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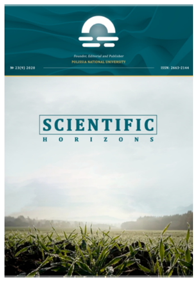

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Comparative characteristics of plant protection against copper and sulphur influence

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Abstract. Efficient agriculture provides not only food security but also improves the economy of the country. Despite the existence of different types of agricultural production (traditional or organic), plant protection is currently a necessary component. Copper and sulphur are effective against pests and improve the quality and quantity of crops, but are toxic and harm the environment, biodiversity, and human health. The purpose of the study is to investigate the current situation regarding the use of copper and sulphur in plant protection in the Republic of Albania and other countries of the Balkan Peninsula and Europe. Theoretical and empirical research methods were used in the study. As a result, it was determined that the studied elements were actively used in different European countries, both in traditional and organic agriculture. There is a tendency to reduce the norms of use, and in some countries – the removal of these chemical elements

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from plant protection programmes. The paper includes a comparative characteristic of the use of copper and sulphur and a survey among Albanian agricultural producers on the use of preparations based on these elements. It is established that in the republic, copper and sulphur are actively used mainly in the form of herbicides and fungicides. They are used on vegetable and fruit crops, as well as grapes and olives. There is a problem of informing producers about the negative impact of copper and sulphur on the environment and human safety, as well as control by the state. The practical significance of the study lies in the analysis of the current situation of copper and sulphur use in Albania and in the identification of ways to change it for the better

Keywords: inorganic pesticides; nanofertilisers; efficiency; crop production; organic production

INTRODUCTION

Agriculture is an integral part of the well-being of any country, as it provides food security, which is especially important considering recent events. Thus, the COVID-19 pandemic and Russia's war with Ukraine have led to an economic crisis around the world, especially in Europe and Central Asia (The World Bank, 2022). The constant and rapid growth of the world population, as predicted by many researchers, is also an issue that needs to be addressed (Shahini *et al.*, 2022). All this requires paying more attention to the agricultural sector. Gaps in the research on the use of copper and sulphur in plant protection in several Balkan countries determine the relevance of the study.

Following M.A. Horvat *et al.* (2019) and D. Dokic *et al.* (2022), the agricultural sector of the Balkan countries has undergone significant changes that occurred several decades ago because of the transition from a planned to a market economy. The desire of these countries to integrate into the European Union (EU) is caused not only by geographical but also by political reasons. F.Z. Zupanic *et al.* (2021) report that agriculture in the Western Balkan countries accounts for an average of about 10% of gross domestic product (GDP), and according to the World Bank (2020), the agricultural sector in Albania accounted for more than 18% of GDP and provided 36% of employment in 2019. Wahab *et al.* (2022) argue that it is possible to increase agricultural production using pesticides, which allows increasing gross yields and improving the quality of products, but the use of chemicals also harms the environment and human health, especially their uncontrolled use. This requires a re-evaluation of agriculture, and the introduction of modern, environmentally friendly technologies, including plant protection.

According to M. Ranjith and S. Sridevi (2021), it is necessary to increase agricultural production while minimising the harmful impact on the environment for sustainable development. World experience shows that this can be achieved through integrated plant protection, modern fertilisation technologies using smart fertilisers with slow or controlled release of elements, biological control agents, and genetic breeding. Copper and sulphur have been used for a long time in plant protection and are well studied, but modern requirements of environmental friendliness and safety for human life require limiting their use or complete removal from the system of agricultural pest and pathogen control. Despite the high efficacy of inorganic pesticides, studies show that they pose ecotoxicological problems for the biodiversity of agricultural landscapes and aquatic ecosystems, and copper and its compounds are among the most prominent soil pollutants (Global assessment of the impact..., 2017).

A. Kir *et al.* (2022) investigated the use of copper oxychloride against olive leaf spots and found that copper accumulated in the soil and in the fruits and leaves of olive trees, which posed a risk to human health. A. La Torre *et al.* (2018) argue that copper cannot penetrate plant tissues and is washed away by rain, accumulating in the soil. However, copper and sulphur are allowed for use not only in traditional but also in organic agricultural production regardless. Notably, in recent years, the EU countries have been actively searching for alternative substitutes for copper, while less attention is currently paid to sulphur, although it has been proven to be toxic to pollinators and other beneficial arthropods (Gesraha & Ebeid, 2019).

The purpose of the study is to investigate the use of copper and sulphur in agriculture in the Republic of Albania and other countries of the Balkan Peninsula and Europe. The main objectives were to analyse scientific literature on the subject; to compare the characteristics of copper and sulphur, which are actively used in the form of inorganic pesticides and fertilisers; to conduct a survey of agricultural producers on the use of copper and sulphur in plant protection.

MATERIALS AND METHODS

The study applied theoretical and empirical research methods. The theoretical basis was the main provisions and results of research by many scholars of European countries and the Balkan Peninsula, dedicated to the use of copper and sulphur in the production of agricultural products. To search for scientific literature, the following web resources and databases were used: Google Scholar, World Wide Science, Directory of Open Access Journals (DOAJ) and AGRIS. Scientific literary sources were selected by the topic, using a series of searches by key words, by the type of journals, and the year of publication. First, the articles were identified, then the review and selection of only those publications that were relevant to the topic of the current study was carried out. Literary sources were analysed on the following issues: the use of the investigated microelements in traditional and organic agriculture, their effectiveness, effects on plants, pathogens and pests, biodiversity, ecology, and human health. Moreover, an important aspect was the study of the use of alternative copper and sulphur plant protection products. In addition to the analysis of literary sources, the abstract logical method and the method of analogy were also applied to investigate the use of copper and sulphur-based pesticides and their alternatives; comparative method was used during the study of the main characteristics of these elements; grouping, abstraction, and generalisation of the received information was also conducted.

A survey was conducted to investigate the issue of the use of copper and sulphur in plant protection and the attitude of agricultural producers towards these micronutrients in the Republic of Albania in 2022. The questionnaires were distributed through the online testing software Google Forms, as well as among representatives of agricultural enterprises in Tirana, Elbasan, Berat, and Gjirokastra. The number of respondents was 216, of which 179 were Google Forms participants. The survey included 8 questions and three specific answer options for each item (Table 1).

***Table 1**. Questionnaire content*

No.	Question	Answers
1	What system of crop production do you consider appropriate?	a) traditional; b) integrated; c) organic.
2	How do you regard chemical plant protection?	a) positive, I use it in full; b) negative, I try to use alternative means of protection; c) tolerant, I use it only when necessary.
3	What are your concerns when deciding on protective measures with pesticides?	a) cost and effectiveness of chemicals; b) necessity; c) price, safety, effectiveness, and environmental friendliness.
4	How often do you use pesticides and fertilisers based on copper and sulphur?	a) constantly; b) if necessary, occasionally; c) do not use.
5	Do you use alternatives to copper and sulphur?	a) yes; b) no; c) if possible.
6	What sulphur-based products do you use the most?	a) herbicides; b) fungicides; c) fertilisers.
7	On which crops do you use inorganic copper- and sulphur-containing preparations?	a) on all crops grown on the farm; b) do not use on any crops; c) only on vegetables, fruits, olives, and grapes.
8	Do you support the ban on copper and sulphur in plant protection?	a) yes; b) no; c) I support only partial limitation of the norms of use.

***Source:** compiled by the authors*

In a survey with the participation of producers of agricultural products regarding the use of copper and sulphur in plant protection, the following ethical principles were used: legality; respect for human rights and freedoms, prevention of discrimination; objectivity and impartiality; voluntariness; competence and professionalism; honesty and confidentiality.

RESULTS

A survey on the use of copper and sulphur by crop producers in the Republic of Albania by questionnaire method showed that most of them were oriented towards integrated (50.5%) and traditional (30.1%) farming systems, and only 19.4% of respondents were interested in organic production (Table 2).

***Table 2**. Results of the survey on the use of copper and sulphur in plant protection, Republic of Albania, 2022*

Question number	Respondent answers					
	a		b		c	
	quantity	share, %	quantity	share, %	quantity	share, %
1	65	30.1	109	50.5	42	19.4
2	106	49.1	11	5.1	99	45.8
3	78	36.1	16	7.4	122	56.5
4	151	69.9	62	28.7	3	1.4
5	28	13.0	104	48.1	84	38.9
6	123	56.9	77	35.6	16	7.4
7	39	18.1	3	1.4	174	80.6
8	6	2.8	106	49.1	104	48.1

***Source:** compiled by the authors*

It was also determined that crop producers had different opinions on chemical plant protection: almost half of the respondents expressed a positive assessment of the use of inorganic fertilisers and pesticides, about 5% gave a negative answer, others were tolerant in this matter. When choosing protective measures, more than 56% of Albanian producers consider not only the cost and effectiveness of such measures but also their environmental friendliness and safety. This figure indicates an incomplete understanding of the respondents about the impact of chemicals on the environment and human health, which requires clarification and control by the state authorities. Most agricultural producers (about 99%) use copper and sulphur-based products. Among them, sulphur-containing herbicides take the first place, fungicides (mainly copper-based) take the second place, and fertilisers take a small share. It was established that copper and sulphur-based fertilisers in the Republic of Albania were used on vegetable (mostly solanaceous) and fruit crops, grapes, and olives. Regarding alternative plant protection products to copper and sulphur, it was determined that almost half of the producers did not use them at all. The ban on copper and sulphur-containing products was supported by only 2.8% of respondents, while other producers were divided almost in half into those who do not support such an initiative and those who support the introduction of certain restrictions on the use of such products. As such, the survey shows that Albanian crop producers actively use copper and sulphur in plant protection; and a low level of awareness of the negative impact of these chemical elements on the environment and human health.

It has been established that today the elements under study are allowed for use in most countries of the world (Andrivon, 2018; Hykas *et al.*, 2022), but due to the ability to accumulate in the environment and food, and due to toxicity, copper-based preparations are gradually abandoned, especially in European countries (Katsoulas *et al.*, 2020). Despite this worldwide trend, copper-based fungicides are still actively used, even in organic agriculture. Eurostat data (2022) on the volume of pesticide sales in European countries in 2020 indicate that fungicides and bactericides accounted for the largest share (43%) of their total volume, followed by herbicides (35%), insecticides and acaricides (14%). It was noted that inorganic fungicides containing copper and inorganic sulphur accounted for almost 57% of the fungicides and bactericides sold during this year (Fig. 1).

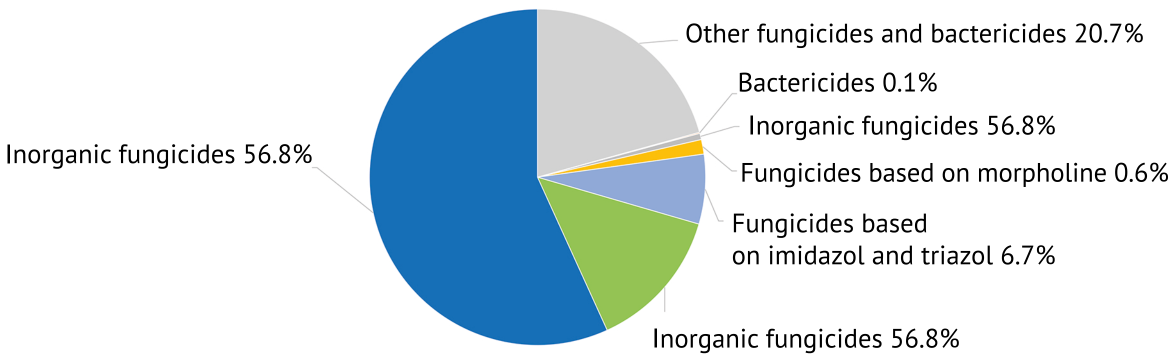

***Figure 1**. Share of fungicides and bactericides sales by active ingredients in European countries in 2020, %*
***Source:** Eurostat (2022)*

Eurostat data (2022) show that the leaders in sales of fungicides and bactericides in 2020 were Spain, Italy, France, and Turkey. The volume of these sales ranged from 20.5 to 37.9 thousand tonnes. The lowest level of sales of these goods was recorded in Iceland, Malta, and Norway. It was at the level of 0.2-93.6 tonnes. Such figures are related to the level of development of agricultural production in these countries.

The European Commission data on the intensity of pesticide use indicate that the most active substances are used in the production of agricultural products by the most economically developed countries. For example, the Netherlands – 8.8 kg/ha, Ireland – 6.9 kg/ha, and Belgium – 6.7 kg/ha of active substance. The lowest level of pesticide application (1.5 kg/ha) is typical for Slovakia, Lithuania, Latvia, Denmark, and Bulgaria (EU Pesticides Database, 2022), that is for countries with a less developed economy. In Spain, Italy, Germany, France, and Poland are seeking to reduce or even ban the use of copper compounds in agriculture. This is conditioned by the development of organic production and increased demand for ecological and safe food products. It was also clarified that copper is not registered as a means of plant protection in five European countries: Denmark, Estonia, the Netherlands, Finland, and Sweden (Tamm *et al.*, 2022).

Under the European Commission (EU Pesticides Database, 2022), the following active substances containing copper are allowed for use in agriculture in the EU countries: copper compounds, copper hydroxide, copper oxide, copper oxychloride, copper tri-basic sulphate, and the prohibited ones are 8-hydroxyquinoline with salicylic acid and dithiocarbamic acid derivatives. Among sulphur-containing pesticides allowed for use in plant protection are preparations with the following active ingredients: amidosulfuron, bensulfuron, flazasulfuron, foramsulfuron, halosulfuron-methyl, iodosulfuron, mesosulfuron, metsulfuron-methyl, nicosulfuron, prosulfuron, rimsulfuron (or renriduron), sulfosulfuron, sulfuryl fluoride, tifensulfuron-methyl, triflusulfuron and tritosulfuron.

Copper group fungicides are characterised by contact-prophylactic and protective action. Their fungicidal action is more effective against the spores of the pathogens than against the development of the mycelium of the fungus. Preparations of the copper group are characterised by the fact that the active substance is adsorbed by the cytoplasm of the cells of fungi. Fungal spores gradually adsorb copper from solutions up to lethal doses. The solubility of copper preparations is facilitated by the excretion of plants, fungi, carbon dioxide from the air, precipitation, etc. The intense transition to the soluble state helps to increase the fungicidal activity of drugs of the copper group, but at the same time increases their phytotoxic effect. The biological effectiveness of fungicides of the copper group depends on the correctly defined period of application and the uniformity of coverage of vegetative organs with working mixtures.

Copper compounds are most effective in protecting against pathogens of mildew, apple and pear scab, and some spots of fruit, berry, and vegetable crops. The biological features of the development of mushrooms are characterised by the fact that their mycelium lives and harms inside the cells of plants. On the surface of vegetative organs, fungi form only asexual sporulation. The mechanism of action of copper compounds has only a preventive protective nature. Therefore, copper fungicides should be used in accordance with the forecast of the spread and development of phytopathogens. Plants must be sprayed with working mixtures of preparations from the beginning of the spore flight until the possible infection of the tissues of the host plant. When a pathogen enters plant cells, drugs of this group are not able to destroy it. The duration of the protective effect of drugs of the copper group is 10-20 days. Therefore, the subsequent use of drugs is determined by weather conditions, the intensity of disease development, and the duration of the protective effect of the fungicide. One of the serious disadvantages of fungicides of the copper group is their phytotoxicity, which is manifested in long-term and significant humidity. Plants are especially sensitive during the period of active growth. Therefore, it is necessary to remember that not only different types of plants, but also their varieties react differently to the phytotoxicity of copper-based preparations. Due to such circumstances, it is necessary to consider all the factors that determine the sensitivity of plants to the preparations of this group.

Sulphur, along with copper, is also an important microelement for plants and is involved in various physiological processes. In plant protection, sulphur-containing preparations are used to destroy weeds, pathogens, and pests (mites, insects). Previously, sulphur was actively used for the fumigation of warehouses and greenhouses to control pests and mould fungi, but now there are more effective and safer means. Recently, the main use of sulphur is in herbicides and fungicides. Table 3 illustrates the comparative characteristics of copper and sulphur by the main indicators.

The fungicidal and acaricidal properties of sulphur-based preparations are revealed at high air temperature, but they must be applied in the morning or evening. Gooseberries and black currants are very susceptible to sulphur fungicides, therefore, before applying on large areas, it is advisable to check their effect on several bushes of certain varieties. Sulphur preparations can be used not only for processing vegetative plants, they can be applied to the soil to limit damage to cabbage by clubroot and root rot (*Pythium*). Sulphur suppresses the development of powdery mildew pathogens, and also restrains the spread of apple and pear scab.

Thus, the study results showed that those elements differed in terms of action and objects of use, but their relatively low cost and the absence of alternative means contributed to their wide application for plant protection in the research region under both traditional and organic agriculture.

***Table 3**. Comparative characteristics of copper and sulphur application in plant protection*

Attribute	Copper	Sulphur
Plant protection means	fungicides, fertilisers	herbicides, fungicides, insecticides, acaricides, fertilisers
Biochemical functions in plants	participation in photosynthesis and transpiration, synthesis of chlorophyll, anthocyanins, etc., increase of stress resistance to drought, improvement of pollen fertility	participation in protein metabolism, involvement in photosynthesis, improvement of root nutrition, increase immunity to diseases
Harmful element	oomycetes, peronospore fungi, bacteria	weeds, powdery mildew fungi, mites, and insect pests of storage products
Effect on harmful organisms	copper ions cause the denaturation of proteins in pathogen cells and accelerate intracellular oxidative processes	blocks the synthesis of amino acids in the growth points in weeds, disrupts the processes of hydrogenation and dehydration in fungi, effect on insects and ticks has not been studied
Advantages of usage	wide range of effects, formation of a low level of resistance to pathogens, relatively low acute toxicity to mammals, high efficiency in rainy weather, low cost, permit in organic crop production	low level of resistance to harmful organisms, wide range of effects, low cost, permission for use in organic production
Disadvantages	toxicity to invertebrates (worms, pollinators, entomophages), phytotoxicity, formation in the soil of compounds inaccessible to plants, can accumulate in the environment	phytotoxicity, narrow temperature range of application (18-28˚C)

***Source:** compiled by the authors*

DISCUSSION

The use of copper and sulphur in plant protection is important in the current context. Their accumulation in agricultural landscapes may hurt the environment in the future. According to D. Andrivon (2018), the large volumes and widespread use of copper in agriculture are subject to increased regulation. Since the invention of Bordeaux mixture in the late 19th century, copper has been a key element in methods of combating fungal and bacterial diseases, especially in viticulture, fruit, and vegetable growing. According to N. Katsoulas *et al.* (2020), this remedy is still used in several European countries: France, Greece, Germany, Turkey, etc.

Following Wahab *et al.* (2022), the volume of pesticide use in the Republic of Albania is 350-400 tonnes per year, with a steady increase in this figure. Currently, chemicals are actively used on vegetables both in the field and in greenhouses, as well as in vineyards and intensive orchards. The survey determined that the use of copper and sulphur-based pesticides in the country is widespread. Albanian agricultural producers use them on almost all crops against weeds (sulphur-containing herbicides), and on potatoes, tomatoes, cucumbers, grapes, olives, and in orchards against diseases and pests.

Notably, the countries of the Balkan Peninsula (Albania, Bosnia and Herzegovina, Serbia, North Macedonia, Montenegro) are heading towards the EU, and due to the lack of domestic production of pesticides and fertilisers in this region, imports of these products prevail. According to T. Brankov and B. Matkovski (2022), the same pesticides and fertilisers are used in the Western Balkan countries as those allowed for use in the EU, but according to the World Health Organization (2008), there are risks of using unregistered and obsolete chemicals that remain in large quantities from the past.

Copper is allowed on perennial crops against fungal and bacterial diseases affecting vines, bunches, and leaves of grapes, fruits and leaves of stone fruits and pome fruits, and nuts. The authors note that copper is also used, contrary to recommendations, against brown rot on apricots and black rot on grapes (Kullaj *et al.*, 2017). Copper-based fungicides are also approved for use on vegetable crops of various botanical groups (in the field and greenhouses), on cereals against some seed diseases, aromatic, essential oil, and ornamental and medicinal plants. Copper and sulphur can be used in organic agricultural production, but with certain restrictions.

The main characteristics of these chemical elements will be considered in more detail. Copper (Cu) is of great importance for living systems and is involved in energy metabolism and has biocidal properties that are used to manage human, animal, and plant health. L. Tamm *et al.* (2022) admit that copper has a broad spectrum of action against several harmful objects of agricultural plants (oomycetes, ascomycetes, basidiomycetes, and bacteria), which is especially important for the control of widespread and harmful diseases: tomato late blight and grape mildew, and diseases of other crops.

According to G. Borkow, J. Gabbay (2005) and D. Andrivon (2018), the exact mechanisms of action on pathogens are not fully understood. The authors argue that there are several hypotheses in this regard. For example, the biocidal effect of copper ions is manifested through the loss of electrolytes from the cell through its membrane, by blocking the normal functioning of proteins in microbial cells, or by disturbing the ionic balance of cells, etc. Copper compounds are used in chemical protection in the form of fertilisers, which contributes to the enhancement of natural plant immunity, but most often in the form of fungicides. They are used against the following diseases: cucumber peronosporosis, grape mildew leaf spot of olives, and phytophthora infestans.

Despite the widespread use and high efficiency of copper and sulphur in plant protection, these elements, depending on the concentration dose, have a toxic effect. L. Kiaune and N. Singhasemanon (2011) state that copper- and sulphur-containing inorganic fungicides can run off and reach surface waters and accumulate in the soil. For example, recent studies conducted by G.D. Gikas *et al*. (2022) in vineyards showed that long-term use of copper-based fungicides led to the accumulation of high concentrations of copper in the soil, which affected pesticide biodegradation, soil structure, availability of nutrients to plants and their resistance to pathogens. According to the authors, sulphur also has toxic properties towards beneficial fungi and bacteria. In addition, their studies show that sulphur is phytotoxic to pumpkins, apricots, and raspberries.

It was established that the repeated use of copper and sulphur-based products was the main source of soil and water pollution. A. Kir *et al*. (2022), while studying the use of copper on olive plantations, concluded that copper accumulated not only in the soil layer, but also in the leaves and branches of trees, which negatively affected biodiversity and human health.

A. La Torre *et al*. (2018) state that high copper concentrations in the soil layer can reduce the population of earthworms and carabids, which is a cause of ecological imbalance, as these animals play an important role in maintaining healthy ecosystems and soil formation processes. K.J. Rader *et al*. (2019) also noted that these elements could have a detrimental effect on aquatic biota when released into water bodies. Thus, according to their data, the toxicity of copper was influenced by pH and the amount of organic carbon in dissolved water. M. Ranjith and S. Sridevi (2021) report the negative effects of chemical pesticides on soil microorganisms and animals. They also note that to reduce the harmful effects of copper and sulphur on beneficial organisms, it is necessary to use the achievements of nanotechnology in agriculture: sulphur nanoparticles (SNPs) and copper nanoparticles (CuNPs), which have low cytotoxicity. A. Karthik and M.U. Maheswari (2021) argue that nanofertilisers retain a large number of nutrients with a particle size of 30-40 nm, slowly releasing them according to the planned yield.

E. Angeleska *et al*. (2011) note the harmful effects of elevated copper concentrations in the soil on the condition of cultivated plants. It is known that excessive amounts of copper compounds negatively affect the growth and development of aboveground and underground plant organs, which leads to a decrease in their total biomass and yield. Legumes, grapes, hops, and cereals are particularly sensitive to copper. The toxicity of this element is related to the bioavailability of copper ions. It has been established that copper concentrations above 2 μM can be phytotoxic. This situation requires the search for new alternative means against diseases.

As a result of the analysis, it was determined that there were no effective and affordable alternatives to the use of copper and sulphur. According to M.E. Sadek *et al*. (2022), various plant extracts with fungicidal effects, chitosan, seaweed, etc., are currently among the proposed alternatives to copper. It is also stated that no copper substitutes for plant protection are effective, and research on this issue is ongoing. The study by N. Katsoulas *et al*. (2020) included a survey of organic producers on alternative plant protection products to copper and sulphur. They determined that in ten European countries, resistant varieties, biological control agents, plant extracts, etc., were used as substitutes for the chemical elements under study. The research showed that in European countries, copper is still used quite often in plant protection, while sulphur and mineral oils are used less often. As the authors admit, this indicates a limited use of alternatives to chemical elements, or such products do not have the necessary effect compared to inorganic substances. Similar conclusions were obtained after a survey of Albanian agricultural producers, which revealed the total use of sulphur-containing herbicides on almost all crops and copper fungicides mainly on vegetables and fruit crops, olives, and grapes.

The studies by A. Karthik and M.U. Maheswari (2021) describe in detail the protective measures alternative to inorganic chemicals. As such, alternatives to copper include combinations of substances with a reduced copper content of up to 2-6%, which reduces the amount of this chemical element per hectare of crops; potassium compounds (e.g., K_2SiO_3 and potassium bicarbonate), sulphur lime, zeolite, and kaolin; natural alternative formulas that allow replacing or reducing the copper usage rate; plant extracts with biocidal properties; biological control agents that have different mechanisms of action against bacterial and fungal pathogens of crops; chitosan, a natural polymer derived from chitin; seaweed extracts (*Ascophyllum nodosum* and *Laminaria digitata*) that can enhance the natural immunity of plants; pest-resistant plant varieties.

G.D. Gikas *et al*. (2022) argue that sulphur alternatives are not currently used, mainly for economic reasons, as sulphur is cheaper and more readily available than other substances. In addition, sulphur is considered a substitute for mineral oil, which is used against harmful mites and insects on citrus, olives, and tomatoes. Aside from pesticides, fertilisers containing copper or sulphur are also used in agriculture. An analysis of the situation with the use of copper and sulphur in Europe and the Balkans has shown a tendency to limit, and in some countries – to completely ban, the use of copper in plant protection. Thus, according to L. Tamm *et al.* (2022), over the past ten years in Europe, there was a gradual restriction on the use of copper in plant protection, and in 2021, the maximum amount of copper allowed for use was 28 kg. The authors note that the goal is to phase out copper from production, and this element is already on the EU's list of replacement candidates.

Thus, copper and sulphur are widely used in Europe and the Balkans, although there is a gradual tendency to reduce it in plant protection. It was established that it was impossible to abandon their use for objective reasons at the moment. Moreover, active searches for alternatives to these substances have been ongoing recently.

CONCLUSIONS

The survey of Albanian agricultural producers showed the total use of copper (fungicides) and sulphur (herbicides, fungicides, acaricides) in plant protection. The majority of respondents adhere to integrated and traditional farming, and less than 20% practice organic farming. In the Republic of Albania, copper and sulphur are used on vegetables, fruits, grapes, and olives. Alternative plant protection products are rarely used. The positive and tolerant attitude of producers to these chemicals was revealed, which indicates problems with awareness of the negative impact of chemicals on the environment and human health, or the lack of other options to protect the crop.

In Europe, the volume of sales of fungicides and bactericides in 2020 among all types of pesticides was 43%, of which 57% were based on copper and sulphur. Economically developed countries used the largest amount of copper and sulphur in plant production.

A comparison of the main characteristics of copper and sulphur in plant protection showed that those two chemical elements had several common features related to their participation in plant physiological processes (photosynthesis, protein metabolism, etc.), development of natural plant immunity to stressors, phytotoxicity, and negative effects on the environment and human health (in certain concentrations). Otherwise, copper and sulphur are very different: in terms of objects and methods of use, mechanism of action, etc. For example, copper has a biocidal effect in the presence of droplet moisture, its ions penetrate pathogen cells and cause protein degradation, while sulphur has a fumigant effect due to the formation of hydrogen sulphide, which causes the death of fungal spores.

This research showed that in further studies, it is necessary to conduct an additional analysis of global developments in the use of copper and sulphur in plant protection, and to continue research to find substitutes for these elements that would be highly effective in combating harmful crop pests and minimise the burden on the environment. This would allow any country, including Albania, to ensure food security in a constantly changing world.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Анотація. Актуальність питання, представленого в даній роботі, визначається сучасними даними про синтез саліцилової кислоти (СК) в рослинах, які свідчать про те, що наявність деяких транзиторних факторів у бавовнику є сигналом про активацію стрес-протекторних функцій рослини. Збільшення вмісту ключових медіаторів захисної сигнальної системи в клітинах бавовнику спричиняє активацію стресових факторів, запускаючи захисні механізми живого організму. Таким чином, стійкість рослин до певних видів абіотичного стресу досягається за рахунок активації захисних реакцій сигнальної системи. Цей процес дозволяє цілеспрямовано використовувати біологічно активні речовини, такі як саліцилова кислота. Тому метою даної роботи є дослідження комбінованих властивостей захисної сигнальної системи деяких генетичних типів рослин бавовнику за умов синтезу в них фенольних кислот. Провідним підходом до вивчення цього питання є лабораторний експеримент, який дозволив комплексно розглянути лінії бавовнику, що містять РНК, чутливі до певних видів абіотичного стресу. Додаткові біологічні та хімічні методи були використані як допоміжні в польових умовах для перевірки специфічного впливу засолених ґрунтів на концентрацію саліцилової кислоти в РНК бавовнику. У цьому дослідженні представлені дані про стійкість генотипу ESKIMO1 з РНК-інтерференцією (RNAi) до засолення та обмеженого зрошення. Досліджено вміст саліцилової кислоти в тканинах бавовнику за дії різних концентрацій NaCl. Обґрунтовано утворення активних форм кисню в процесі активації захисних реакцій рослин на окремі види абіотичного стресу. Матеріали дослідження мають практичне значення для мікробіологів, генетиків та агрономів. Дослідження біотехнологічних особливостей генотипу рослин відіграє важливу роль у розумінні адаптації рослин до природних умов, спричинених певними типами абіотичного стресу. Доступність саліцилової кислоти дозволяє широко застосовувати її як комерційний реагент у практиці рослинництва

Ключові слова: саліцилова кислота; стійкість; засолення; рідинна хроматографія; метаболізм