, changes in the natural biological balances, by means of a reduction of beneficial and non-target organisms and insects, including predators as well as parasites of pests in addition to honeybees (Stoytcheva, 2011; Naqqash et al., 2016). On the other hand, the human population is exposed to these chemicals primarily through the consumption of pesticide contaminated farm products, leading to long-term health hazards. Pesticide degradation intermediates are often more persistent and of higher toxicological levels than the starting compound, and as a rule residues remain for a long time in soil or water (groundwater). Listed problems associated with the use of synthetic pesticides driven reduction of pesticides consumption to a necessary minimum and to replacing risky products with alternative modes of protection against harmful organism.

To mitigate these consequences, it is necessary to harmonize plant nutrition and protection (PNP) by introducing innovative, sustainable and environmentally safe solutions

and bio-rational technologies in agriculture, i.e. the use of fertilizers and pesticides of biological origin. This represents both the main goal and a great challenge for agriculture in the 21st century.

NATURAL SOURCES AS FARMING INPUTS

In recent years, research in the field of biotechnology, that lead to the creation of sustainable principles in agriculture, has become more and more relevant, and there are more and more discoveries of suitable environmentally safe products and techniques in the practice. Numerous examples from practice demonstrate excellent results from microbial inoculation (Higa & Parr, 1994; Kloepper *et al*., 2004; Pešaković & Milivojević, 2014; Pešaković et al., 2015; Tomić et al., 2015; Mosa et al., 2015; Pešaković et al., 2017; Simonović et al., 2019). By introducing living cells of microorganisms into the soil, the growth of plants is seeded, the root activity is increased, and the utilization of nitrogen, phosphorus, potassium, and microelements is intensified. The process of photosynthesis is also enhanced, as well as the content of microbiological biomass in the soil. This method eliminates the negative impact of pesticides and mineral nutrients, increases plant resistance to diseases, low temperatures, and drought. The effectiveness of microbial inoculation is conditioned by numerous factors that significantly influence the ability of introduced microorganisms to adapt to new conditions and then dominate the autochthonous microflora. It is crucial that the initial population of introduced microorganisms meets the critical threshold, which ensures that the amount of bioactive material they produce is sufficient to achieve desirable effects in both productivity and plant protection. The next important step is to provide optimal conditions, primarily determined by soil properties and factors that influence the growth and activity of introduced microorganisms, including temperature, light, aeration, pH, water content, organic matter, and, of course, sources of nutrient food. If these conditions are not met, introduced microorganisms, regardless of how beneficial they may be, will have little or no effect.

Microbial inoculation can be applied as single strain of a specific species or as a mixture of strains of one or more species. The rates depend on soil fertility, plant species needs and the phenological stage of plant development. Regarding the frequency of application, in some soils, a single application may be sufficient to induce desirable effects, while in others, even repeated applications may not produce the desired effects. The main reason for this is that introduced microorganisms need more time to adapt to new conditions and become stable, efficient, and dominant in relation to the autochthonous microflora. It is very important that the mixture of microbial cultures consists of compatible strains. It is also important to emphasize that repeated applications, especially during the first year, significantly contribute to the establishment of an effective microbial community. Once such communities are established, further applications are not necessary.

One more possibility for improving the nutrition system of agricultural crops is based on the application of vermicompost, a product that arises from the microbiological decomposition of organic matter through the digestive tract of the California worm (Eisenia fetida) (Mitchell, 1997). Given that numerous industrial processes, including agriculture and food production, result in the generation of large amounts of waste, a significant number of studies are dedicated to the potential use of vermicomposting for the production of vermicompost. In many countries such as Germany (Ernst et al., 2008), Spain (Monroy et al., 2009), the USA (Arancon et al., 2008), and Vietnam (Yadav et al., 2010), vermicomposting is seen as a key step in sustainable waste management. Due to its better physical characteristics, higher microbial and enzymatic activity, and higher content of

readily available nutrients, vermicompost has several advantages over synthetic fertilizers, and according to Venugopal et al. (2010) and Abul-Soud et al. (2014), it is significantly more acceptable to producers than compost. Quaik et al. (2012) link the increased interest in vermicomposting to its positive impact on the environment. The use of vermicompost in agricultural soils can intensify the formation of soluble micro-nutrient compounds, increase soil cation exchange capacity and soil buffer capacity (Kiehl et al., 1985), and consequently increase productivity.

Among the various methods of plant nutrition aimed at sustainable use of natural resources, significant attention is directed towards the use of compost products such as teas, extracts, or leachates. Ingham (2002) states that the benefits of compost tea (a liquid extracted or brewed from compost) have been known since ancient times, including by the Romans. However, its use has been neglected due to the increasing use of mineral nutrients. Interest in its use has increased in recent years in conjunction with demands for producing safe and healthy food. Considering that compost tea contains beneficial microorganisms and dissolved nutrient materials, both organic and inorganic, its use allows for the effective utilization of nutrient components and waste management in agriculture in a sustainable and economically justified manner. Diver (2002) highlights that compost and plant teas are tools that can increase crop productivity and inoculate the phyllosphere and rhizosphere with soluble nutrients, beneficial microorganisms, and microbial metabolites. Raw materials used to produce liquid products based on vermicompost are mainly animal and agricultural waste (Pant et al., 2009; Gutiérrez-Miceli et al., 2011). Numerous studies indicate the positive effects of their use in crop and vegetable production. However, few studies indicate the effects of their use in fruit production. Singh et al. (2010) found an increase in leaf surface, vegetative growth, and strawberry yield while investigating the effects of vermicompost leachate. Welke (2005) also found a positive impact of compost tea on strawberry yield. The same study also indicates the positive impact of compost tea on suppressing the pathogen *Botrytis cinerea* Pers, which causes gray mold on fruits.

Given the information above, there was a need to discover a new product that would contribute to increasing productivity, quality characteristics, and economic efficiency of production, primarily for different fruit species, while simultaneously respecting ecological and health safety standards. To this end, a complete technological procedure (new formula) of liquid biofertilizer, based on vermicompost and enriched with different strains of beneficial microorganisms (VCMo), has been developed at the Fruit Research Institute, Čačak (Republic of Serbia).

The production process occurs in several stages (Pešaković et al., 2017), starting with the construction of a special bioreactor and optimization of technological parameters for the process of nutrient extraction and multiplication of microorganisms from vermicompost. The process continues with the preparation of supplements 1 and 2 (microbial starter) and ends with brewing in a specially designed bioreactor. The process takes place under previously defined conditions (pH, electrical conductivity, temperature, and stirrer speed). For the preparation of supplements 1 and 2, appropriate strains of microorganisms (in this particular case, from Azotobacter, Bacillus, Pseudomonas, and Trichoderma genera) are isolated and characterized. These strains have a significant influence on the growth, yield, and quality of various fruit species. They exert their effects through specific mechanisms, including increasing the availability of nutrients (biofertilizers), stimulating plant growth through hormone production (phytostimulators), decomposing organic pollutants (rhizomediators), or controlling plant diseases through the production of antibiotics and antifungal metabolites (biopesticides).

Studies have shown that the newly formulated biopreparation has several advantages over the raw material from which it was produced. Firstly, the efficiency of use is increased, as the number of beneficial microorganisms in this product is up to ten times greater than in the raw material. This means that the same or even better effects can be achieved using significantly smaller amounts of vermicompost, overcoming the problem of the limited vermicompost market. This product's high efficiency is the result of selected strains of microorganisms that activate and stimulate the autochthonous saprophytic microflora to increase nutrient content in the rhizosphere of plants. The product produces various physiologically active substances, amino acids, vitamins, and biofungicides that protect plants from economically significant fungal diseases.

Secondly, the flexibility of use is increased thanks to its liquid form, which makes it suitable for both foliar application and rhizobial application via fertigation systems. This product allows for more precise nutrient delivery tailored to the plant's requirements during specific phenological stages of development, providing better nutrient utilization efficiency, not only by cultivated plants but also by microorganisms contained in the preparation.

Thirdly, the biopreparation exhibits phytotherapeutic action, displaying antagonistic effects on plant pathogens, allowing for the reduction of plant protection problems.

Lastly, the production efficiency is increased as the application of the fertilizer system provides simultaneous irrigation and nutrition. Additionally, the mentioned application methods allow for multiple use during vegetation with reduced volume of manipulative tasks, which justifies the commercial use of this preparation with the reduced amount of product used as raw material.

In order to investigate the efficiency of the newly formulated bio-preparation, research was conducted in the orchards of different fruit species.

EFFICIENCY OF LIQUID VERMICOMPOST BASED PRODUCT (VCMO) ON PRODUCTIVITY OF DIFFERENT FRUIT SPECIES

Studying the effect of VCMo application on the productivity of 'Senga Sengana' strawberries in an organic production system, Pešaković et al. (2018) found that liquid vermicompost extracts (VCMo) significantly influenced an increase in yield. According to their study, VCMo application resulted in higher yield per plant and unit area. They explained this by the presence of microorganisms in the biopreparation that provide nutrients for plants in the soil and increase the content of bioregulators such as indoleacetic acid or gibberilic acid. Diver (2002) also noted that compost and herbal teas can increase crop productivity and introduce soluble nutrients, useful microorganisms, and microbiological metabolites to the philo- and rhizosphere. Singh et al. (2010) observed an increase in leaf area index, vegetative growth, and yield of strawberries when examining the influence of vermicompost leachates. Welke (2005) also found a positive influence of compost tea on the yield of strawberries.

Additionally, Karaklajić Stajić et al. (2022) reported that berry weight increased by 7% (blackberry ‘Čačanska Bestrna’) and 9% (blueberry ‘Aurora’) with the application of VCMo. The authors further stated that the positive effect of the applied VCMo on fruit weight was directly reflected in the increase in yield in all tested fruit species. Similar trends in terms of berry weight were reported by Hassan et al. (2018) for the black cherry tomato treated with vermicompost leachates. However, these results contradict those of Budiastuti et al. (2012), who reported that melon fruits obtained under organic or natural fertilization generally have lower weight and yield than those produced using conventional chemical fertilization.

EFFICIENCY OF LIQUID VERMICOMPOST BASED PRODUCT (VCMO) ON PHYSICAL PARAMETERS OF DIFFERENT FRUIT SPECIES

Overall, the application of vermicompost leachate can have a positive influence on the morphometric parameters of fruit species by increasing nutrient availability in the soil and promoting plant growth. However, it's important to note that the specific effects may vary depending on the fruit species, the composition of the leachate, and other environmental factors.

In a study by Pešaković et al. (2018), the application of VCMo positively influenced the weight, firmness, length, and width of the fruit. Strawberry plants treated with VCMo had larger and heavier fruits than those of the control plants. The increase in fruit size was attributed to the increase in nutrient availability in the soil.

In a more recent two-year study (2019-2020) by Pešaković et al. (2021) on the growing technologies of 'Čačanska Lepotica' and 'Stanley' plums, the application of VCMo significantly affected the morphometric traits of the fruits. The largest fruits were recorded in the VCMo treatment in both cultivars, which may be related to the activities of beneficial microorganisms present in VCMo. These microorganisms possess plant growth-promoting properties, such as nitrogen fixation, phosphate dissolution, iron chelation, siderophores, and phytohormone production. Other authors have also reported that changes in fruit morphometric traits are associated with higher production of assimilates in plants inoculated with beneficial microorganisms.

The positive effects may be the result not only of the activities of the beneficial microorganisms contained in VCMo but also of the cumulative effect of microorganisms and nutrients extracted from vermicompost, as demonstrated by studies by Thakur and Thakur (2014) and Chauhan (2008). The highest growth of plum trees and yields were detected in the combined application of biofertilizers, chemical fertilizers, vermicompost, and green manures. Finally, the positive effect of VCMo application may be due to the translocation of photosynthates to the fruits, as reported by Kamatyanatti et al. (2019), who showed that applications of Azotobacter and phosphate-solubilizing bacteria in 'Kala Amritsari' plum orchards enhanced the availability of N and P to the plant roots, increasing their translocation rate from roots to flowers by intensively developing an extensive extra-radical mycelium that helps plants exploit mineral nutrients and water from the soil

EFFICIENCY OF LIQUID VERMICOMPOST BASED PRODUCT (VCMO) ON INTERNAL FRUIT QUALITY TRAITS OF DIFFERENT FRUIT SPECIES

Soluble solids and fruit firmness are two important factors that have a significant impact on consumer acceptance of plums (Paz et al., 2008). Soluble solid content is a key determinant of fruit eating quality, and plums with less than 12.5% soluble solids are generally not acceptable to most consumers (Vangdal et al., 2007). Fruit firmness, on the other hand, is a useful indicator of fruit softening and can be used to predict bruising damage during harvest and postharvest handling.

Despite the importance of these factors, there are very few studies that investigate the influence of eco-friendly technologies on internal fruit quality in orchard management. However, a recent study by Karaklajić Stajić et al. (2021) found that the application of VCMo had a positive effect on soluble solids content in blackberries, but not in strawberries or blueberries. In contrast, Budiastuti et al. (2012) found that compost-tea treatments were superior in terms of important criteria such as soluble solids content in melon fruit.

Pešaković et al. (2021) investigated the implementation of VCMo in plum growing technology for two consecutive seasons and found that the eco-friendly technology led to larger and firmer fruits in both cultivars and in both investigated years. The study also found that the interaction effects of cultivar × year were statistically significant, with a higher value of fruit firmness recorded in the 'Čačanska Lepotica' cultivar. In addition, Kamatyanatti et al. (2019) reported maximum firmness in the treatment with biofertilizer, consistent with the results of Pešaković et al. (2020), which showed that biofertilizer treatment significantly affects fruit firmness.

Interestingly, the study by Pešaković et al. (2021) found higher values of both soluble solids content and fruit firmness in the 'Čačanska Lepotica' cultivar compared to the 'Stanley' cultivar, which is contrary to their previous study (Pešaković et al., 2020). This could be due to the cumulative effect of beneficial microorganisms contained in VCMo, which have the ability to affect the physiological traits of plants and indirectly influence their soluble solids content and fruit firmness. Overall, these findings highlight the potential benefits of eco-friendly technologies for improving internal fruit quality in orchard management.

EFFICIENCY OF LIQUID VERMICOMPOST BASED PRODUCT (VCMO) ON CHEMICAL CHARACTERISTICS OF DIFFERENT FRUIT SPECIES

Fruits are a significant source of phytochemicals, particularly phenolic compounds, that contribute to both their nutritional value and sensory attributes. The concentration of these compounds is affected by genotype and growing technologies used (Veberic et al., 2005). The use of liquid vermicompost products in nutrition management has been reported to positively affect the total phenol content and antioxidant activity of various fruits, such as strawberries and plums, due to the presence of beneficial microorganisms and nutrients. Several studies, including Dong et al. (2013) and our own research (Pešaković et al., 2018; Pešaković et al., 2020), have shown that the application of vermicompost tea and biofertilizers containing beneficial microorganisms leads to higher levels of phenolic compounds and antioxidants in fruits.

Our previous studies on strawberry, blueberry, and blackberry species found that growing these fruits without the use of synthetic fertilizers resulted in higher amounts of phenols (Karaklajić Stajić et al., 2022). While there were no significant differences in total phenolic components in strawberries grown according to standard production criteria and those grown with VCMo biofertilizer, our research confirmed a positive effect on nutritional composition, such as total phenolic acids, flavanones, and flavonols. The application of VCMo also resulted in significant effects on the phenolic composition of blueberries and blackberries, with higher values of total flavonols and anthocyanins content. Similarly, studies on plums have reported increased TPC and AA with the use of vermicompost extract, resulting in improved fruit quality parameters.

Likewise, a research on plums demonstrated that using products of organic origin and liquid vermicompost products led to an increase in the total phenolic content (TPC) and antioxidant activity (AA) of the fruits. According to Cuevas et al. (2015), plums grown under organic production management had 5-10% higher TPC and AA compared to those grown conventionally. In our previous study (Pešaković et al., 2021), we observed that plum cv 'Čačanska Lepotica' had higher titratable acidity (TA) than cv 'Stanley,' which was superior in terms of TPC and AA, both in the treatment where VCMo was applied especially in the second year of growing (Pešaković et al., 2020). The notable impact of the second year of investigation could be attributed to the higher production of assimilates in plants and

improved physical, chemical, and microbiological properties of the soil since the cumulative effect of two years was established. This helped the introduced microorganisms to adapt to the new conditions and establish dominance over the autochthonous microflora, which in turn enhanced the availability and uptake of nutrients, leading to better plant growth and synthesis of these compounds in fruits.

In addition, an another our previous study (Pešaković et al., 2021) also suggest that the use of VCMo can positively affect the phenolic composition and nutritional value of plum fruits, highlighting the importance of sustainable growing practices (Pešaković et al., 2021).

EFFICIENCY OF LIQUID VERMICOMPOST BASED PRODUCT (VCMO) ON PLANT DISEASE SUPPRESSION

There are several studies dealing with the application of liquid vermicompost products that can help control pathogens in different fruit species. Studying the effect of the use of vermicompost tea and microbial inoculants on suppressing apple blight caused by the bacterium *Erwinia amylovora*, Waweru et al. (2021) showed a significant reduction in the number of infected plants and disease intensity compared to untreated plants. Acosta-Mercado et al. (2017) evaluated the effect of vermicompost tea (VCT) on the incidence of *Fusarium oxysporum* and growth of strawberry plants showed that the use of VCT significantly reduced the incidence of *F. oxysporum* in soil and improved the growth and yield of strawberry plants. The authors concluded that VCT has the potential to be an effective biocontrol agent against soil-borne pathogens in strawberry cultivation. Similarly, Fialho et al. (2019) highlighted the potential of VCT as a sustainable alternative to chemical pesticides in their review paper on the application of vermicompost tea (VCT) for the management of plant diseases, as it contains beneficial microorganisms that can suppress plant pathogens. Our previous study (Pešaković et al., 2023) related to the effectiveness of VCMo on the occurrence of gray mould (*Botrytis cinerea*) of strawberry fruits demonstrated its similar effectiveness as synthetic fungicides (Switch+Signum). Overall, these studies suggest that the application of liquid vermicompost products and microorganisms can be an effective way to control pathogens and improve plant health in orchards.

EFFICIENCY OF LIQUID VERMICOMPOST BASED PRODUCT (VCMO) ON THE PRESENCE OF CERTAIN SYSTEMATIC AND PHYSIOLOGICAL GROUPS OF MICROORGANISMS IN THE RHIZOSPHERE

Changes in the abundance of certain systematic and physiological groups of microorganisms can serve as one of the indicators of the potential and effective production capacity of soil when optimizing the nutrition of agricultural crops (Hole et al., 2005). The total number of microorganisms, which is the total number of bacteria that grow on soil agar in a certain ecosystem, can be considered one of the main indicators of its biogenicity. Based on the quantitative differences in the total number of microorganisms, the properties of the soil can be assessed, as well as its potential and effective fertility (Jarak and Hajnal, 2006). Since it reacts to minimal changes in soil conditions by reducing its abundance, *Azotobacter* can also be used to indicate the productive capacity of the soil. Arthursson et al. (2006) state that the application of microbial inoculants in plant production leads to an increase in the number and enzymatic activity of microorganisms, microbial biomass, microbial diversity in the rhizosphere, resulting in an improvement in the productive capacity of the soil. However, after introducing inoculants into the soil, there is a possibility that they may affect

the indigenous microorganisms, and vice versa. The impact will depend on the interaction within and between the indigenous populations from the plant and the soil (Higa and Parr, 1994). Certain groups of microorganisms can be stimulated, others inhibited, and introduced microorganisms may not affect the structure of the indigenous population (Dobbelaere et al., 2003).

A study conducted by Pešaković et al. (2018) examined the effect of vermicompost extract (VCMo) applied in three modes: rhizobial (R), rhizobial + foliar (R+F), and foliar (F) on soil biogenicity. The results showed that VCMo had a stimulating influence on the presence of all studied groups of microorganisms (total numbers of microorganisms, fungi, actinomycetes, oligonitrophils, aminoheterotrophs, and *Azotobacter*) in the strawberry rhizosphere, with the most pronounced effect observed in the combined treatment of rhizobial + foliar. Previous research (Pešaković et al., 2013; Pešaković and Milivojević, 2014) on the effect of microbial inoculation on soil biological activity also showed a positive influence of inoculation of strawberry rhizosphere, primarily by the diazotrophic *Klebsiella planticola* TSHA-91, but also by a mixture of bacteria of the genus *Azotobacter*, *Derxia*, *Pseudomonas*, and *Bacillus*. This phenomenon is the result of the nitrogen-fixation ability of the strains contained in the biofertilizer, as well as the cumulative effect of a number of factors, such as inhibition of phytopathogen development, phytotohormone synthesis (Sukhovitskaja et al., 2004), detoxification of heavy metals, and synthesis of extracellular polysaccharides.

CONCLUSION

In general, all of these studies have shown the superiority of production systems that do not use synthetic fertilizers and pesticides, resulting in higher levels of micronutrients and health-related secondary metabolites, such as phenolic compounds. These findings suggest that the use of liquid vermicompost products (VCMo) can lead to stable yields and high-quality fruits with increased content of phenolic compounds responsible for antioxidant capacity, making it a promising approach to improving the nutritional quality and health-promoting properties of fruits. Overall, this enables the creation of an input-primary-final product system without negative consequences for human health and the environment. However, it's important to note that the effects may vary depending on the type of fruit, the composition of the vermicompost product, and the application method and timing. Further research is necessary to fully understand the potential benefits and optimize the use of VCMo in fruit growing.

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