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Preparation of organic nano-fertilizers as a growth boosting agent for mustard and lettuce

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Abstract

In Hakha of Chin state, Myanmar, mustard and lettuce are basically grown in every part of the town irrespective of the season for both at-home and out-of-home consumers. The fertilizers used by growers are mostly conventional. They do not use any fertilizers which are scientifically prepared. In this study, organic nano-fertilizers (ONFs) were systematically prepared from cow manure combined with carbon nanoparticles produced from banana peels extracts. This research was aimed to analyze physicochemical properties and to evaluate the effect of fertilization efficiency of the prepared ONFs on mustard and lettuce. They were characterized using analytical techniques such as UV-vis, FTIR, XRD, EDXRF, SEM and AAS. And the application of ONFs in agriculture was studied. As a result, prepared ONFs were found to be 430 nm of UV-vis peak, 64 nm in diameter, potential functional groups, high content of potassium and iron fertilizer, amorphous nature and homogeneity with stable coating structures of microscopic deformations. The NPK fertilizers demonstrated a balanced ratio of 34:1:70 ppm in ONFs, however; phosphorus was found in very small amounts. Most importantly, the growth percentage of mustard and lettuce with applying ONFs was found to be 97.7% and 93%, respectively. To sum up, it is hoped that these organic nanofertilizers could be used effectively as a growth promoting agent of mustard and lettuce in vegetable crops agriculture according to the explored results and findings.

Keywords: banana peels, cow manure, carbon nanoparticles, nanofertilizers

Introduction

Organic fertilizers can be found naturally in mineral sources, containing moderate amounts of essential plant nutrients. They are relatively efficient in reducing unwanted problems associated with synthetic fertilizers (Shaji et al., 2021). They do not need to be used repeatedly like synthetic fertilizers to maintain soil fertility. Their nutrients are released into the soil to maintain nutrient balance for healthy plant growth. They also serve as an important energy source for soil microbes which, in turn, enhances soil texture and plant growth. (Verma et al., 2020). Organic fertilizers are considered to be safer fertilizers than synthetic fertilizers. They are slow-release and contain many trace elements. However, inappropriate use of organic fertilizer causes excessive fertilization or lack of nutrients in the soil (Bamdad et al., 2022).

Organic fertilizers consist of various plant-originated materials, ranging from fresh or dried plant material to animal feces and litters to agricultural by-products. Depending on the different starting materials, the nutrient composition in organic fertilizers is very different, and better sources of nutrients are widely available from biodegradable materials (Barłóg et al., 2022). The content of nitrogen and phosphorus is lower to a great extent in organic fertilizers in contrast with chemical fertilizers. Moisture content affects the reduction or dilution of nitrogen and phosphorus concentrations of organic fertilizers (Sankar Ganesh et al., 2017).

Therefore, if high moisture content of organic fertilizers is transported over long distances, it becomes less effective. However, it is applicable if their use is in conformity with the production methods (Rashmi et al., 2020). The nutrient value is not having a fixed ratio in animal manures in contrast to that of agriculturally ready-made fertilizers. Manure nutrient content is much affected by factors such as animal's food, bedding material, manure lifetime, and the place where it was stored; among farms, these factors are variable depending on region and geographic scale (Das and Avasthe, 2018). On the other hand, nutrient value is found less variable in agricultural by-products in accordance with the industrial process of production (Das and Avasthe, 2018).

Recently, organic fertilizer has drawn great attention to agricultural scientists since the use of organic waste is growing fast as fertilizers. Organic fertilizers can be readily generated from plant-based wastes using composable organic matter wastes, which, in turn, can be used for soil fertility. For instance, one of organic wastes, banana peel, has gained special attention due to its noticeable components such as vitamins, flavonoids, essential amino acids, growth promoters, and potassium element. They play a key role in plant growth (Hussein et al., 2019). Moreover, banana peel has played in a very important aspect in plant cultivation, increasing seed germination rate due to high contents of potassium, amino acids (i.e., L-tryptophan), and other growth promoters (Naksing, 2020).

Furthermore, carbon nanoparticles are also providing the agriculture sector acting as nanocarriers due to its friendly environment and high surface-to-volume ratio. They can induce water and nutrients for months or years, releasing steadily as much as the plant required. So, this characteristic makes them smart nanofertilizers (Supriya et al., 2020). Many advantages have been found in nanofertilizers for the reduction of synthetic fertilizers through their target-specific strategy. They are capable of supporting nutrition to the cell, which protects the unwanted release of chemicals in human society. Soil and water pollution of synthetic chemicals can be reduced by application of nanofertilizers, which are known as sustainable fertilizer agents. Therefore, different kinds of carbon-based nanomaterials have been researched as fertilizers towards different crops (Avila-Quezada et al., 2022).

Carbon-based nanomaterials have a high resistance to stress of plants. A study confirmed that fullerenol exhibited the ability to alleviate drought stress. It was explored that fullerenol entered the root and plant leaves with a certain water supply (Shekhawat et al., 2021). Similarly, it was also found that the toxic effect of salt stress in sorghum and switchgrass was significantly decreased by prepared carbon nanoparticles. They also found that the carbon nanoparticles could enhance stages of the seed germination and young seedlings. Moreover, carbon-based nanomaterial helps in suppressing the salt stress condition due to the stress tolerance proteins in sorghum. In particular, water-soluble carbon nanomaterials are more useful in enhancing plant growth in contrast with nonfunctionalized carbon nanomaterials (Rezaei Cherati et al., 2021).

Moreover, ONFs are fertilizers that combine organic matter with nanoparticles to improve nutrient delivery and soil health. For example, they were designed from nano-humic acid fertilizers combined humic acid with nanoparticles to increase nutrient uptake and enhance soil microbial performance. They are one of green nanoparticles which originated from raw organic wastes (Soman and Balachandran, 2021). It was then prepared as nutrients supplied to the soil. They are green and environmentally friendly, which are produced from natural products. They are capable of maintaining adjustable pH levels and soil moisture, supplying plants to receive essential nutrients. Organic nanoparticles can be prepared from smaller atoms or molecules to obtain largely different capsules, polymer conjugates, vesicles, micelles, liposomes, polymersomes, dendrimers, and polymeric nanoparticles. The common natural polymers for the preparation of nanofertilizers are various gums and seeds (Soman and Balachandran, 2021).

Furthermore, ONFs can provide more efficiently in growing plants due to its slow release of nutrients to soil, which leads to better growth and increased yields. Soil fertility and structure can be improved properly by applying ONFs, increasing aggregation and porosity, enhancing water infiltration, aeration, and root penetration (Lehmann and Kleber, 2015). Moreover, organic matters act as a key of nutrients carrier for soil microorganisms, stimulating their growth and features (Masciandaro et al., 2013). In this regard, nutrient release and availability were certainly contributed to the plant's cultivation area, which further improve soil fertility and plant growth (Prasad et al., 2021). ONFs are commonly preparable from organic wastes such as plant waste, manure, and compost. For instance, NanoMax-NPK, one of nanofertilizers, is commercially available in the real market for all crops. It was designed with various organic micronutrients such as vitamins, probiotics, and organic acids (protein-lacto-gluconates) containing chelated N, P, K, O, amino acids, and organic carbon (Fatima et al., 2021).

Organic nanofertilizers derived from combining organic materials with ONFs gained unique properties including abiotic stress tolerance, high sorption capacity, amplified surface-to-volume ratio and controlled-release kinetics to directed sites (Kamaly et al., 2016). Thus, they help them give fast growth of plant in soil. These distinguishing features make it become a plant's smart delivery system of nutrients. In contrast with other common fertilizers, ONFs support delayed nutrient release, which improves nutritional management, such as reducing nutrient leaching and amplifying nutrient-use efficiency (Iqbal and Mahmooduzzafar, 2019).

Chin State is situated in the western part of Myanmar, bordering with Sagaing Region in the east, India in the west, Kachin State in the north and Rakhine State in the south. The main livelihood of the rural community of Chin State is shifting cultivation. The limited area of arable farmland on the steep hilly areas and growing population of the State shorten the shifting cultivation fallow period and lead to poor soil fertility. In addition, deforestation, climate change and irregular rainfall across the State have a negative impact on food production. In Hakha of Chin state, Myanmar, rapid climate change like drought stress in winter is a main problem, which results in significant reduction in the yield potential of major vegetables and crops. Thus, the above-mentioned occurrences greatly motivated us to do the research.

In this research, banana peels extracted-carbon nanoparticles and cow manure extracted liquids were mixed together to enhance soil fertility. Bananas (*Musa acuminata*) are grown all over the world and consumed as ripe fruit or used for culinary purpose. All parts of the banana plants have medicinal applications. This research mainly aims to support mustard and lettuce growers in Hakha. The formulated ONFs were subjected to characterize physical and chemical properties using important analytical techniques such as UV-vis, FT-IR, XRD, EDXRF and AAS. In particular, the prepared ONFs were applied as fertilizer towards mustard and lettuce irrigation, and it was noticed that the growth percentage of mustard and lettuce was increased to 97% and 92%, respectively, when applying the optimum dose of 25g/ L of ONFs in contrast to the standard zero applied ONFs. Therefore, it is anticipated that these ONFs could be used effectively as a growth promoting agent of mustard and lettuce in vegetable crops agriculture according to the explored results and findings.

The aim of this research is to prepare organic nanofertilizers (ONFs) and to assess the effect of ONFs on the plant growth percentage of mustard and lettuce. The objectives of this research were: to prepare organic nanofertilizers (ONFs); study the maximum absorbance peak of prepared ONFs; identify the characteristic peaks of functional groups of produced ONFs; characterize the nature of phase of carbon nanoparticles; investigate the elemental contents of prepared ONFs; find out nitrogen content by kjeldahl method; identify heavy metals contents and to evaluate fertilization efficiency of prepared ONFs on the growth of mustard and lettuce. Research problems were: How to prepare ONFs successfully from combining cow manure with waste of banana peels extract? Is the used method effective and what analytical techniques were used for characterization of the prepared ONFs? How to evaluate the effect of fertilization efficiency of prepared ONFs on mustard and lettuce growth?

This research provided information that wastes of banana peels and cow manures were transformed into value-added products of organic nanofertilizers. In addition, the study used an easy and fast method effectively and also this research explored cost-effective ONFs for boosting mustard and lettuce growth.

Materials and methods

Chemical and reagent

The materials used in this research were NaOH, concentrated HCl, ammonia, and KOH, which were purchased from Myanmar Chemical Mart (244/246 Konezaydan street, Yangon, 11141). All of the chemicals were analytical grade. Deionized water was used throughout the experiment.

Preparation of carbon nanoparticles

Firstly, the fresh banana peels (300 g) were washed well with tap water to remove the dust and impurities adhered to the outer surface. They were chopped into small pieces and grinded using domestic blender until viscous slurry was obtained. Then, the fresh slurry of banana peels was obtained. Those banana peels liquids were filtered using Whatman filter paper. The clear liquid was collected. Secondly, the clear liquid was placed on hotplate magnetic stirrer for 2 hr at 80 °C under vigorous stirring. Then, 20 mL of the ammonia solution was added into the mixture solution and stirred for 1 hr again. Finally, homogenous mixture was obtained and 250 mL of the homogeneous mixture was put into laboratory oven at 190 °C for 2 hr. Then, the temperature was cooled down. Solid black crystal particles were obtained. The process of filtration, separation and centrifugation were done to optimize carbon nanoparticles for further analysis (Hano and Abbasi, 2021).

Preparation of cow manure extract

The fresh and wet cow manure (1000 g) was collected in the clean pot. After that, it was to keep the air dry in the laboratory room for 3 weeks and grinded into very small pieces. Then, the powders of fine cow manures were boiled to obtain viscous slurry and 0.5 M of potassium hydroxide solution was added into the extracted cow manure with constant stirring under heating at 80 °C on hotplate. After the liquid of the cow manure solution was nearly getting dried, the temperature was cooled down. Dried particles were obtained for further use (Hano and Abbasi, 2021).

Preparation of organic nanofertilizers

ONFs were synthesized through the following procedure. To the reaction flask, 100 g/ L of carbon nanoparticles solution was added into 200 g/L of cow manure dried extract and continued reaction with stirring for 30 min. Then 100 mL of deionized water was added by means of drop wise. The reaction was further allowed to continue under stirring for 2 hr at 80 ℃ and centrifuged at 3000 rpm for 20 min to obtain homogeneous clean mixture solution. The pH of homogenous clean mixture was adjusted at 6.5. After that, the pure concentrated solution of ONFs was obtained and it was successively heated at 100 °C in oven until it was getting dried. Finally, the dried powder of ONFs was collected and kept in bottle for further characterization and application.

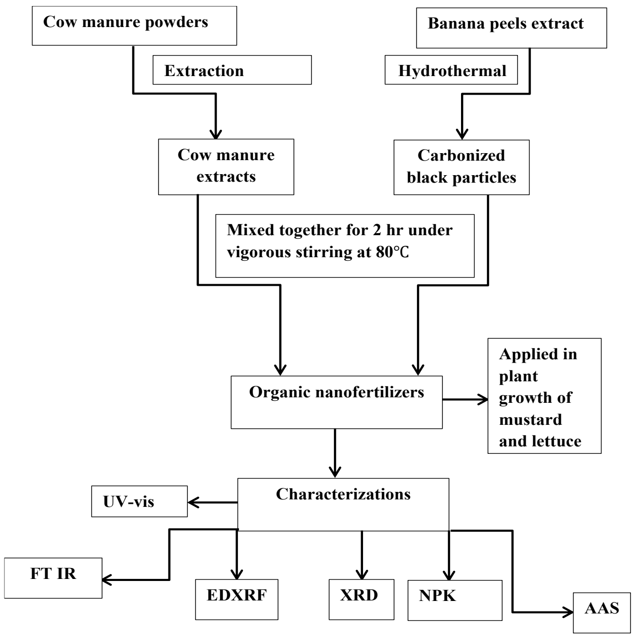

Figure 1. The schematic diagram of research flow chart.

Characterization of organic nanofertilizers

The present study described the synthetic process of ONFs. The prepared ONFs were further characterized by using UV-vis, FTIR, EDXRF, XRD, SEM and AAS analysis. Moreover, nitrogen contents in ONFs were done by kjeldahl method. Moreover, the absorbance peak of ONFs was carried out using UV-vis spectrophotometer of LAMBDA™ 265 (PerkinElmer). The FTIR analysis was used to identify the functional groups in ONFs using FTIR spectrophotometer (IRPrestige-21, Shimadzu, Japan) within the range of 400-4000 cm^{-1}. The elemental analysis of ONFs was determined by using EDXRF (Shimadzu EDX-700 Spectrometer). The XRD studies were used to give the information of nanosize of the prepared carbon nanoparticles using Rigaku Multijlex 2KW Powder X-ray, Akishima, Tokyo, Japan in the Universities' Research Centre of Yangon University (URC-YU). The morphology and structural distribution of ONFs were analyzed by SEM technique using FESEM, Zeiss Ultra60 in the Department of Chemistry, Yatanapon University, Myanmar. The elemental contents in ONFs were studied using atomic absorption spectrophotometer (Nov AA 400) technique.

Application of organic nanofertilizer in agriculture

Seeds of two vegetative crops (mustard and lettuce), 10 seeds of each crop, were used, and the seeds were cultivated in the collected soil from the research site at Hakha University, Chin state, Myanmar with its physical properties and composition of sand 25%, silt 37% and clay 38%. The seeds were irrigated in the taken soil and watered them twice a day under humid subtropical climate. And different concentrations (0, 5, 10, 15, and 25 g/L) of prepared ONFs solutions were applied on mustard and lettuce plants, respectively (Photo 1). Afterward, data concerning with growth percentages were recorded every 10 days for 2 months and variances were analyzed according to the Duncan formula (Duncan, 1955).

The equation for the growth percentage formula is

$$= \frac{S2-S1}{T} \times 100\ \%$$

Where, S1 = first measurement, S2 = second measurement and T = the number of days between each

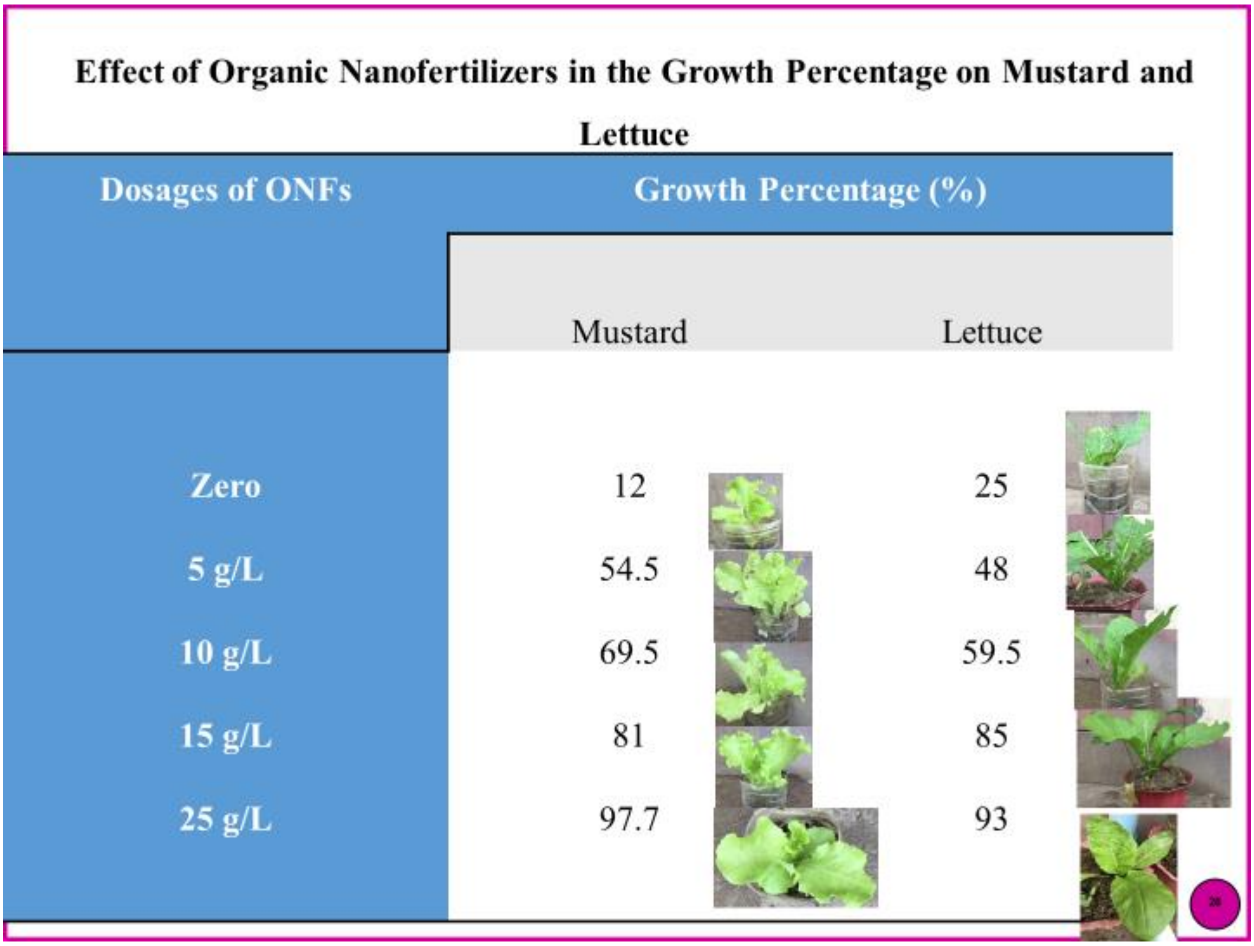

Photo 1. Effect of organic nanofertilizers in the growth percentage on mustard and lettuce.

Results and discussion

Preparation of organic nanofertilizers

Organic nanofertilizers (symbolized as ONFs) were successfully prepared as shown in Figure 1. Firstly, for obtaining banana peels extracts, the banana peels extracts were prepared by cutting, chopping, grinding and filtrating by using a common tap water filter. Secondly, the cow manure extracts were prepared by heating it to get slurry. And each 20 mL of ammonia and potassium hydroxide was used as extracting agents at optimum operating conditions. Finally, the ONFs were produced from the mixing of dried extracts of banana peels and cow manure extracts by using hydrothermal method. The prepared ONFs were collected for further analysis as shown in Fig. 2(b).

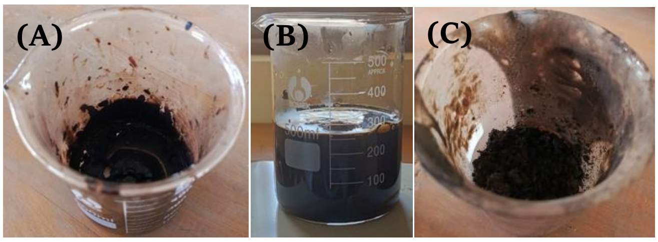

Figure 2. (a) The banana peel extracts, (b) The cow manure extracts and (c) The prepared ONFs.

Physicochemical properties of ONFs analysis

After preparing ONFs, the results of physicochemical characteristics were studied by using of UV-vis, FTIR, EDXRF, XRD and SEM techniques in order to verify the structural formation of produced organic nanofertilizers. NPK contents of ONFs were also evaluated. Moreover, the results of AAS were analyzed for assessing heavy metals contamination in prepared ONFs.

Firstly, the absorption of prepared organic nanofertilizers (ONFs) was recorded by UV-vis spectrophotometry to determine the maximum wavelength absorbed by the sample. The UV–Vis spectrum showed typical absorption peaks at 370 nm and 430 nm, respectively. From this analysis, the first peak at 370 nm is depicted by aromatic and/or unsaturated compounds with an absorption bonds of C=C, C=O and N≡N. While the second absorbance peak at 430 nm reflects the humification of organic matter, indicating the presence of highly humified materials with a high degree of condensed aromatic groups as shown in Fig. 3, which is in correspondence with other reports of organic fertilizers (Biyada et al., 2020).

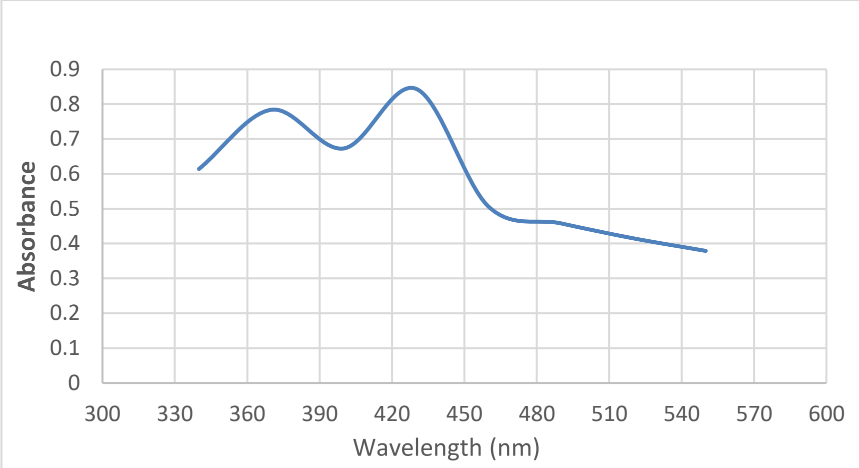

Figure 3. The UV-visible peaks of organic nanofertilizers.

Moreover, functional groups of produced ONFs were confirmed by FTIR to identify important functional groups contained in the prepared ONFs at wave numbers of 400-4000 cm^{-1}. Its FTIR spectrum was reported in Fig. 4. According to the obtained results, the peak at 3256 cm^{-1} exposing a wide and strong absorption band, this can be related to the hydroxyl (OH) and amine (NH) group. Moreover, the emergence of the absorption peaks at 2919.20 and 2848.1 cm^{-1} in the ONFs, which were only faintly noticeable in the FTIR spectrum of ONFs, could be assigned to the symmetric and asymmetric C–H stretching vibration. The signal at 1573 cm^{-1} respecting to C=O bond of the carboxylic group and the band at 1537 cm^{-1} revealing the medium peak which corresponded to N-O stretching groups, are related to the presence of nitrate in the peak, which organic nanofertilizer possessed. Moreover, the peaks at 1259.70 cm^{-1}, 1033.20 cm^{-1}, 777.68 cm^{-1} and 522.20 cm^{-1} were assigned the C–O stretch, PO_4^{3-} asymmetric stretching group, the carbonate (CO_3^{2-}) group, and the presence of Fe–O bending groups due to the interaction of COO-Fe, which was in correspondence with other study (Sebastian et al., 2023).

Furthermore, energy dispersive X-ray fluorescence (EDXRF) was used to evaluate the composition of elements containing in prepared organic nanofertilizers (ONFs). The peaks were shown in Fig. 5. The presence of significant peaks for potassium revealed the formation of potash-rich organic nanofertilizer which was a great deal of potential for promoting high yields for crops. According to Figure 6, the major elemental components of K (53.173%), Cl (14.784%), Ca (13.327%), Si (7.836%), Fe (5.292%) S (1.524%) and Al (1.048 %), respectively. Furthermore, other trace amounts of P, Mn, Ti, Zn, Br, Cu, Sr, Rb and V were detected to be 0.987, 0.935, 0.621, 0.128, 0.104, 0.095, 0.068, 0.067 and 0.010%, respectively. In particular, the major contents of potassium can provide for yielding high value fruit and vegetable farming that increase the crops quality. And calcium is also necessary for forming seeds and fruit and helps protect plants from disease and pests. Moreover, the concentration of silicon in fertilizer has known to improve plant growth and yield especially under biotic and abiotic stresses. The content of iron in fertilizer also plays a key role in manufacturing process of chlorophyll, and it is required for certain enzyme functions (Morya et al. 2022). Sulphur is also an essential plant mineral for helping protein synthesis, enzyme activation, and production of vitamins and hormones. Moreover, trace elements are administered to the plant in various nutrients, including manganese (Mn), zinc (Zn), copper (Cu), strontium (Sr), rubidium (Rb), and vanadium (V). The combination of major elements and these trace elements is important to achieve continuous growth and healthy growth of plants (Kaur et al. 2023).

XRD also provides detailed information about structural information of nanomaterials such as lattice parameters, phase nature, and crystalline structure. In Fig. 6, the XRD pattern of organic nanofertilizer showed its many amorphous shoulder peaks which were not detectable accurately the particle size. It was likely due to the given low temperature of the sample. Nevertheless, the prepared organic nanofertilizer was confirmed its amorphous nature with defect of crystallinity.

Finally, SEM was applied to first determine the structure and morphology of the prepared organic nanofertilizer. The images illustrated the structure of compost that can be used to recognize the layout structure of agglomerated organic nanoparticles produced from combining cow manure and nanoparticles from banana peels. The images indicated that the compost was made up of overlapping layers of organic cow manure particles and nanoparticles which were slightly fluorescent in the top layer. Particles of cow manure and nanoparticles could connect roughly and randomly to homogeneity each other that brought with stable coating structures of microscopic deformations, which have a better nutrient enrichment (Tarafder et al. 2020). This phenomenon is conducive to improving the nutrient enrichment activity for promoting crops growth, especially mustard and lettuce. Moreover, Image J software was utilized to calculate the particle size distribution by measuring several hundreds of particles from the SEM image. According to the calculation, the particle size of prepared organic nanofertilizer was found to be in the range of 64-67 nm as indicated in Fig. 7.

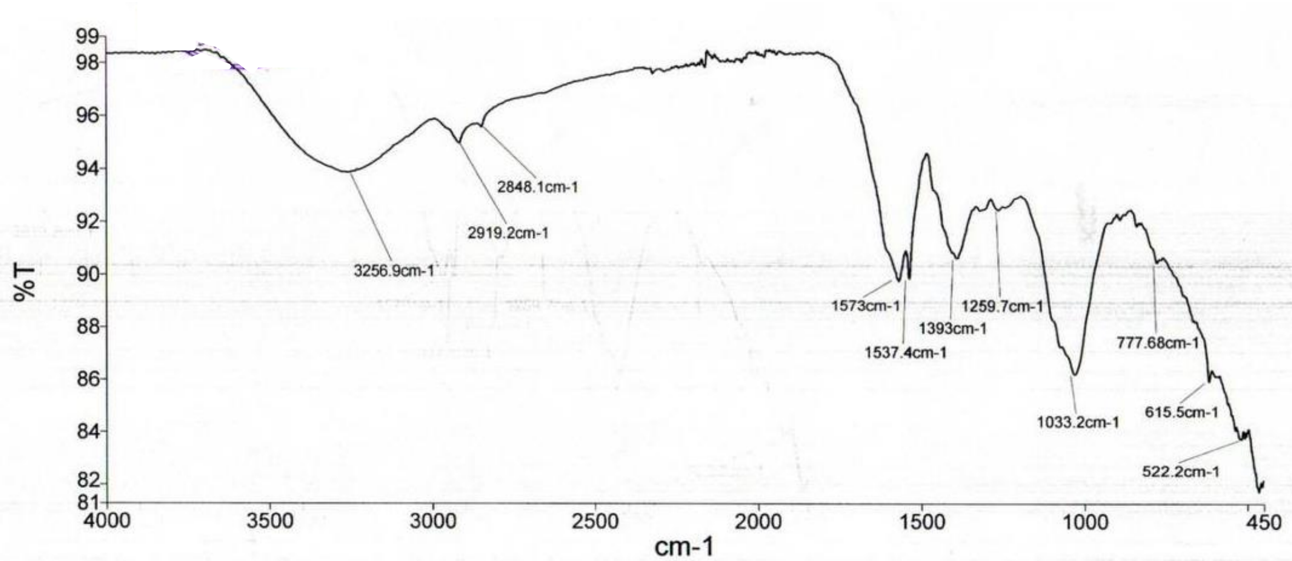

Figure 4. The FTIR spectrum of prepared organic nanofertilizers.

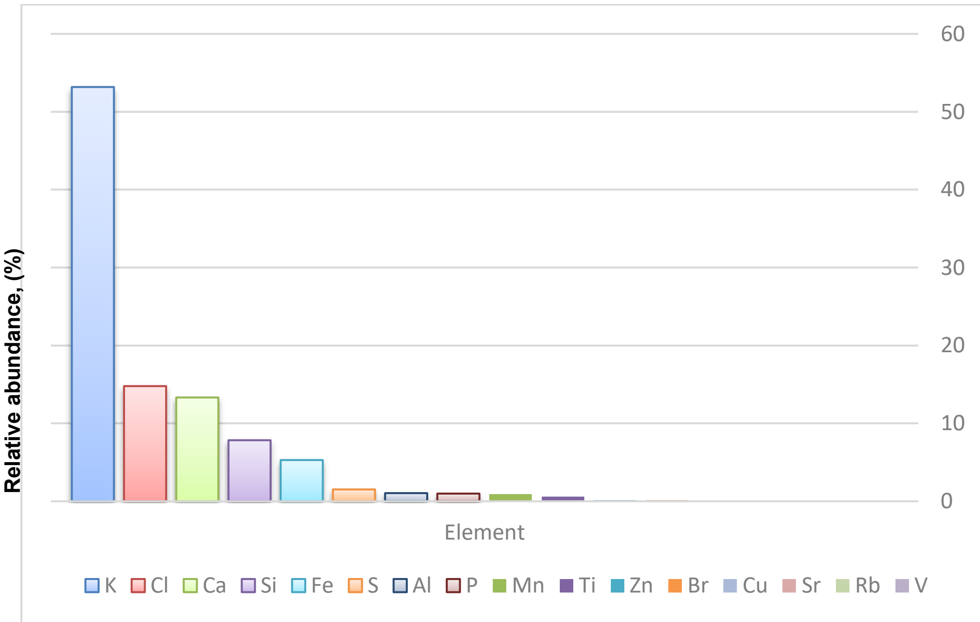

Figure 5. The chart of elemental composition in organic nanofertilizers.

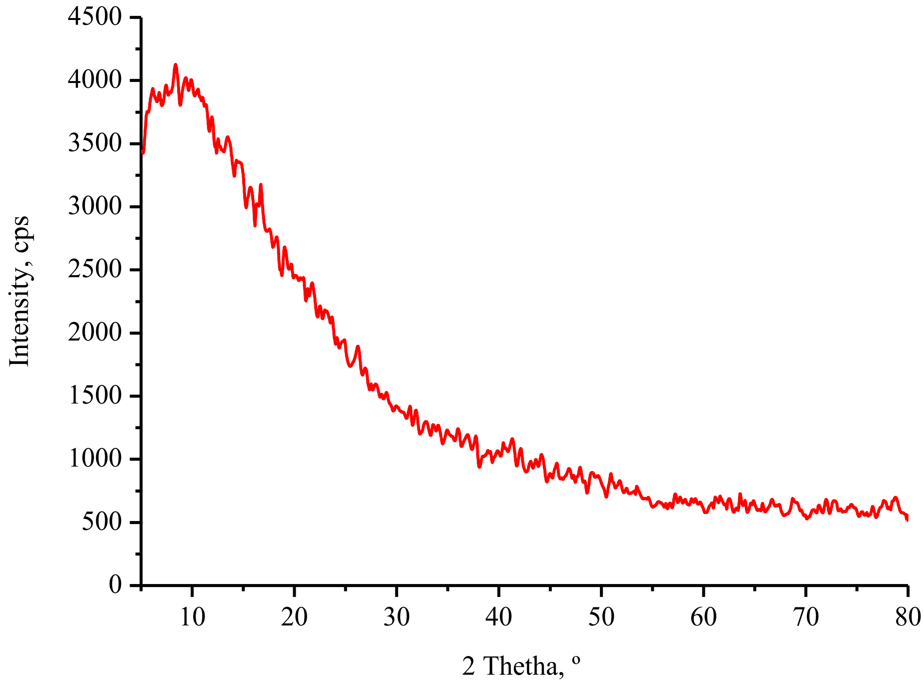

Figure 6. The XRD peaks of organic nanofertilizers.

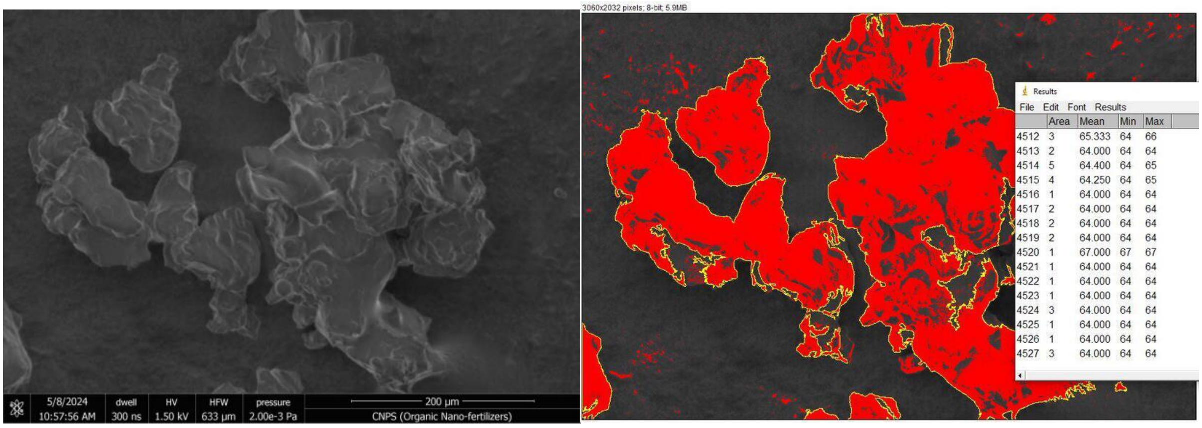

Figure 7. The particle size of organic nanofertilizers reported by Image J software.

Analysis of NPK fertilizers value in prepared ONFs

The NPK ratio represents the percentage composition by weight of prepared fertilizer, each of the percentage composition of N as nitrogen, K as K_2O and P as P_2O_5. As shown in Table (1), the nitrogen, phosphorus and potassium concentrations were found to be 10365 ppm (1.04%), 298.52 ppm (0.03%), and and 20894.7 ppm (2.09%), respectively. The nutrient composition expressed as a ratio on a ppm basis was N:P:K = 34:1:70 ppm in prepared organic nanofertilizers. According to the above-mentioned ratio, potassium content was significantly higher than those of nitrogen and phosphorus. As a result, higher potassium content in these ONFs can help the overall functions of the plant perform correctly (Jiaying et al. 2022). As a second large amount of nitrogen in this prepared ONFs can support vigorous, leafy growth and rich green color. Without enough nitrogen, plants turn pale and growth slows. However, phosphorus is a very small amount in contrast with potassium and nitrogen contents in prepared ONFs. Phosphorus is largely responsible for root growth and flower and fruit development. As a deduction, the organic nanofertilizer prepared in this research would be suitable for all vegetable crops because of significantly optimal content of potassium in prepared ONFs.

Table 1. NPK ratio contents in prepared organic nanofertilizers

Sample	N (ppm)	P (ppm)	K (ppm)
ONFs	10365	298.5200	20894.7000

Determination of organic nanofertilizer by atomic absorption spectrophotometer

Atomic absorption spectrometry (AAS) is a very sensitive method of elemental analysis, allowing the determination of metals in a variety of sample at the picogram level. In particular, some toxic heavy metals content in the prepared organic nanofertilizer has been also determined by the method of atomic absorption spectroscopy (AAS) in this research. According to Table (2), potassium is significantly the highest content of 989.4740 ppm in average value in the prepared organic nanofertilizer, there was evidence that was mostly due to the banana peels extract. The high content of potassium supplied the plant with enough of the nutrient to help the plant become hardier so that it may withstand periods of stress usually occurring in the summer and winter seasons. Furthermore, the iron was found to be 41.279 ppm in average in the sample and it was very important for the growth and health of the plant. It also plays an essential role in metabolic processes such as energy transfer, respiration, and photosynthesis. Iron helps carry important elements through a plant's circulatory system. Moreover, sodium was found to be the third most abundant amounts of 12.8790 ppm in these ONFs. It was not considered an essential plant nutrient, however; certain crops benefit from applications of sodium for sugar beet and fodder beet, grassland and other root crops. Zn was also found as the allowable level in the prepared ONFs. Zinc can also be used in the formation of chlorophyll and some carbohydrates. And it helps plant tissue withstand cold temperatures. The results of other toxic heavy metals such as Cu (copper), Pb (lead) and Cd (cadmium) concentrations were under the maximum allowable level according to the standard of the United State Environmental Protection Agency (USEPA) (Khatun et al., 2022).

Table 2. Elemental contents in prepared organic nanofertilizer

No.	Sample	Met. Time	Cu (ppm)	Zn (ppm)	K (ppm)	Fe (ppm)	Pb (ppm)	Cd (ppm)	Na (ppm)
1	ONFs	X1	0.835	3.114	971.076	41.695	0.703	0.04	12.85
		X2	0.818	2.989	1016.247	41.261	0.761	0.04	12.666
		X3	0.773	2.808	981.099	41.279	0.644	0.058	13.121
		Average	0.8087	2.9703	989.4740	41.4117	0.7027	0.0460	12.8790
		USEPA	10.00	45.00			61.50	10	

Note: Maximum contaminant level in fertilizer indicated by US EPA

Cu = 10.00 ppm, Zn = 45.00 ppm, Pb = 61.50 ppm, Cd = 10 ppm

Application of ONFs in agriculture

On applying ONFs in mustard and lettuce irrigation, it was noticed that the plant growth increased compared with the zero sample as indicated in Table 3. The results may be referred to the high content of nutrients elements such as nitrogen, phosphorus and potassium. The authors investigated other plant growth promoters, for example, as indicated in EDXRF result, iron, silicon and zinc could regulate the plant growth, metabolism of plants under water stress, and increasing physiological availability of water and nutrients, besides the effect of them on increasing growth percentage. As shown in Table 3, it was found that the percentage growth of mustard demonstrated 12%, 54.5%, 69.5%, 81% and 97.7% when dosages of nanofertilizers such as 0 g/L, 5 g/L, 10 g/L, 15 g/ L and 25 g/L were applied. At the same time, the percentage growth of lettuce demonstrated 25%, 48%, 59.5%, 85% and 93% when dosages of nanofertilizers such as 0 g/L, 5 g/L, 10 g/L, 15 g/ L and 25 g/L were applied. Then, it was found that the 25g/L of prepared organic nanofertilizer liquid was the best optimum for mustard and lettuce growth. Therefore, the 25 g of the prepared ONFs was chosen as the optimum value for cultivation of vegetable crops, especially for mustard and lettuce as shown in Fig. 8.

Table 3. Effect of organic nanofertilizers in the growth percentage on mustard and lettuce.

Dosages of ONFs	Growth Percentage (%)	
	Mustard	Lettuce
Zero	12	25
5 g/L	54.5	48
10 g/L	69.5	59.5
15 g/ L	81	85
25 g/L	97.7	93

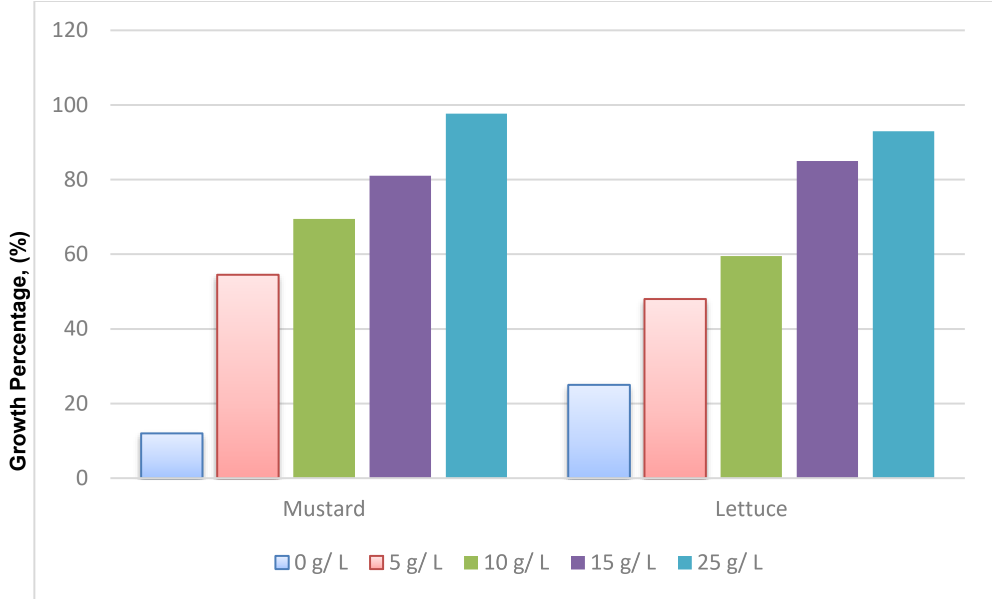

Figure 8. The chart of the growth percentage of mustard and lettuce under applied amount of ONFs.

Table 4. The nanosize in comparison of other studied nanofertilizers with present study.

Extracts	Nanoparticles	NanoSize	Ref.
Ganoderma lucidum extract	Zinc Oxide nanoparticle	-	Sedefoglu et al., 2022
Microalgae	Silver nanoparticles	13-31 nm	Terra et al. 2019
Using microalgal algal extract	Iron-oxide nanoparticles	76.5 nm	Win et al., 2021
Using Lactobacillus casei Subsp. Casei	Copper-oxide nanoparticles	30-75 nm	Kouhkan et al., 2020
Acidophilus, Lactobacillus casei, and Bifdobacterium sp.	Se nanoparticles	100-500 nm	Eszenyi et al., 2011
Cow manure extract	Carbon nanoparticle	64-67 nm	Present study

Conclusion

In summary, the low-cost organic nanofertilizer was successfully prepared from the starting materials of cow manure and banana peels by extraction and hydrothermal methods in this study. Moreover, the starting materials are low-cost and effective. The reaction is not tedious and simple. According to the findings of prepared ONFs, it was found that ONFs possess highly humified organic matter, some important functional groups, 64 nm in size distribution, rich in potassium better nutrient enrichment, favorable contents of nitrogen and non-toxic behavior. Most importantly, the prepared ONFs exhibited satisfying growth percentage of mustard (91%) and lettuce (92%), respectively, while applying 25g/L dose of the sample, in contrast to applying the standard zero dosage of ONFs. Thus, the prepared ONFs demonstrated better growth of sample dosage (25g/L) at adjusted pH 6.5. To sum up, it is anticipated that the prepared ONFs could be used effectively as a growth promoting agent of mustard and lettuce in vegetable crops agriculture according to the results and findings.

Author Contributions
Yaung Kwee: Conceptualization, investigation, methodology, and writing, review, and editing the manuscript.
Van Rem Cawi: Laboratory work.

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Conflict Interest
The authors declare that they have no known competing financial interests that could have appeared to influence the work reported in this research.

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Priprema organskih nano-đubriva kao sredstva za podsticanje rasta senfa i zelene salate

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Apstrakt

U Haki u državi Čin, Mjanmar, senf i zelena salata se gaje u svakom delu grada, bez obzira na godišnje doba, kako za kućnu tako i za vankućnu upotrebu. Đubriva koja koriste uzgajivači su uglavnom konvencionalna. Ne koriste nikakva đubriva koja su naučno pripremljena. U ovoj studiji, organska nano-đubriva (ONF) su sistematski pripremljena od kravljeg stajnjaka kombinovanog sa ugljeničnim nanočesticama proizvedenim od ekstrakata kore banane. Cilj ovog istraživanja bio je da se analiziraju fizičko-hemijska svojstva i da se proceni efekat efikasnosti đubrenja pripremljenih ONF na senf i zelenu salatu. Karakterisana su korišćenjem analitičkih tehnika kao što su UV-vis, FTIR, XRD, EDXRF, SEM i AAS. Takođe je proučavana primena ONF u poljoprivredi. Kao rezultat toga, utvrđeno je da pripremljena ONF imaju UV-vis pik od 430 nm, prečnik 64 nm, potencijalne funkcionalne grupe, visok sadržaj kalijuma i gvožđa u đubrivu, amorfnu prirodu i homogenost sa stabilnim strukturama premaza mikroskopskih deformacija. NPK đubriva su pokazala uravnotežen odnos sadržaja od 34:1:70 ppm u organskim nanođubrivima (ONF), međutim; fosfor je pronađen u veoma malim količinama. Najvažnije je da je procenat rasta senfa i zelene salate uz primenu ONF-a bio 97,7% i 93%, respektivno. Ukratko, nada se da bi se ova organska nanođubriva mogla efikasno koristiti kao sredstvo za podsticanje rasta senfa i zelene salate u poljoprivredi povrtarskih kultura, prema istraženim rezultatima i nalazima.

Ključne reči: kore banana, kravlji stajnjak, ugljenične nanočestice, nanođubriva

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Lichens and epiphytes as sentinel organisms for the determination of the water balance in forest ecosystems of South Tyrol

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ABSTRACT

Lichens and fog are one of the primary components of the water balance in the coniferous forest, which affect the hydrological cycle in the ecosystem. This paper investigates the role of fog during mixed rain-fog situations in an old-grown forest with presence of lichens – *Evernia divaricata* and *Pseudevernia furfuracea*. Fog represents a form of low-lying cloud and is greatly impacted by geographic setting, wind conditions, and water streams. Using methods of environmental statistics, the effect of forest stand age, fog, and abundance of lichens on the water balance were investigated. The results demonstrated that the presence of lichens and fog are related to humidity and maintains water balance in the forests of South Tyrol. Specifically, the interception was found to play a dominant role in the precipitation and evapotranspiration partitioning, especially in the older stand, where it was enhanced by lichens. Using modelling techniques, this study proved the importance of fog and lichens for the boreal forests ecosystems: fog transfers water from the atmosphere to the terrestrial surface, and lichens plays a significant role in increasing humidity in old stands.

Key words: lichens, remote sensing, image processing, satellite image, scripting language

Introduction

In a hydrological context, water balance refers to the volume of water inflows, outflows, and storage changes within a defined ecosystem over time (Skalova et al., 2022; Bréda et al., 2006). Changes in water balance components can affect forest ecosystem through water evaporation, precipitation or interception by plants. Lichens are capable of storing significant amounts of water. This capacity is related to the nature of lichens as poikilohydric organisms (Kumari et al., 2024). The internal water content in lichens fluctuates depending on the external hydrological and environmental settings, because these plant do not actively regulate their hydration (Nash et al., 1990). With this regards, epiphytes can intercept rainfall and change the amount and chemical composition of throughfall water. Such regulatory mechanism affect water balance and microclimate of forest ecosystems.

Lichens are essential to ecosystems because they help build soil, cycle nutrients, and are used in bio-monitoring projects to evaluate the sustainability of ecosystems, including air quality (Joly et al., 2010; Rodríguez-Quiel et al., 2019; Dunford et al., 2006). Lichens, while not directly performing transpiration, contribute significantly to evapotranspiration through their ability to absorb and release water and thus determine ecological processes (Asplund and Wardle, 2017). Evapotranspiration is an important process which includes evaporation as a physical phase and transpiration as a biological phase. Such mechanism refers to the phenomenon of water evaporating from the Earth's surface into the atmosphere and is crucial for the balance of forest ecosystems (Wang et al., 2014; Taheri et al., 2025; Benyon et al., 2015). As a mechanism for storing and releasing water, lichens affect local water cycle and may have an effect on the surrounding flora in the coniferous forests (Asplund & Wardle, 2013). Nevertheless, there is a lack of study on how lichens react physiologically to water exposure in their natural habitats. The majority of the previous studies were focused on water accumulation in lichens (Harris et al., 2018; Potkay et al., 2020) or trees that have artificial environments, such as transplanted lichens (Holopainen, 1984; Garty et al., 1998).

Lichens response to hydrological effects in the subalpine ecosystems is not studied sufficiently. At the same time, statistical methods are important to analyse data for revealing trends in environmental processes (Dale & Fortin, 2002; Duckworth, and Stephenson, 2002; Lemenkova, 2022a; Wang et al., 2010). Because of the growing interest in mathematical and cartographic methods in Earth sciences, long-tested methods (statistical, comparative, cartographic) are being actively used in environmental sciences (Lemenkova, 2022b, 2023a, 2023b). In order to close the existing knowledge gap and application of statistical methods to lichen research, we studied lichens from South Tyrol, mountainous region of Italy, and looked at whether physiological indicators like water content, growth of trees with different heights, and age could be used to identify differences in ambient. In this way, current research contributes to the environmental analysis of lichen, their capability to held water and distribution on trees with various age and height (Caruso and Thor, 2007).

In aged forests, lichens continue to grow on old plants and increase interception capacity, when the stand leaf area index has already reached its maximum (Ahmadjian, 1993; Yang et al., 2023; Lemenkova, 2025a; Tsai & Kuo, 2012). The physiological response of lichens to water content varies depending on where they are collected: water content is significantly impacted by tree height and precipitation (Kumar et al., 2022). Higher contents of water are linked to the extent of rainy days in lichens. Since natural lichens can detect even little changes in ambient water concentrations, our study demonstrates the usefulness of lichens as bioindicators (Gannutz, 1968; Djupström et al., 2010). This study shows the potential of lichens for further ecology research by showing which physiological variables might be employed as indicators of particular tree traits – height, age, leaves (Avalos et al., 1986).

Since lichens are sensitive to water and tree health, they are commonly acknowledged as bioindicators of environmental sustainability (Jairus et al., 2009; Carter et al., 2017). As a result, their distribution and health can be utilized to track the forest stands' air quality. Prolonged humidity is a major environmental stressor that damages trees and ecosystems. It builds up in lichens and alters their physiology in a number of ways. Fine particles containing water can be deposited on the surface of lichens and in the intercellular spaces of their medulla, where they can stay unchanged for extended periods of time.

In this work, we aimed to answer the following questions: (1) What is the contribution of fog and lichens to the water balance of the coniferous forests? (2) How does the presence of epiphytes affect the water supply to the boreal coniferous ecosystems?

Materials and Methods

This paper aimed to better understand the potential influence of fog and tree age and the associated abundance of lichens on the water balance. To estimate the water balance, we measured the relative contribution of the water components in the balance at the catchment level. Water storage capacity of lichens was investigated using Eddy covariance technique. This technique is used to quantify the energy and gas exchange between the atmosphere and the Earth's surface (Burba, 2022). In this study, the turbulent air flows (eddies) were measured as and scalar entities using sonic anemometers and gas analyser to calculate fluxes. Using Eddy covariance, the values of fluxes of the environmental properties are obtained as high-frequency wind and scalar atmospheric data series, including data on gas and energy fluxes, as described in previous studies (Bond-Lamberty, 2018; Dias et al., 2007; Guenther and Hills, 1998). Local trees and spruces were characterised by an almost columnar shape (Marcolla et al., 2005). This shape and the high leaf area index (LAI) (4.74 ± 0.88 for the 200-year-old stand and 4.65 ± 0.86 for the 30-year-old stand, as measured by hemispherical images), created peculiar microclimatic conditions within the crown, possibly favouring lichen growth, Figure 1.

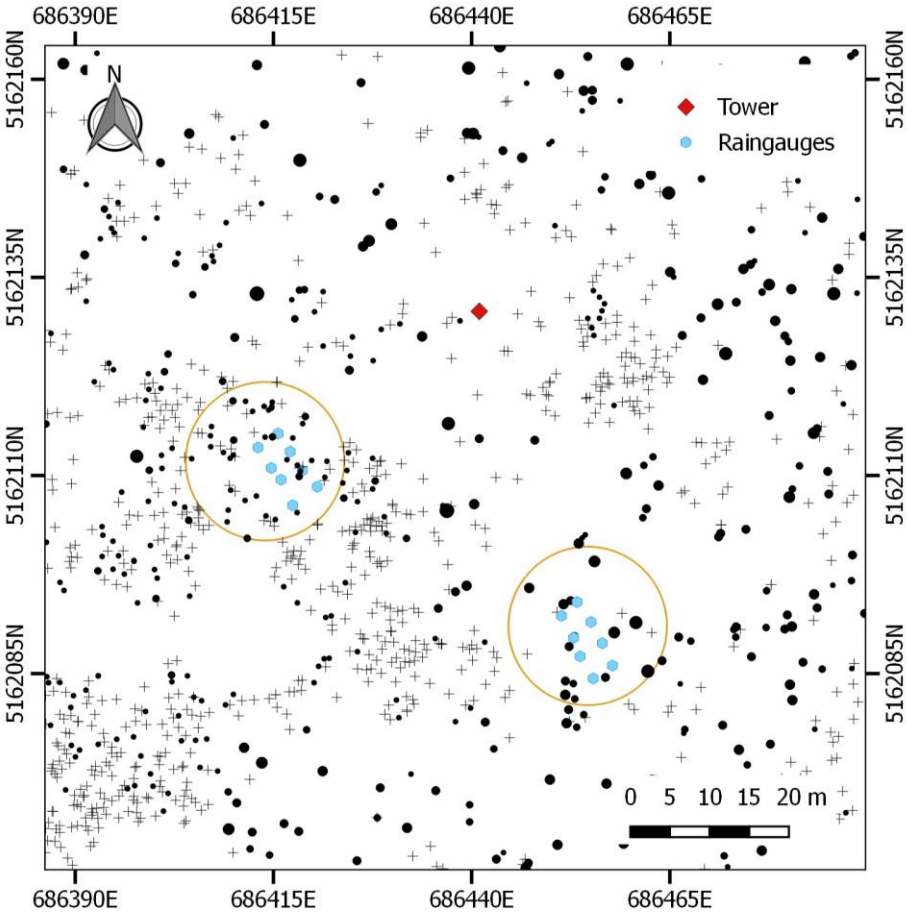

Figure 1. Map with topographic location of trees with lichens in the measurement set

The soil has developed above a layer of glacial till, with a depth of approximately 1 m, placed on top of a porphyry bedrock. The soil was classified as Haplic Podzol according to the FAO soil taxonomy (FAO, 1998) and on average consisted of 49% sand, 39% silt, and 12% clay. To characterize the growing conditions for lichens, we measured some meteorological variables inside the forest. As expected, the relative humidity was higher within the forest, especially at 15 m, where VPD was lowest (Table 3). The temperature was not significantly different outside and inside the canopy, which correlates with previous research (Campbell and Coxson, 2001). The highest temperature and consequently highest VPD was measured at 23 m but the differences were within the error range. Standard deviations were high, as they were calculated over time, thus included daily and seasonal variability, and were the highest within the canopy at 23 m. Therefore, the presence of lichens is likely more related to humidity than to temperature.

Results and Discussion

The results shown that forest stands with older trees (≥200 years) have higher interception capacity and lower throughfall rates than younger stands in part due to the presence of epiphytic lichens in older forest. Besides, fog plays an important role in the water balance during numerous days with mixed precipitation, maintaining for several days a high relative humidity inside the dense coniferous crowns composing the forest, Table 1. This helped the trees to maintain a large amount of leaf area, and the filamentous lichens to grow in the upper part of the canopy (branches, all trunk, or their cumulative variable), Figure 2. These two features led to a large capacity of the crown, particularly in the mature coniferous forest, to intercept liquid precipitation, release only a small amount of precipitation to the soil and eventually to runoff, sustaining local ET with an associated reduction of the sensible heat flux.

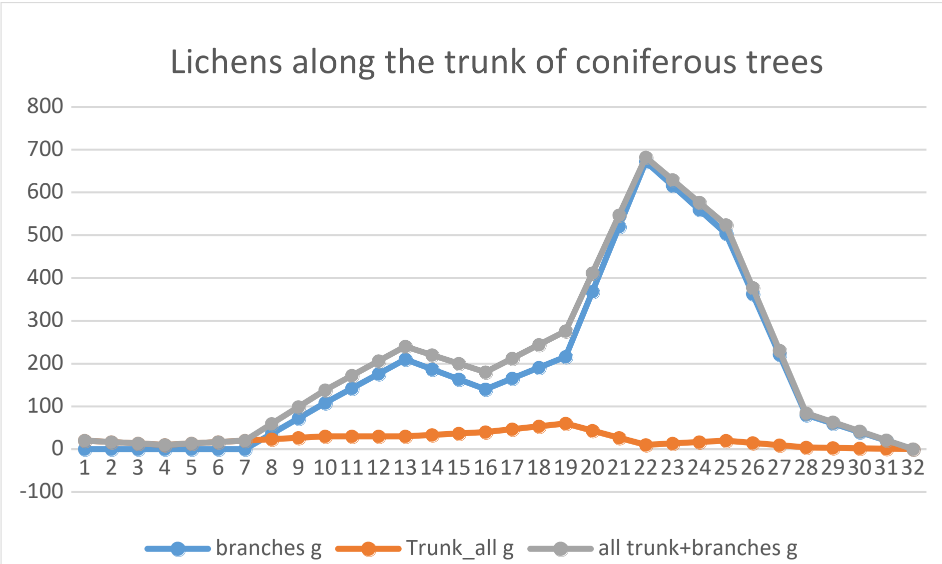

Figure 2. Distribution of lichens along the tree trunk of the coniferous forests

The philological characteristics were obtained and summarised in Table 1. Due to their protected status, we did not conduct a systematic survey on lichens, but we collected them from one fallen tree representative of the old forest. This tree held 7.26 kg of dry lichens; 0.71 kg (10%) of them were located on the trunk and the rest on the branches with the highest concentration located at 22 m above the soil at approximately ¾ of the tree height (Lemenkova, 2025c). Once rewetted, the lichens reached a fresh weight of 19.63 kg, thereby holding 12.37 kg of water; however, they lost ⅔ of that water again within two days when air-dried.

Table 1: Characteristics of lichens and their capacity of water retain

Total lichens dry weight in g on a 52 cm diameter tree	6544
Total lichens fresh weight in g on a 52 cm diameter tree	19632
Total water held by lichens in a 52 cm diameter tree (kg)	7,276E-15
Water mm (or kg m^{-2}) held by lichens	2,91E-12
Water availability as annual liquid precipitation events	200
Total intercepted water by lichens (mm y^{-1})	5,821E-14

The abundance of lichens in the old but not in the young stand could be a major reason for lower throughfall rates indicating a higher interception capacity in the old stand, even though leaf area index (LAI) was similar in both stands. Indeed, rainfall partitioning processes by trees differs as throughfall processes in response to rainfall depth, leaf type and phenological periods, bark texture, and LAI (Beidokhti and Moore, 2021). The water storage capacity of the lichens was assessed in spring from a tree falling in the previous winter, with a tree height of 28 m and a DBH of 53 cm which is representative of the old stand (Lemenkova, 2025b).

Table 2: Lichens in the net

Lichens in the net	ID Nr.	With net, saturated of water (g)
29.06.20	h12	286
29.06.20	h22	142
30.06.20	h12	126
30.06.20	h22	96

To estimate the lichen weight, the tree was divided into 3-m sections. In each section, all the branches were counted and all lichens present above a single randomly selected branch were collected, together with the lichens growing on half of the main stem. In the laboratory, the lichens were first wetted until water saturation and then weighed to assess the fresh weight. They were then dried in an oven at 45 °C until a constant weight was achieved and then weighed (Sartorius Entris 2202, Göttingen, Germany) to assess their dry weight, Table 2. The role of lichens in the water balance was assessed by measuring air temperature and humidity inside the crown and the water storage capacity of the lichens at different heights of trees (m), Table 3. To this end, a combination of temperature sensors and hygrometers was integrated into a single device for data capture using instruments designed for environmental monitoring.

Table 3: Characteristics of the measured occurrence of lichens on trees with different heights. Lichens weight is given on the sampled branch; number of branches is estimated for 1 m vertical section; weight (g) of lichens is calculated on 1 m vertical section

Height of trees (m)	ID Nr.	0.1 m section half-circumference	Lichens weight on 1 m section	Trunk_all	Lichens weight	No of branches	Weight (g) of lichens	Branches_all
			g	g	g			
0.9-1	0	1	20	20	0		0	0
	1			16,66			0	0
	2			13,33			0	0
3.9-4	3	0,5	10	10	0		0	0
	4			13,3			0	0
	5			16,66			0	0
6.9-7	6	1	20	20	0		0	0
	7			23,33				36
	8			26,66				72
9.9-10	9	1,5	30	30	12	9	270	108
	10			30				142
	11			30				176
12.9-13	12	1,5	30	30	14	15	450	210
	13			33,33				186,66
	14			36,66				163,33
15.9-16	15	2	40	40	20	7	280	140
	16			46,66				165,333
	17			53,33				190,66
18.9-19	18	3	60	60	36	6	360	216
	19			43,33				368
	20			26,66				520
21.9-22	21	0,5	10	9,99	56	12	120	672
	22			13,33				616
	23			16,66				560
24.9-25	24	1	20	20	42	12	240	504
	25			14,66				362,66
	26			9,33				221,33
27.9-28 m	27	0,2	4	4	10	8	32	80
	28			3				60
	29			2				40
	30			1	0	0		20
	31	0	0	1,24	0	0	0	-1,7

The results revealed (Tables 1, 2 and 3) that lichens play an important and underestimated role in the regulation of water balance in older parts of our forest. When accounting for the interception, tree transpiration contributed slightly less to ET than the soil and understory E(T), while there is a contribution of the understory that accounts for 10–70% of the total transpiration. This can be explained by the mechanism of water capture by interception in the tree canopies. Hence, it plays a certain role in evapotranspiration, however the impact is generally less significant than transpiration from trees and evaporation from the soil and understory. In contrast, Transpiration refers to the fact that trees transpire water from their leaves, returning water to the atmosphere during periods of moist soil. Uncertainties regarding the ability of sap flow measurements to measure and predict absolute values could have played a role and led to an underestimation of tree transpiration. For example, micro-meteorological conditions, such as vapour pressure deficit, are key determinants of transpirational cooling in forest stands. Besides, the tree age has significant effect on the hydrology, because younger trees have less drought stress due to reduced surface sealing (Tams et al., 2024). Possibilities for in situ calibration and realistic estimation of measurement errors are still open for examination in sap flow research.

Our findings demonstrate the value of lichens as one of the important regulators and determinators of water source in the region of Dolomites, northern Italy, where lichens increased in the old stand forest which correlated to higher humidity. Prior research has generally recognised the significance of lichens (e.g., Pérez et al., 2024; Hämäläinen and Fahrig, 2024; Soleimannejad et al., 2025). Lichens are acknowledged as vital components of forest ecosystems. In view of the existing limitations of relevant studies on lichens and difficulty in their fieldwork measurement and evaluation, this paper contributed to our understanding of the role of lichens in the European forests with an example of Italy.

The biosphere of the coniferous forests is a natural model system that reflects the environmental change. Understanding the water balance, hydrology and plant health in forests can support monitoring of the biodiversity changes. Moreover, it is useful for ecosystem function services and maintaining multi-variable analysis in silviculture research. Therefore, understanding the role of ecosystem components, such as lichens or fog, to the ecosystem balance enables to correctly estimate aboveground and belowground processes. Data integration and modelling indicate that forest ecosystem is an complex nonlinear system with exceptional functionality. This paper contributes to the sustainable forest monitoring. Finally, we demonstrated the effects of individual components of forest ecosystems, such as functional groups and lichen species, on the balance of the whole structure.

Conclusion

In this study, the capacity of the forest was quantified to intercept water in the canopy, and an estimate of this capacity was provided in the two different forest stands, old (200-year) and young (30-year) stand, which continues existing studies on lichen-tree relationships (Cleavitt et al., 2009). The higher water storage capacity of the old stand did not depend on the LAI, which was identical in the two stands, but on the other structures, mainly epiphytes. Such organisms, typically represented by filamentous lichens, e.g., *Evernia divaricata* and *Pseudevernia furfuracea*, were relevant for the water cycle in the old section only and had a water-holding capacity of 0.6 mm for each precipitation event. Lichens are a unique symbiosis of specialised fungi with photoautotrophic components, which may include other lichens and affect hydrology of tree tranks (Furmanek et al., 2019; Aslan et al., 2006).
The relevance of this interception capacity was particularly high when precipitation was light (based on field observations) and compared to other research (Jayalal et al., 2012). Interception refers to

water that is temporarily held on the surfaces of vegetation (like leaves) and then evaporates back into the atmosphere, rather than reaching the ground. In our case, the liquid water was used to refill the canopy and soil reservoirs, without being lost as runoff. This large amount of water intercepted by the canopy, which represents most of the liquid precipitation in the old forest stand, is then locally re-emitted as evaporation without stomatal control (Caruso et al., 2008). In addition, in some ecosystem types, part of this water and fog can be directly taken by the plant for its needs (Bruijnzeel et al., 2005). This study proved that the role of lichens is to sustain positive feedback in water cycle, favouring the presence of dense vegetation, and increasing water vapour, which is in line with the previous studies (Dietz and Hartung, 1998; Porada et al., 2014;).

In order to effectively identify environmental characteristics and their relationship with meteorological conditions, it is essential to understand diversity patterns and the co-variation of different ecological parameters (Klaučo et al., 2013; Su et al., 2019; Wang et al., 2025; Lemenkova, 2023c, 2023d). In this study, we analysed the extent to which lichens co-vary with characteristics of trees, their ability to correlate with other parameters in a studied network, and their patterns of diversity with regards to tree age and stand structure. Since there is now a reduction of water vapour in the air with possible future disruption of the positive feedback in the water cycle in terrestrial ecosystems, the presence of old-growth vegetation represents a critical element for climate regulation in the Alpine region (Clement & Shaw, 1999; Gupta et al., 2007). This evidence is in line with recent studies indicating the capacity of natural forests to regulate extreme heat conditions. In view of this, this paper contributes to the better understanding of the role of trees and tree heights to the distribution of lichens that plays regulatory role in water balance in the forests of subalpine ecosystems of South Tyrol, Italy.

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Lišajevi i epifiti kao organizmi čuvari za određivanje vodnog bilansa u šumskim ekosistemima Južnog Tirola

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IZVOD

Lišajevi i magla su jedna od primarnih komponenti vodnog bilansa u četinarskoj šumi, koje utiču na hidrološki ciklus u ekosistemu. Ovaj rad istražuje ulogu magle tokom mješovitih situacija kiše i magle u staroj šumi s prisustvom lišajeva - *Evernia divaricata* i *Pseudevernia furfuracea*. Magla predstavlja oblik niskoležećih oblaka i na nju uveliko utiču geografski položaj, uslovi vjetra i vodotoci. Korištenjem metoda statistike okoliša istražen je uticaj starosti šumske sastojine, magle i brojnosti lišajeva na vodni bilans. Rezultati su pokazali da je prisustvo lišajeva i magle povezano s vlagom i održava vodni bilans u šumama Južnog Tirola. Konkretno, utvrđeno je da intercepcija igra dominantnu ulogu u podjeli padavina i evapotranspiracije, posebno u starijoj sastojini, gdje je pojačana lišajevima. Korištenjem tehnika modeliranja, ova studija je dokazala važnost magle i lišajeva za ekosisteme borealnih šuma: magla prenosi vodu iz atmosfere na površinu Zemlje, a lišajevi igraju značajnu ulogu u povećanju vlažnosti u starim sastojinama.

Ključne riječi: lišajevi, daljinsko istraživanje, obrada slike, satelitska slika, skriptni jezik

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Ukupan sadržaj arsena, olova i žive u poljoprivrednom zemljištu na području Bačke, Autonomna Pokrajina Vojvodina

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Izvod
Abstract

Cilj rada je bio da se utvrdi uticaj ukupnog sadržaja ispitivanih toksičnih elemenata (As, Pb i Hg) na kvalitet poljoprivrednog zemljišta tipa černozem. U ovoj studiji, koja je realizovana tokom 2024. godine, ukupno je prikupljeno i analizirano 53 reprezentativna uzoraka zemljišta tipa černozem, sa različitih lokaliteta u Bačkom regionu AP Vojvodine. Utvrđeno je da ukupan sadržaj As, Pb i Hg u ispitivanim uzorcima nije prelazio maksimalno dozvoljene količine teških metala (MDK) u mg/kg koje su propisane Pravilnikom o dozvoljenim količinama opasnih i štetnih materija u zemljištu i vodi za navodnjavanje i metodama njihovog ispitivanja, koji je naveden u literaturi. Iako je utvrđeno da je ukupan sadržaj As, Pb i Hg u ispitivanim uzorcima zemljišta bio u okviru maksimalno dozvoljenih količina, neophodno je kontinuirano praćenje i ispitivanje sadržaja ovih zagađivača zemljišta radi očuvanja životne sredine i sprečavanja njihovog unošenja u lanac ishrane, što predstavlja veliku opasnost jer potencijalno može ugroziti zdravlje svih živih organizama.

Ključne reči: zemljište, černozem, teški metali, arsen, živa, olovo

Uvod
Introduction

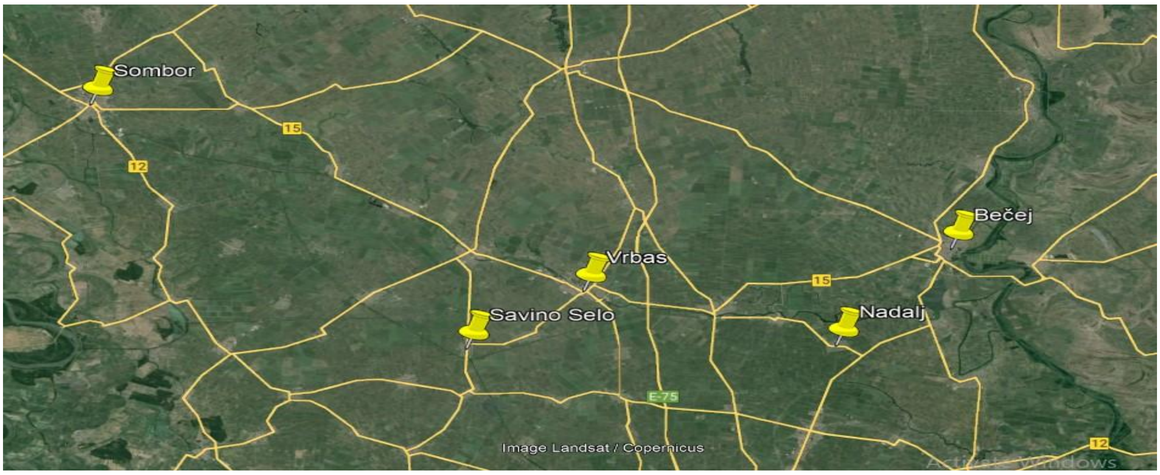
Povećan broj izvora zagađenja pedosfere i biosfere uslovljen je ubrzanim tehnološkim razvojem kao i prekomernom industrijalizacijom, što predstavlja ozbiljnu opasnost za životnu sredinu, kako u urbanim područjima, tako i na poljoprivrednim površinama. Neki od najznačajnijih zagađivača su različita hemijska sredstva, ostaci iz raznih industrijiskih postrojenja, sredstva za zaštitu bilja koje se koriste u svrhu intenzivne poljoprivredne proizvodnje. Proteklih decenija posebna pažnja se skreće na uticaj toksičnih elemenata, među kojima su i As, Pb i Hg. Vrednosti maksimalno dozvoljenih količina (MDK) za arsen, olovo i živu u R. Srbiji prikazane su u Tabeli 1. (Službeni glasnik RS, br. 23/1994). Važno je napomenuti da poreklo nekih teških metala može biti prirodnog, geohemijskog porekla kao posledica formiranja zemljišta na određenim stenovitim podlogama, kao i antropogenog porekla, kao posledica čovekovog uticaja na životnu sredinu (Domi et. al., 2001). Ponašanje opasnih i štetnih materija u zemljištu uslovljeno je mnogobrojnim faktorima, koji mogu uticati na njihovu mobilnost i akumulaciju od strane biljaka, a najznačajniji su reakcija zemljišta, sadržaj organske materije i koloidne gline. Pored ovih i drugi faktori mogu uticati na njihovu mobilnost i štetno dejstvo, kao što su vlažnost, sadržaj kalcijum-karbonata, hidratisani oksidi gvožđa i aluminijuma, kapacitet razmene katjona, redoks potencijal, nivo podzemne vode i dr. (Jakšić i sar. 2012).

Černozem je zemljište, tamno smeđe boje, sa izraženom zrnastom strukturom, veoma povoljnih hemijskih i fizičkih osobina. Uz primenu intenzivnih mera kultivacije, kontrolu plodnosti i racionalno đubrenje omogućava postizanje visokih prinosa poljoprivrednih kultura. U Republici Srbiji nalazi se u Banatu, Bačkoj, Sremu, delimično Mačvi i pojedinim delovima severne Šumadije kao i oko Beograda i Požarevca. Černozem pripada redu automorfnih, te klasi humusno akumulativnih zemljišta. Razvija se u stepskom području, na karbonatnim, ilovastim, ređe peskovitim rastresitim supstratima. Jakšić i sar. (2012) navode da količina arsena u analiziranim uzorcima zemljišta na teritoriji AP Vojvodine, tipa černozem, nije značajna (7,00–9,10 mg/kg) i nalazi se kod svih ispitanih uzoraka u dozvoljenim granicama koje su propisane "Uredbom o dozvoljenim količinama opasnih i štetnih materija u zemljištu i vodi za navodnjavanje" . Ovaj zaključak se takođe odnosi i na sadržaj olova, koji se u ispitanim uzorcima kretao u intervalu od 27,98 – 30,32 mg/kg. Izmereni sadržaj Hg u ispitanim uzorcima se kretao u intervalu od 0,008 – 0,974 mg/kg i takođe je niži od maksimalno dozvoljenih vrednosti. Koncentracija teških metala se iz godine u godinu povećava, ali ipak u većini poljoprivrednih zemljišta nivo nije toliko visok da bi prouzrokovao akutne probleme toksičnosti, ali se ovoj vrsti kontaminacije u narednom periodu svakako mora posvetiti velika pažnja. Važna je i činjenica da zemljišta zagađena ovim metalima predstavljaju veliki problem za životnu sredinu, jer mnogi od njih su postojani stotinama i hiljadama godina (Dozet i sar. 2011).

Materijal i metod
Materials and Metod

Prikupljeni uzorci na teritoriji AP Vojvodine (Slika 1), su vazdušno sušeni, a zatim samleveni mlinom za zemljište do veličine granula < 2 mm, prema SRPS/ISO 11464:2004. Priprema uzoraka, radi određivanja ukupnog sadržaja teških metala: As, Pb i Hg vršena je digestijom uzoraka u zatvorenom mikrotalasnom sistemu pod visokim pritiskom na aparatu Milestone Vario EL III sa koncentrovanom HNO_3 i H_2O_2 (5 : 10), u odnosu čvrsta faza : rastvor za digestiju 1 : 12, postepenim zagrevanjem do 180˚C u ukupnom trajanju od 35min. Iz pripremljenog uzorka, sadržaj metala je određen metodom indukovano kuplovane plazme na

ICP-OES VistaPro Varian. Za proveru tačnosti primenjene metode, periodično je korišćen BCR referentni materijal CRM-141R za digestiju carskom vodom. Dobijene vrednosti su varirale u opsegu od ±10% od sertifikovanih vrednosti.



Slika 1. Lokaliteti prikupljenih uzoraka zemljišta za analizu
Figure 1. Locations of collected soil samples for analysis

Sadržaj žive određen je direktnom metodom iz čvrstog uzorka na aparatu Direct Mercury Analyzer DMA 80 Milestone. Za proveru tačnosti primenjene metode, periodično je korišćen BCR referentni materijal 143R. Dobijene vrednosti su varirale u opsegu od ±5% od sertifikovanih vrednosti.

Obrada podataka istraživanja i geostatistika urađena je u Geografskom Informacionom Sistemu: GIS (ESRI ArcEditor 10).

Rezultati i diskusija
Results and discussion

Arsen (As) je metaloid koji je opšte prisutan element u gornjoj litosferi, a zbog svojih štetnih efekata na biotu, označen je kao zagađivač životne sredine. Hemijski element arsen je poznat po svojim toksičnim svojstvima, mada su se u novije vreme pojavile indicije da bi on u malim količinama mogao da ima i korisnu ulogu po zdravlje ljudi (Velimirović 2013). Arsen se prirodno javlja u obliku minerala, a retko u elementarnom stranju. Prirodnim putem, arsen ulazi u okolinu kroz geohemijske procese, mineralne rude i kroz podzemne vode. Njegova neorganska jedinjenja, su veoma otrovna, a pored primene u industriji, korišćen je i u poljoprivredi kao komponenta agrohemijskih sredstava protiv biljnih štetočina, što može biti uzrok njegove povećane koncentracije u zemljištima (Hooda Et. al., 2010). Iako su minerali i jedinjenja As lako rastvorljivi, migracija As je veoma ograničena zbog snažne sorpcije od strane glina, hidroksida i organske materije. Povećana količina As u glinovitim sedimentima kao i u površinskom zemljištu, u poređenju sa koncentracijama u magmatskim stenama, očigledno odražava i neke spoljne izvore As, poput vulkanskih izduvnih gasova i još nekih zagađenja (Kabata-Pendias Et. al., 2001). Koncentracija arsena u zemljištu najčešće se kreće u intervalu od 2 do 20 mg/kg (Jakšić i sar. 2012), a zbog njegove velike adsorpcije i akumulacije, najveća koncentracija ovog metala je u površinskom sloju zemljišta. Neorganski arsen je generalno toksičniji od organskog. Sadržaj i zadržavanje As u zemljištima, kao i drugih teških metala, u velikoj meri zavisi od fizičko-hemijskih svojstava zemljišta. Prosečne vrednosti arsena u černozemu, najčešćem tipu zemljišta u Vojvodini, bile su 8,6 mg/kg i 0,4 mg/kg za ukupni i pristupačni sadržaj, respektivno (Ninkov i sar. 2017).

U ispitivanim uzorcima sadržaj arsena je bio u intervalu od 1,7 do 10,7 mg/kg, što znači da je sadržaj arsena u zemljištu svih ispitivanih lokaliteta ispod MDK. Prosečan sadržaj As je u površinskom sloju zemljišta iznosio 5,9±2,1 mg/kg. S obzirom da zemljište nije kontaminirano ovim teškim metalom, u površinskom sloju, u kojem inače dolazi do akumulacije, može se zaključiti da je prvenstveno poreklo arsena iz matičnog supstrata. Ovo je razumljivo, pošto su ispitivani lokaliteti udaljeni od saobraćajnica i drugih potencijalnih zagađivača.

Živa (Hg) je jedini tečni metal. Procenjuje se da ga u Zemljinoj kori ima oko $6 \cdot 10^{-7}$ % (Kastori 1993). Pretežno se javlja u obliku sulfida. Poznato je da se nalazi u više od 20 minerala a kao najvažniji živin mineral je cinabarit (HgS). Ovaj mineral je veoma stabilan, jer nije podložan raspadanju. Najvažnije geo-hemijske karakteristike žive su sklonost ka formiranju jakih veza sa sumporom (na primer HgS) kao i formiranje organskih jedinjenja žive koja su raletivno stabilna u vodenim sredinama. Ukupan sadržaj Hg u zemljištu je jako varijabilan. Smatra se da zemljišta sa sadržajem od 0,003 do 0,03 ppm Hg nisu kontaminirana (Kastori 1993). Pokretljivost i dostupnost žive u zemljištu su veoma niske, sa prosečnim vrednostima od 0,28 do 2,45% (Różański et. al., 2016). Sadržaj žive u zemljištima u najvećoj meri zavisi od pH vrednosti kao i od sadržaja organske materije.

Akumulacija žive u zemljištu se drži pod kontrolom formiranjem organskih kompleksa i taloženjem. Pokretljivost žive zahteva procese rastvaranja i biološke i hemijske razgradnje njenih organskih jedinjenja. Hloridi žive su dosta pokretljivi u zemljištu ali osnovni zaključak je da živa u zemljištu ima malu i ograničenu pokretljivost. Ta pokretljivost je daleko veća putem isparavanja. Akumulacija žive je povezana sa nivoima organskog C i S u zemljištima i raspoređena je u površinskim slojevima zemljišta nekoliko puta više nego u podzemnim slojevima. Generalno, organska zemljišta imaju veći sadržaj žive od mineralnih zemljišta. To je uglavnom zbog velike sposobnosti humusa, posebno sirovog humusa, da veže živu. Visoke koncentracije žive u sirovom humusu, često premašuju 0,3 ppm (Kabata-Pendias et. al., 2001).

Sorpcija žive varira sa pH vrednošću, pri čemu je najviša pri pH vrednosti od 4 do 5. Ipak, objavljeni podaci za različita zemljišta širom sveta pokazuju da prosečne koncentracije žive u površinskim zemljištima ne prelaze 400 ppb. Najviše prosečne koncentracije žive kako navode Kabata-Pendias et. al., (2001) su izmerene za histozole Kanade (400 ppb) kao i za pirinčana zemljišta Japana (350 ppb) i Vijetnama (300 ppb). Očigledno je da organska zemljišta i pirinčana zemljišta sadrže više žive nego bilo koja druga zemljišta što je rezultat razgradnje biljnog materijala i apsorpcije iz atmosfere. Sadržaj žive u vojvođanskim zemljištima je nešto niži u poređenju sa sadržajem žive u svetu, pošto je 60% površine Vojvodine pokriveno černozemom (Ninkov i sar. 2017). Prema ovoj globalnoj proceni, zemljišta koja su bogata organskom materijom imaju veći sadržaj žive. Živi, kao elementu danas se posvećuje veća pažnja u poljoprivredi, posebno od momenta kad su švedski naučnici utvrdili da se ona akumulira u hrani (Kabata-Pendias A. i sar. 2001).

Dobijeni rezultati ukupnog sadržaja Hg u poljoprivrednom zemljištu tipa černozem AP Vojvodine, prikazani su u Tabeli 1. Rezultati su bili u intervalu od 0,022 do 0,051 mg/kg. Ovaj interval je u skladu sa najčešće citiranim rasponom 0,01–1 mg/kg u zemljištu bez poznatih izvora kontaminacije (Ninkov i sar. 2017). Prosečna koncentracija Hg bila je 0,033±0,007 mg/kg. Prosečna vrednost Hg u vojvođanskom zemljištu od 0,033 mg/kg vrlo je blizu tipične koncentracije Hg za svetska zemljišta, koja je prijavljena na oko 0,06 mg/kg (Ninkov i sar. 2017). Osim toga, podudara se sa nacionalnim prosekom za kinesko tlo od 0,065 i provinciju Liaoning od 0,064 mg/kg (Ninkov i sar. 2017).

Tabela 1. Sadržaj teških metala u uzorcima zemljišta
Table 1. Heavy metal content in soil samples

Lokaliteti	**As** [mg/kg]	**Pb** [mg/kg]	**Hg** [mg/kg]
1. Vrbas	3,5	6,8	0,032
2. Vrbas	5,5	9,8	0,032
3. Vrbas	4,5	9,9	0,035
4. Vrbas	5,7	11,3	0,034
5. Vrbas	4,8	9,2	0,031
6. Vrbas	2,7	9,6	0,024
7. Vrbas	2,2	10,6	0,026
8. Vrbas	3,1	9,4	0,024
9. Vrbas	1,7	9,8	0,024
10. Vrbas	2,3	9,7	0,025
11. Sombor	9,5	9,9	0,027
12. Sombor	2,6	5,8	0,022
13. Sombor	8,8	7,6	0,025
14. Sombor	6,1	8,6	0,025
15. Sombor	10,2	8,1	0,025
16. Sombor	5,7	8,8	0,028
17. Sombor	6,5	10,5	0,031
18. Sombor	4,7	8,3	0,030
19. Sombor	5,1	9,8	0,035
20. Sombor	4,2	9,7	0,029
21. Sombor	7,2	9,5	0,051
22. Sombor	4,4	11,0	0,030
23. Sombor	7,1	13,2	0,031
24. Sombor	5,9	11,6	0,034
25. Sombor	4,6	12,8	0,031
26. Sombor	5,1	10,7	0,029
27. Sombor	6,2	13,3	0,035
28. Sombor	5,0	12,4	0,040
29. Sombor	7,3	12,4	0,028
30. Sombor	5,3	11,0	0,032
31. Bečej	4,7	11,6	0,033
32. Bečej	3,8	11,6	0,032
33. Bečej	5,8	11,5	0,031
34. Bečej	4,1	11,1	0,031
35. Bečej	6,1	11,9	0,039
36. Bečej	5,5	11,0	0,034
37. Bečej	7,3	12,7	0,050
38. Nadalj	6,4	13,5	0,042
39. Nadalj	5,7	11,9	0,044
40. Nadalj	6,8	12,7	0,047
41. Nadalj	4,8	13,6	0,038
42. Nadalj	5,6	13,1	0,035
43. Nadalj	5,8	13,1	0,032
44. Nadalj	5,7	12,7	0,031
45. Nadalj	9,0	11,7	0,044
46. Nadalj	7,0	11,7	0,042
47. Nadalj	8,1	12,8	0,038
48. Savino Selo	7,5	12,5	0,039
49. Savino Selo	7,0	14,4	0,031
50. Savino Selo	7,6	15,2	0,033
51. Savino Selo	9,2	11,6	0,031
52. Savino Selo	10,2	11,9	0,029
53. Savino Selo	10,7	12,5	0,030
Srednja vrednost±SD	5,9±2,1	11,1±1,9	0,033±0,007
MIN [mg/kg]	1,7	5,8	0,022
MAX [mg/kg]	10,7	15,2	0,051
MDK* [mg/kg]	**25**	**100**	**2**

* *Maksimalno dozvoljene količine*

Olovo je metal koji ne spada u esencijalne elemente živog sveta. Poseduje dva stabilna oksidaciona stanja Pb^{2+} i Pb^{4+}, pri čemu je oksidaciono stanje Pb^{2+} dominantnije. Veoma je otrovno, kao i njegova jedinjenja, što dovodi do kontaminacije zemljišta. U zemljišnom okruženju poznate su dve vrste olova: primarno i sekundarno. Primarno olovo je geogenskog porekla i inkorporiran je u minerale u vreme njihovog oblikovanja, a sekundarno olovo je radiogenskog porekla od raspada U i Ti (Kabata-Pendias A. i sar. 2001). Olovo se retko javlja u elementarnom stanju, nerazdvojeno od drugih elemenata i prvenstveno se nalazi u sulfidnom obliku (rudama) a njegovi najpoznatiji minerali su galenit (PbS) i anglezit ($PbSO_4$). Zna se da se Pb nalazi u rastvorljivom halogenom obliku (PbClBr), a kasnije nastaju i druga relativno rastvorljiva jedinjenja kao što su $PbCO_3$ i $Pb_3(PO_4)_2$. Zbog nastanka ovih jedinjenja i njegove velike adsorpcije, pokretljivost Pb u zemljištu je veoma mala. Svi ovi oblici imaju veoma nisku rastvorljivost u vodi. Na dinamiku Pb u zemljištu od posebnog uticaja su pH-vrednost, sadržaj organske materije i gline (Kastori 1993). Povećanje kiselosti obično povećava rastvorljivost Pb-a, ali mobilizacija je obično sporijeg tempa u poređenju sa akumulacijom Pb-a u sloju bogatom organskom materijom. Atmosfersko taloženje je glavni izvor Pb-a u površinskom okruženju. Prašina i pare Pb-a mogu ući u atmosferu kako iz prirodnih tako i iz antropogenih procesa i izvora. Karakteristična lokalizacija Pb-a blizu površine zemljišta u većini profila zemljišta pretežno je povezana sa površinskim nakupljanjem organske materije (Kabata-Pendias A. i sar. 2001).

Kao element olovo je veoma važno za savremenu industriju. Posebno je važno naglasiti da se dodaje kao aditiv benzinu čijim sagorevanjem Pb dolazi na površinu zemljišta i zagađuje ga. Sva njegova jedinjenja su otrovna. Sadržaj Pb u zemljištu je veoma varijabilan. Tu varijabilnost najviše prouzrokuje matični supstrat na kome je zemljište formirano. Kao prosečan sadržaj olova u zemljinoj kori navodi se po literaturnim podacima oko 16 ppm. Za zemljišta koja se koriste u poljopriverdne svrhe važi varijabilnost olova od 2 do 200 ppm. Najčešći udeo Pb u normalnim zemljištima, neutralne reakcije kreće se od 0,1 do 20 ppm. Veće količine olova u poljoprivrednom zemljištu treba očekivati oko industrija koje prerađuju olovo, pored velikih saobraćajnica kao i zemljišta gde je korišten kanalizacioni mulj u kome sadržaj olova može varirati od 50 do 2600 ppm, što zavisi od njegovog porekla (Kastori 1993).

U ispitivanjima sadržaja olova u 53 reprezentativna uzorka sa površine AP Vojvodine, nismo zabeležili prekoračenje granične vrednosti za Pb, a prosečna vrednost je iznosila 11,1±1,9 mg/kg. Ukupan sadržaj olova se kretao u intervalu od 5,8 do 15,2 mg/kg, sa tim što je prosečan sadržaj Pb u dolini reke Tise bio 11,6±0,55 mg/kg što je takođe ispod MDK. Ovakvi rezultati su razumljivi, pošto su ispitivani lokaliteti udaljeni od saobraćajnica i drugih potencijalnih zagađivača. Jakšić i sar. (2012) su prilikom ispitivanja zemljišta Vojvodine zabeležili prosečnu koncentraciju olova od 28,89±0,68 mg/kg i time dokazali da nijedan ispitivani lokalitet nije imao povećanu koncentraciju olova. Slične razultate su dobili Brankov i sar. (2006) prilikom ispitivanja nepoljoprivrednog zemljišta Vojvodine.

Zaključak
Conclusion

Ukupan sadržaj arsena u ispitivanim uzorcima zemljišta tipa černozem bio je u intervalu od 1,7 do 10,7 mg/kg, što znači da nema kontaminacije ovim elementom, jer je utvrđeni sadržaj ispod maksimalno dozvoljene količine. Nije zabeležena ni kontaminacija olovom, koje je u ispitivanim uzrocima zemljišta bilo u intervalu od 5,8 do 15,2 mg/kg, što je ispod propisane granične vrednosti. S obzirom da se ukupan sadržaj žive kretao od 0,022 do 0,051 mg/kg, svi uzorci analiziranih lokaliteta zadovoljavaju kriterijume nekontaminiranog zemljišta. AP Vojvodina, koja se nalazi u severnom delu Srbije, predstavlja njeno najvažnije poljoprivredno područje, stoga je kako za ekonomski razvoj Vojvodine tako i za očuvanje životne sredine od ključnog značaja zaštita zemljišta. Iz tih razloga neophodna je dalja kontrola sadržaja ovih teških metala u zemljištu, kao i ispitivanje pristupačnosti i ekstrakcije od strane biljaka, kako bi se sprečio njegov ulazak u lanac ishrane i obezbedila bezbedna proizvodnja zdrave hrane.

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Total arsenic, lead and mercury content in agricultural land in the area of Bačka, Autonomus province of Vojvodina

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Abstract

The aim of the work was to determine the influence of the total content of the investigated toxic elements (As, Pb and Hg) on the quality of agricultural soil of the chernozem type. In this study, which was carried out during the year 2024, a total of 53 representative soil samples of the chernozem type were collected and analyzed, from different localities in the Bačka region of AP Vojvodina. It was determined that the total content of As, Pb, and Hg in the examined samples did not exceed the maximum permitted concentrations (MPC) of heavy metals in mg/kg as prescribed by the Regulation on permitted levels of hazardous and harmful substances in soil and irrigation water and the methods for their testing, as cited in the literature. Although it was determined that the total content of As, Pb and Hg in the examined soil samples was within the maximum allowed amounts, it is necessary to continuously monitor and test the content of these soil pollutants in order to preserve the environment and prevent their introduction into the food chain, which represents a great danger because it can potentially endanger the health of all living organisms.

Key words: soil, chernozem, heavy metals, arsenic, mercury, lead

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Quality and control of organically produced fruit as a factor of sustainable soil conservation in the Republic of Serbia

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Abstract

Organic agriculture plays a key role in providing healthy food, preserving the environment and sustainable use of natural resources, primarily soil. Organic production implies a system of cultivation based on the principles of sustainable and ecological agriculture, which avoids the use of artificial fertilizers, pesticides, GMOs and other chemicals, while protecting people and the natural environment. In addition to ecological and nutritional benefits, the development of the market for organic products allows consumers access to safe, high-quality and diverse foods, while providing producers with economic sustainability and a competitive advantage. Effective control and certification of organic products is necessary to maintain consumer confi-dence and ensure compliance with international food quality and safety standards. The integration of production, markets and control mechanisms is the key to improving a sustainable food industry system. The aim of this work is to point out the importance of the market and quality control of organic fruit in Serbia (2019-2024), which represents one of the most famous organic plant species, of which the raspberry, apple, plum and cherry are the leading ones. In addition to the introduction, the paper consists of three parts. The first part of the paper discusses the causes and effects of pollution from agriculture, as well as sustainable production strategies, including organic agriculture, which enables the production of healthy food in the context of modern environmental challenges. The second part of the paper indicates the connection between the goals of sustainable development and organic agriculture, their relationship through the 2030 Agenda, as well as the importance of controlling organic agriculture and organic products in order to produce safer and better quality products for the environment and human health. The third part of the work shows the most famous organic plant and fruit species in Serbia.

Keywords: *market, quality control, organic fruit, Serbia.*

Introduction

The standard of living and the state of the environment are going through a phase of significant changes due to the pressures of global development processes, with food production occupying a central place. The traditional agricultural model, which relies on high-yielding varieties and hybrids, synthetic fertilizers, chemical agents for crop protection and modern mechanization, although it brings high yields, has led to serious environmental and health problems, calling into question the long-term sustainability of this type of production (Bajagić et al., 2023; Sarker et al., 2024; Bajagić, Ignjatović, 2025). At the same time, from the consumer's point of view, there is a growing need for food that is of nutritional quality and free of toxic residues — that is, for products that are obtained in accordance with the principles of ecological sustainability and food safety standards (Bajagić et al., 2024; Ignjatović et al., 2025). Agriculture conceived in this way no longer meets only quantity criteria, but also demands for quality, environmental protection and human health. In this context, the transition to methods that minimize the use of chemical inputs, increase biodiversity and nurture soil health becomes necessary, so that food production is based on the principles of sustainability and safety (Leskovac, Petrović, 2023; Singh et al., 2024; Raveloaritiana, Wanger, 2024).

The state of the environment, caused by various sources and forms of pollution — land, water and air, has a direct or indirect impact on the quality of the ecosystem and, indirectly, on the health of the population. Soil pollution, soil degradation and contamination of water resources are parts of a wider problem, which cannot be seen in isolation from production and agricultural processes (Hakami, 2015; Tasleem et al., 2023).

Key environmental problems, such as excessive use of pesticides and agrochemicals, improper use of fertilizers, soil pollution with industrial and municipal waste, and water contamination are factors that significantly threaten agroecosystems. Such conditions can lead to soil and water no longer functioning as a "filter" and a source of healthy raw materials, but becoming a source of contamination (FAO, 2018). Furthermore, due to soil and water pollution, pollutants, i.e. chemicals, heavy metals, persistent organic compounds (such as pesticides, industrial chemicals, contaminants from waste) can enter the food chain. Plants or fodder grown/treated in such conditions can accumulate harmful substances, which then reach consumers through food. Such food can pose a serious risk to public health (Lu et al., 2015). In this context, the production of health-safe food is particularly important, which implies that the production process, from soil processing, through cultivation, to final consumption, must be in compliance with ecological, sanitary-hygienic and legal standards. Without such an approach, even food that seems adequate in terms of nutritional value may carry a hidden risk of contamination (Guerrieri et al., 2024; Lazarevic-Pašti, Potkonjak, 2025).

Contemporary research indicates that sustainable agricultural practices, such as crop diversification, organic fertilizers, crop rotation, reduced use of chemicals, responsible management of soil and water resources can significantly contribute to the preservation of soil fertility, biodiversity and ecosystem health, while food production remains productive (Babar, Akan, 2024; Raveloaritiana, Wanger, 2024; Islam, 2025). Also, sustainability policy and regulations (e.g. CAP in the EU) promote the application of these practices as part of a long-term strategy for the preservation of natural resources and food safety (Nikolić Popadić & Milenković, 2023). In the era of climate change and increasing pressure on resources, an integrated approach to the environment and agricultural production, supported by modern technologies (organic agriculture, precision agriculture), represents the only sustainable way for food to reach consumers in a safe and healthy way.

Fruit quality is essential for nutrition and human health and requires attention in agricultural practice. Organic agriculture can provide higher quality in fruit crops, thanks to the absence of synthetic fertilizers and pesticides, improved pollination, reduction of protective treatments, which encourages

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the production of antioxidant compounds (Munne-Bosch & Bermejo, 2024). Organic production systems promote resilience, stability and security in the face of unforeseen circumstances. In this regard, organic agriculture can be the answer in a strategy for a sustainable future for a long period of time, when it comes to the food crisis (Padel et al., 2007; Arben et al., 2016). According to Ignjatović et al. (2025) organic production in the Republic of Serbia is governed by laws and regulations that are in accordance with the regulations of the European Union, and the control of organic production is carried out in accordance with the law and refers to all stages of organic production and high quality products (Bošković, 2016). Simić (2020) states that the Law on Organic Production ("Official Gazette of the RS", number 30/10, 17/19-second law) regulates the production of agricultural and other products using organic production methods, control and certification of organic products, processing, labeling, storage, transportation, circulation, import and export of organic products, as well as other issues.

Pollution in agriculture — contemporary context

Agriculture and food production are necessary for the survival and development of society, but in modern intensive farming systems, a significant negative impact on the environment occurs more and more often. Soil, water and air pollution, land degradation, loss of biodiversity and food contamination — these are all risks that agriculture can generate, and which also affect public health (Blagojević et al. 2024).

The moderate development of the agricultural sector for the needs of food production in the shortest possible time for the population has led to the creation of aggressive destruction of natural and renewable resources. The cause of the problem is the progressive work of the chemical industry, and the use of various synthetic agents for plant protection is often excessive and uncontrolled (Ahmad et al., 2024). The consequences occur through the following problems: climate change, global warming, destroyed environment, which results in the loss of ecosystem elements and functions, as well as the loss of functional biodiversity. The constant use of mineral fertilizers and chemical inputs, irrigation and mechanization in agriculture contributed to an increase in CO2 emissions by about 14% (The Carbon Footprint of Crop Protection Products, 2012). Facts from recent research confirm that the topic of pollution in agriculture is more current and urgent than ever (Table 1).

Table 1. Causes and consequences of pollution in agriculture

Cause / agricultural practice / chemical substance	Example / mechanism	Consequences / effects (on soil, water, food, health, biodiversity)	Reference / the source
Excessive / inadequate use of pesticides	Systematic pesticides, insecticides, herbicides, fungicides in intensive agriculture	Viral contamination of soil and water; degradation of soil biodiversity: destruction of beneficial microbes, insects, deposition of resistance; harmful accumulation in plants — death or disease of plants, entry into the food chain, danger to human and animal health.	Alengebawy et al., 2021 Rad et al., 2022
Long-term use of mineral / synthetic fertilizers (NPK, superphosphates, etc.)	Fertilizers containing nitrogen, phosphorus, sometimes traces of heavy metals (cadmium, lead, copper...)	Accumulation of toxic metals in the soil; reduction of soil fertility; plant contamination; risk of metal entering food; water pollution: nitrate/phosphate leaching, eutrophication, groundwater contamination.	Tasleem et al., 2023
Washing (run off) and washing of fertilizers and pesticides from fields into surface and underground water	Rain and irrigation wash undistributed pesticides and fertilizers into waterways	Pollution of rivers, lakes and springs — eutrophication (excessive growth of algae), reduced oxygen in the water, death of fish and other aquatic organisms; endangered drinking and irrigation water.	Wijekoon, 2017 Bayabil & Teshome, 2022
Changes in the chemical and biological structure of the soil (pH, microbes, soil biodiversity)	Soil acidification (from nitrogen fertilizers), reduction of organic matter, reduction of beneficial microorganisms and soil fauna	Reduced fertility, soil degradation, poorer structure and lower soil resistance; reduced ability of soil to support healthy plant growth; potentially greater need for chemicals, necessitating a cycle of degradation.	Morariu et al., 2018 Rashid et al., 2023
Destruction of natural habitats and replacement of natural ecosystems with monocultures / intensive use of agricultural land	Deforestation, transfer of natural areas to arable land; monoculture of crops, lack of awareness of the ecological diversity of the soil	Reduction of biodiversity — plants, animals, microorganisms; loss of ecosystem functions (eg natural pest regulation, soil fertility, natural resilience) — increased risk of degradation and chemical dependency.	Apoorva & Kundlas, 2024

Source: Authors.

The importance of soil quality in organic agricultural production

Soil is a key resource in organic agriculture because its biological, physical and chemical structure depends on the fertility and stability of the agroecosystem (Antony, 2022).

Organic production emphasizes preserving and increasing the content of organic matter in the soil, which contributes to better structure and water retention without the use of synthetic fertilizers (Janković et al., 2022). Organic practices, such as compost application, green manure and crop rotation, promote the activity of beneficial microorganisms and nutrient cycling (FAO and ITPS, 2021). Research shows that soils in organic systems have greater microbial diversity and more stable aggregates compared to conventional systems (Huang et al., 2025). Preservation of organic carbon in the soil contributes to reducing erosion and increasing resistance to drought and climatic extremes (John et al., 2025). Healthy soil provides plants with better nutrition and natural resistance to diseases and pests (FAO, 2022). Soil quality directly affects the yield and nutritional value of organic products (Antony, 2022). In the long term, maintaining soil fertility is the basis of sustainable organic production and environmental protection (Janković et al., 2022).

Sustainable Solutions: Strategies and Management of Agricultural Systems

Contemporary challenges require a transition from conventional, intensified production models to sustainable, environmentally responsible practices. Some of the recommended approaches are:

- Ecological / organic farming - reducing the use of synthetic pesticides and fertilizers, using natural materials, maintaining the biological activity of the soil, crop rotation, tilling the soil without toxic chemicals. This contributes to the conservation of soil, water and biodiversity (Sarker et al., 2024; Bajagić, Ignjatović, 2025).
- Precision and integrated agriculture (integrated pest/soil/water management) - rational, targeted use of resources and chemicals, monitoring of soil and crop conditions, minimization of waste and contamination, combining agroecological practices (Janković et al., 2024; Modu et al., 2025).
- Reduction of plastic use, waste control and recycling - avoidance of plastic materials in mulching, packaging, optimization of biological waste, recycling, transition to earth-friendly materials, which helps to reduce micro/nano plastics in the soil (Nuruzzaman et al., 2025).
- Monitoring and regulation, soil and water protection policies - establishment of systematic soil and water monitoring, legal regulations, education of all persons involved in new production systems, implementation of good practices, transparency in the management of agrochemicals (European Commission, 2024).

Organic agriculture is considered an important component of sustainable development because it promotes environmental sustainability and social responsibility, including the use of practices that minimize the negative impact of agriculture on the environment and human health (Panzaru et al., 2023). The sustainability of the planet and human life is closely related to the implementation of measures related to the 2030 Agenda, because through the Sustainable Development Goals, it supports the promotion of large-scale organic agriculture as an essential condition for well-being, quality of life and environmental protection, as well as the reduction of climate imbalances (UN, 2015; Bennetzen et al., 2016). The Food and Agriculture Organization of the United Nations (FAO) clearly supports the fact that organic agriculture is affected by the way all involved actors address the sustainable development goals of the 2030 Agenda, and that organic agriculture has a direct impact on achieving those goals at the global level. This means that the goals of sustainable development are directly or indirectly related to healthy food, a healthy living environment and organic agriculture, and must be the focus of short- and long-term projects and action plans. The Food and Agriculture Organization identifies a total of eight sustainable development goals that are most relevant to organic agriculture, namely: clean water, combating climate change, life under water, life on land, zero hunger, healthy health and well-being, decent work and economic growth, sustainable consumption and production (Panzaru et al., 2023).

Production of high-quality food (high nutritional value), development of sustainable agriculture while preserving the ecosystem, maintaining and increasing soil fertility through the cultivation of legumes, application of green and manure or deep-rooted plants in perennial crop rotation and addition of composted or non-composted organic matter to the soil, is the goal of organic production. Control of organic production in the Republic of Serbia is carried out in accordance with the Law, which is based on European regulations, IFOAM and Codex Alimentarius. One of the main tasks that IFOAM (International Federation of Organic Agriculture Movements) traditionally adopts is to harmonize international standards on organic agricultural production as much as possible (Janković et al., 2023). In the Republic of Serbia, the Law on Organic Production was adopted in 2010, in accordance with the regulations of the European Union - Council Regulation (EC) no. 834/2007 and Commission Regulation (EC) no. 889/2008, until changes were made in 2019 (Filipović et al., 2021). This law regulates the production of agricultural and other products using organic production methods, goals and principles of organic production, organic production methods, control and certification in organic production, and other important issues. The law contains two regulations, namely: the Regulation on control and certification in organic production and methods of organic production ("Official Gazette of the RS", number 95/20) and the Rulebook on documentation submitted to the authorized control organization for issuing a certificate, as well as on the conditions and methods of selling organic products ("Official Gazette of the RS", number 88/16). In order to obtain a certificate for the production of organic food, it is necessary that the soil has not been treated with chemicals for at least 3 years, but is prepared using manure, that is, biological and liquid fertilizer (Jugović et al., 2017).

The Ministry of Agriculture, Forestry and Water Management establishes a list of control organizations (Table 2) (Ignjatović et al., 2025), for a period of one year, which have an impartial role in the control and certification program, in order to comply with the rules of organic production and achieve high product quality (Bošković, 2016). Accreditation of control organizations is carried out by the Accreditation Body of Serbia, in accordance with the SRPS EN ISO/IEC 17065 standard, which is one of the conditions for obtaining authorization from the Ministry of Internal Affairs and Communications (Simić, 2020).

Table 2. The authorized control organizations, 2025.

"CENTAR ZA ISPITIVANJE NAMIRNICA DOO CIN", BELGRADE
"ECOCERT BALKAN DRUŠTVO SA OGRANIČENOM ODGOVORNOŠĆU, BELGRADE
"DOO ORGANIC CONTROL SYSTEM", SUBOTICA
"ECOVIVENDI" DOO, BELGRADE
"PREDUZEĆE ZA TEHNIČKA ISPITIVANJA I ANALIZE SGS" DOO, BELGRADE
"PROFI LAB"DOO, BELGRADE
"JUGOINSPEKT - PREDUZEĆE ZA KONTROLU KVALITETA I KVANTITETA ROBE I USLUGA", DOO, NOVI SAD

Source. Ignjatović et al., 2025a, Ignjatović et al., 2025b.

Based on the performed controls, the authorized control organization issues a certificate, which confirms that the product was obtained using organic production methods (Ignjatović et al., 2025) in accordance with the Law on Organic Production. After successful certification, the product is marked as "ORGANIC PRODUCT", with the national symbol and logo of the authorized control organization (Bošković, 2016). Successful certification confirms that an organic product is a product of 95% ingredients, produced by organic farming methods (Mickovski Stefanović et al., 2024), labeled in accordance with the Law on Organic Production. For the purposes of export, the manufacturer should have a certificate, which is recognized in the country where he plans to market his products, and these regulations are in accordance with the regulations of the European Union (Simić, 2020).

In addition to the national mark and logo, since 2013, the mark "BIOCS Organic Control System" has been in force. "Organic Control System" is an organization also authorized by the Ministry and the Accreditation Body of Serbia, the European Commission with the possibility of certification in the countries of the region as well (Filipović et al., 2021). It is authorized to certify unprocessed products of plant origin and processed agricultural products used as food, including products for export. Apart from these two marks present in Serbia, the products often have a European mark, which is not the accent of domestic producers (Filipović et al., 2021). In addition to the Ministry of Agriculture, Forestry and Water Management, the Group for Organic Production was formed as the competent authority that performs tasks related to organic production. During 2020, the Group came under the jurisdiction of the Sector for Agricultural Policy. The formed Group has the following duties: keeping records of authorized control organizations; conducts annual supervision over the work of authorized control organizations; collects annual reports on organic production from authorized control organizations, keeps summary records on organic production; prepares decisions on the fulfillment of conditions for performing control and certification activities; approves deviations from the methods of organic crop and livestock production and processing rules in organic production; approves the use of reproductive

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material from conventional agricultural production after the conversion period and shortening or extending the conversion period and other tasks (Serbia Organica, 2024).

Table 3. The group of agricultural inspectors for organic production carries out inspection supervision over the implementation of laws and regulations

- control of the ban on the use of food, food and animals, auxiliary means in processing, reproductive material, auxiliary means, microorganisms and animals obtained and/or modified from genetically modified organisms or with the help of genetically modified organisms;
- control of organic plant and livestock production, processing of ingredients, additives and auxiliary substances, cleaning agents and methods of cleaning technological lines;
- control of labeling of products that have organic status and from the conversion period;
- control of storage, distribution, traffic, import and export of organic products;
- control of fulfilled requirements of organizations for performing control and certification tasks;
- sampling and taking measures and actions to prevent illegalities, as well as others jobs.

Source: Simić, 2020.

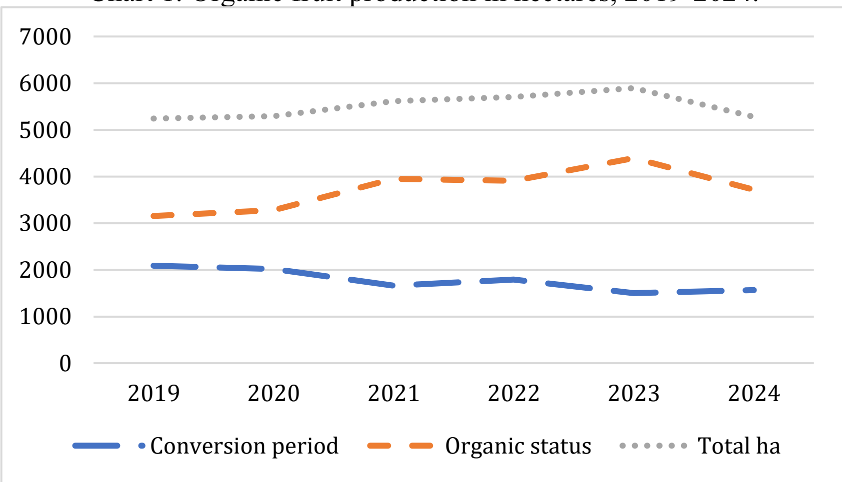
Fruit production shows numerous advantages because it enables using various locations and regions, establishment of orchards on lands of different quality, fruit growth in different climatic conditions (Veličković, Golijan, 2017). In the Republic of Serbia, fruit production is mainly concentrated in the southern region, where the production of organic raspberries, blackberries, plums, strawberries, apples and cherries dominates. The Republic of Serbia represents a country with preserved agro-ecosystems and rich opportunities for improvement, not only of organic fruit production, but also of other organic products. Agroecological conditions in the Republic of Serbia are favorable, especially for the production of organic berries, with an emphasis on raspberries, where production is located in Arilje, which accounts for 30% of the total world production of raspberries. The production of raspberries, compared to other fruits, prevails because they are traditionally grown on large areas. Serbia is the world leader in the production of this type of fruit. In addition to the fact that our country provides extremely favorable conditions for organic production, the full potential of unpolluted soil is not used. Therefore, producers should focus on this shortcoming and improve production, because the demand for organic fruit in the international market is unlimited, which leads to an increase in profits.

The essence of organic production is compliance with nature and its laws, which induces the natural defense mechanism of plants and develops greater resistance to diseases and pests (Veličković, 2002; Veličković & Golijan, 2015). Some of the certified organic fruit producers in Serbia are: "Nectar" doo, "Foodland" doo, "Ethnos Foundation", "BMD", GO "Organic" doo, "VONI-M" doo, "Zdravo organic", Gordana Šoškić, Poljoprovredno gazdinstvo Stojanović organic, Nebojša Antić and others (Serbia Organica, n.d.).

Fruit as an example of organic culture in Serbia

In Serbia, fruit is one of the most famous organic plant species (Ignjatović et al., 2025). The conversion period means the period of organic production, where the certificate has not yet been obtained, that the product can be sold, because there is another problem that needs to be solved (or some toxicant is present in the soil or some harmful organism is being eradicated, so a permitted pesticide must be used, etc.). In the case of certain types of fruit, there was a decrease in the area of plantations during the conversion period, precisely because of the transition to an organic system of production, or there was even an increase due to the acquired favorable conditions, that conventional systems were transferred to the conversion period, or new plantations were planted due to favorable market moments. According to data from the Ministry of Agriculture, the average conversion period for all types of fruit for the period 2019-2024. it was 1770.9 ha, while 3733.6 ha had organic status. The total average of fruit under organic production was on average 5504.6 ha (Chart 1).

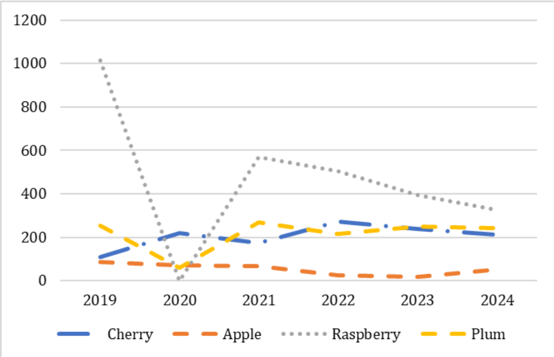
Chart 1. Organic fruit production in hectares, 2019-2024.

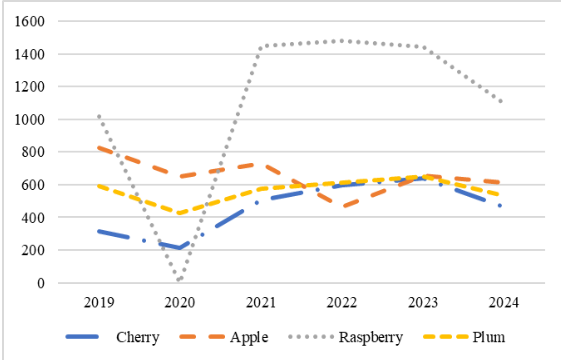


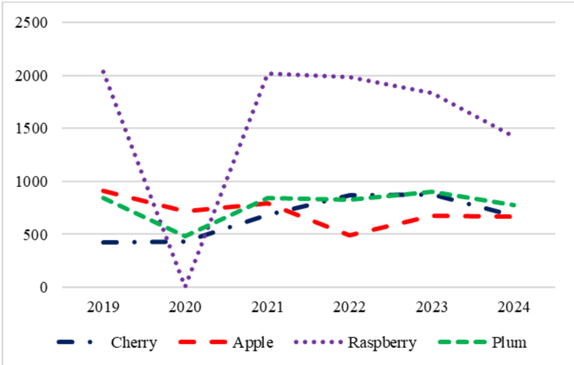
Source: Ministry of Agriculture, Forestry and Water Management, 2025.

In the period 2019-2025. year, the total area of organic fruit in Serbia was 33027.03 ha, of which 5241.3 ha (2019), 5294.8 ha (2020), 5614.9 ha (2021), 5702.7 ha (2022), 5894.1 ha (2023) and 5279.1 ha (2024). The largest areas in the same period 2019-2024. year, they recorded the crops that are the subject of analysis in this work, i.e. raspberry (9292 ha), apple (4842.4 ha), plum (4674.4 ha) and sour cherry (3958.2 ha), etc. The decline in total production in 2024 should be justified by the climatic conditions, which were generally very unfavorable for agriculture. In the period 2019-2024. year, the conversion period was 2880 ha (raspberry), 1287 ha (plum), 1226 ha (cherry) and 310 ha (apple), while the organic status was 6483 ha (raspberry), 3937 ha (apple), 3388 ha (plum), 3731 ha (cherry) (Charts 2, 3, 4).

Charts 2, 3, 4: Conversion period, Organic status, Total ha for cherry, apple, raspberry, plum, 2019-2024.







Source: Authors on the base Ministry of Agriculture, Forestry and Water Management, 2025.

The index level means the level of increase or decrease of some phenomenon in relation to a certain base (initial) value, expressed in %. In this research, the base value is the year 2019, on the basis of which the percentage values of the areas from 2020-2024 are shown. Table 4 shows the values of the areas of vegetable and fruit crops that are in the conversion period. Thus, in the case of cherry cultivation, an index level (%) was calculated that clearly shows the increase in areas from 2020-2024 compared to 2019. In the case of apples and raspberries, there is a high percentage difference in areas for the given period, but in a negative context. In 2020, the areas under plum fell significantly compared to 2019, while in the following year 2021 (6.38%), there was a sudden increase in areas (by 100%) and even a positive increase in the amount of 6.38%. The reason for this is attributed to the Covid-19 situation, where production stopped abruptly, and therefore the registration of areas to certification houses and the competent Ministry. The other years were in a very small percentage decline.

Table 4. Areas (ha) in the conversion period and index level (%), 2019-2024

Frut	Conversion period					
	2019	2020	2021	2022	2023	2024
Cherry	110.6664	220.328	173.8487	274.0939	237.1171	210.6265
I.N.	100.00	99.09	57.09	147.68	114.26	90.33
Apple	84.4862	69.122	66.2694	23.991	16.8534	49.8705
I.N.	100.00	-18.19	-21.56	-71.60	-80.05	-40.97
Raspberry	1014.826	0.087	570.6622	505.3241	393.1749	324.6117
I.N.	100.00	-99.99	-43.77	-50.21	-61.26	-68.01
Plum	252.7867	58.1696	268.9243	215.5197	250.3234	241.5794
I.N.	100.00	-76.99	6.38	-14.74	-0.97	-4.43

Source: Authors on the base Ministry of Agriculture, Forestry and Water Management, 2025.

Conclusion

Current evidence clearly shows that agriculture, if it is based on intensive and chemical-intensive approaches, is a significant source of pollution of soil, water, food and biodiversity. However, sustainable and effective alternatives are available: organic and agroecological practices, precision agriculture, rational use of resources, reduction of harmful inputs and responsible management of land and water. The transition to such systems can contribute to the production of safe food, environmental conservation, stability of agroecosystems and long-term sustainability of agriculture. Organic production is an alternative that contributes to environmental conservation, rational use of resources, reduction of pesticide use, production of higher quality and healthier products, which can achieve sustainable development goals and, through organic agriculture, the achievement of one part of the 2030 Agenda, over a longer period of time. The Republic of Serbia, from the aspect of agriculture, has the potential to expand the market and the production of organic products. In this direction, there are certain institutional bodies that encourage, monitor, and control organic agricultural practices and products, for which a certain certificate is obtained, recognized by the European Union and European laws. In Serbia, fruit is one of the most famous organic plant species. In the period 2019-2025 the total area of organic fruit in Serbia amounted to 33,027.03 ha. The largest areas were recorded by raspberries, apples, plums and cherries. In the same period, the conversion period was the largest in the case of raspberries, plums, cherries and apples, while the highest organic status was recorded for raspberries, apples, plums and cherries. The only exception was in 2024, when climatic conditions were very unfavorable for agriculture.

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Kvalitet i kontrola organski proizvedenog voća kao faktor održive zaštite zemljišta u Republici Srbiji

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Abstract

Organska poljoprivreda ima ključnu ulogu u obezbeđivanju zdravstveno bezbedne hrane, očuvanju životne sredine i održivom korišćenju prirodnih resursa, prvenstveno zemljišta. Organska proizvodnja podrazumeva sistem kultivacije zasnovan na principima održive i ekološke poljoprivrede, koji izbegava upotrebu veštačkih đubriva, pesticida, GMO-a i drugih hemikalija, pri čemu štiti čoveka i prirodnu okolinu. Pored ekoloških i nutritivnih benefita, razvoj tržišta organskih proizvoda omogućava potrošačima pristup sigurnim, kvalitetnim i raznovrsnim namirnicama, dok proizvođačima pruža ekonomsku održivost i konkurentsku prednost. Efikasna kontrola i sertifikacija organskih proizvoda su neophodni za očuvanje poverenja potrošača i osiguranje usklađenosti sa međunarodnim standardima kvaliteta i bezbednosti hrane. Integracija proizvodnje, tržišta i kontrolnih mehanizama predstavlja ključ za unapređenje održivog sistema prehrambene industrije. Cilj ovog rada je da ukaže na značaj tržišta i kontrole kvaliteta organskog voća u Srbiji (2019-2024), koje predstavlja jednu od najpoznatijih organskih biljnih vrsta, od kojih prednjače malina, jabuka, šljiva i višnja. Rad se pored uvoda uvoda satoji od tri dela. U prvom delu rada razmatraju se uzroci i efekti zagađenja proisteklog iz poljoprivrede, kao i strategije održive proizvodnje, uključujući organsku poljoprivredu, koja omogućava proizvodnju zdravstveno bezbedne hrane u kontekstu savremenih ekoloških izazova. Drugi deo rada ukazuje na povezanost ciljeva održivog razvoja i organske poljoprivrede, njihovog odnosa kroz Agendu 2030, kao i važnost kontrolisanja organske poljoprivrede i organskih proizvoda kako bi se proizveli bezbedniji i kvalitetniji proizvodi za životnu sredinu i ljudsko zdravlje. Treći deo rada prikazuje najpoznatije organske biljne vrsta voća u Srbiji.

Ključne reči: *tržište, kontrola kvaliteta, organsko voće, Srbija.*

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