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C– Life Sciences and Biotechnology

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C – Yaşam Bilimleri ve Biyoteknoloji

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C- Life Sciences and Biotechnology
Eskişehir Teknik Üniversitesi Bilim ve Teknoloji Dergisi C – Yaşam Bilimleri ve Biyoteknoloji

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RESEARCH ARTICLE

ANALYSIS OF PROBLEMS EXPERIENCED IN ECO-INDUSTRIAL PARK INSTALLATION BY ANP METHOD

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[3] Endüstri Mühendisliği Bölümü, Kırıkkale Üniversitesi, Kırıkkale, Türkiye

ABSTRACT

As the population increases rapidly in the world, the needs of people increase at the same rate, trying to supply the needs of people. On the other hand, supplying needs raises the problem of consumption of limited resources. In this study, the installation of eco-industrial parks, one of the clean production and recycling studies developed due to the consumption of resources, was discussed. Eco-industrial parks are industrial zones established to increase enterprises' economic, social, and environmental performance and gain ordinary profits through cooperation. In this study, the difficulties of setting up an eco-industrial park were identified through a literature review. Purpose of the study; eco-industrial park installations to be realized smoothly, existing problems before the installation of the eco-industrial park to be identified as the most critical problems, identified issues to be solved, and support to maintain. The criteria determined were evaluated by the ANP method, and the most important criterion was financial problems.

Keywords: Industrial symbiosis, Analytical network process, Eco-industrial park

1. INTRODUCTION

The need for resources is also increasing with industrialization and population. To meet the need for resources, an increase in production, consumption, and environmental pollution accompanied by production has begun. Pollution and consumption growth have also made people, businesses, and states aware of the cyclical economy. The circular economy consists of recycling systems that protect the environment and prevent the consumption of resources [1]. One of these systems is the concept of Industrial Symbiosis (IS). Symbiosis is a relationship in which two or more species benefit and transfer energy, matter, or information to each other [2]. IS is a system in which companies cooperate in an industrial sense and provide mutual benefits to each other [3]. With IS, one company can use the waste of another company as a raw material. Thanks to this, inter-company cooperation increases, waste decanted into the environment decreases, and resource efficiency increases.

With these mutually beneficial partnerships in enterprises, waste, and by-products are recovered, savings are achieved in resource use, and raw materials and energy are used efficiently to reduce environmental emissions. The concrete application of industrial symbiosis approaches is Eco-Industrial Parks. Sustainable and clean production is targeted in these practices [4].

Eco-industrial parks are resource exchange applications that occur with the cooperation of enterprises geographically close to each other, even though they are independent in an industrial zone. Industrial plants that are independent of each other and preferably located close to each other form a coexistence. The total benefit to be obtained by working together will be more than the sum of the benefits based on the business that the businesses will obtain by optimizing their functioning only [5]. This application, which is very important and profitable for enterprises and resource efficiency, requires material flow

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analysis, determining the measures to be taken within the facilities, and eliminating system inefficiencies [6]. However, some problems may occur in accordance with these requirements. Therefore, this study discusses the problems that may be experienced in the eco-industrial park installation process. Looking at the literature, there are many studies on the installation and application of eco-industrial parks. In this study, problems that need to be addressed before installation and applications and that need to be solved before installation have been identified, and priority values of the problems have been calculated. Due to the quantitative structure of the study, it differs from other studies in the literature. This study aimed to identify the most critical problems to identify and solve before the installation was started. While eco-industrial parks have emerged on the concept of sustainability, these parks should also be sustainable. Ensuring this situation is possible by taking solid steps in the first stage when the system is just beginning to be established. Therefore, this study's primary purpose and motivation is to avoid the problems encountered in light of the criteria determined during the planning stage of the installation of these applications and to proceed with solid steps. The studies in the literature were examined, and the criteria that were effective on the problem were determined. These criteria were evaluated by the ANP method. The power of the ANP method to evaluate the interaction and relationships between the criteria was utilized. By converting the qualitative evaluations into quantitative values, the priority values of the criteria that caused the problems encountered during the establishment of eco-industrial parks were calculated. This study answers how businesses that turn to eco-industrial parks due to the environmental damage caused by industrial parks can establish a more accessible system today when sustainability is important. In this respect, contributions are made to businesses and the literature.

This study consists of six parts. In the second part, eco-industrial parks are explained. In the third part, studies in the literature are given. In the fourth part, the method used is explained. Numerical results are also included in the fifth part. In the last part, the obtained results are interpreted.

2. ECO-INDUSTRIAL PARKS

Industrial ecology aims to balance industrial development with the sustainable use of natural resources to develop environmentally friendly production and consumption. On the other hand, ensuring the relationship between society, the economy, and the environment focuses on issues such as protecting renewable resources, carefully using energy, and recycling [7]. Many enterprises aimed at industrial ecology are established at a close distance from each other and in a connected way [8]. Due to the connections between enterprises, industrial zones are transformed into industrial ecosystems. These connections are also called IS [9].

An IS is an approach based on mutual benefit between industries. It is when at least two enterprises working independently, although physically close to each other, establish relations that can improve environmental performance and competitiveness [10]. Some applications of IS have been developed in eco-industrial parks, and these eco-industrial parks are seen as concrete facts of the concept of IS [3].
The eco-industrial park is a community of companies in the production and service sectors that want to improve their environmental and economic performance by cooperating in managing the environment and resources (energy, water, and matter) [11]. Eco-industrial parks aim to reduce the flow of materials and energy and environmental impacts, ensuring profit and common benefit in the economic and social development of facilities close to each other.

An eco-industrial park;

- From a by-product exchange model or exchange network,
- From a recycling business group (resource recovery or recycling companies,
- From all environmental technology companies,
- Green product manufacturing companies,
- An industrial park designed around a single type of environmental theme (solar-powered park),
- From a park with an environmentally friendly infrastructure or structure,
- Industrial, commercial, or local, mixed-use development

there should be more [8].

It is helpful to organize a further study of industrial projects with the exchange of materials; to think differently, although it is suggested by industrial ecology. Chertow proposed five different eco-industrial park models in his study. These recommendations are presented in Table 1.

Table 1. 5 Eco-industrial park models proposed by Chertow [8]

Model	Explanation
Exchange through waste exchanges	In this model, enterprises give their waste to recycling facilities. The waste exchange is one-sided, and there is no energy exchange with water. Since it is an old and traditional method, it is the most distant model to the definition of IS.
An exchange within a facility, company or organization	In this model, an enterprise acts as a separate enterprise to its subunits and provides between units. In this way, profits can be made on purchases and product designs.
An exchange between companies located in a defined eco-industrial park	In this model, water, energy, and material exchange is carried out between companies and organizations in the eco-industrial park. Relations can be established not only between companies in the park but also with organizations outside the park.
Exchange between local firms that are not placed side by side	In this model, exchanges take place between businesses in a region. Although they are not neighbors, a symbiotic relationship be established between businesses with geographical proximity.
Exchange between companies organized in a wider region	In this model, a virtual connection is established between businesses not located in the same region, and item exchanges are performed. However, the options are not unlimited due to shipping costs.

3. LITERATURE RESEARCH

In recent years, the effects and causes of climatic and environmental changes in the world have increased awareness of sustainability. IS is one of the methods considered to be the key strategy that promotes the sustainable use of resources. IS is mainly based on the principle that the waste produced by one company can be used by other companies to replace production inputs or to produce new products [1].

Since the late 1990s, different studies have been carried out on the planning and design of industrial zones that have adopted an IS approach. As a result, industrial diversity and cooperation are ensured in industrial zones and industrial parks thanks to the work done. As a result, energy and water efficiency are maximized, and waste formation and environmental effects caused by waste are minimized; systems can be established in which companies' economic performance increases, product diversity and economic competition increase, and sustainable industrial zones are created [6].

Many studies have been carried out to evaluate systems in existing industrial parks. Economic growth and environmental protection have been critical issues in facilitating the development of eco-industrial parks in China. As the main contributors to China's industrial production, many industrial parks address issues of intensive resource consumption and pollutant production driven by stricter environmental and resource management regulations [12]. In Chinese industrial parks, the central wastewater treatment plant is a critical shared infrastructure for further purification of pre-treated industrial wastewater on-site [13]. In another study conducted in China, they prioritized the benefits of eco-industrial parks by considering their benefit criteria and evaluating them with Gray-Delphi and VIKOR methods [14]. An IS application has been developed in Turkey, which also carries out wastewater treatment and where a

zero-waste process takes place, where the useful use of the waste of one of the two different sectors as the raw material of the other is revealed [15].

In addition to the evaluation studies in the literature, there are also different studies. In one of these studies, a Clean Production and IS decision support platform were implemented with the support of the EU project with the partnership of Turkey-Switzerland. As a result of the studies carried out for this platform, a decision support platform was designed and developed, and case analyses were shared through the platform [16]. In another study, the potential for transforming organized industrial zones and industrial zones into eco-industrial parks is expected to be the most suitable means for foreign capital investments to enter our country and become permanent by turning them into significant investments, has been studied [17]. In a study conducted in Şanlıurfa, companies in the Organized Industrial Zone were examined, and the alternatives to converting this industrial zone into an industrial eco-park were examined. In addition, a survey study on waste has been carried out for companies, and it has been aimed to form the basis of waste assessment systems for the industrial zone [18].

To support decision-makers who wish to establish and operate an IS network, Analytical Network Process and the criteria to be considered and their importance was calculated with the method of analytical hierarchy process [19].

This study focuses on the criteria that cause problems in establishing eco-industrial park applications that will be designed to reduce the harmful effects of the industry on the environment. Making the evaluation of these criteria with the ANP method, taking into account the interaction and relationship between the criteria, contributed positively to the construction of the establishment process of the enterprises in terms of literature review and real life. In addition, it also contributes to the literature by emphasizing the things that should be considered in the light of the criteria to avoid possible problems that may be encountered at the planning stage.

4. MATERIALS AND METHODS

The decision constantly evolves, but it is a selection process made from among the available options, adhering to at least one goal and criterion. At this selection stage, Multi-Criteria Decision-Making (MCDM) methods are used to make the correct decision. MCDM methods, in which binary comparisons of the criteria that have been determined are usually based, contribute to making the right decision through numerical data and in the future [20].
In this study, the problems likely to occur in the eco-industrial park installation were determined with the help of other literature studies. The criteria priority values were calculated using the Analytical Network Process method. The study aims to support the smooth implementation and maintenance of eco-industrial park installations.

4.1. Analytical Network Process Method (ANP)

The ANP developed by Saaty allows more complex relationships between decision levels and features to be taken into account [21].

Stages of the Analytical Network Process Method:

1. Stage: The decision-making problem is determined.
2. Stage: The relationship of the criteria with each other is determined.
3. Stage: Decoupling comparisons are made between the criteria.
4. Stage: The consistency of the comparison matrices is checked.
5. Stage: Super-matrices are created.
6. Stage: The best alternative is determined and the choice is made [22].

In the ANP method, the level of criteria influence on each other is indicated by a network that matches the nodes [23]. Criteria in a node can affect some or all of the criteria in any other node. The established relationships are indicated by arrows in the network structure, and the direction of the arrows, the dependence between the nodes [24-25]. The dependence between two nodes is called an "external dependence" and is indicated by a two-way arrow. In contrast, the dependencies between the lower criteria within a node are called "internal dependence" and are indicated by the arrow as a loop. Considering the studies on ANP in the literature, [26] in performance evaluation, [27], [28], [29], are seen in energy to study.

5. RESULTS

5.1. Defining The Problem

With the industry's progress, the world's natural balance has also begun to deteriorate, leading to many other problems, such as global warming and climate change. Therefore, people have also started to take measures for these problems and to work to make the production in the industry cleaner. Some of these studies aim to increase the industry's resource efficiency, renewable energy sources, and labor productivity. In these studies, the industry has emerged concepts such as clean production, industrial ecology, and eco-industrial park. Eco-industrial parks are systems that target clean production and zero waste so that problems will cause away from the target. In parks that are not well designed and do not have strong management, resource efficiency cannot be achieved, and costs increase in waste disposal. In these cases, there are problems in the establishment of eco-industrial parks. Therefore, it is necessary to identify and solve the problems that may occur in the installation of the park. In this study, the criteria that may occur during the installation of an eco-industrial park have been identified by examining other studies in the literature and the requirements and regulations for installing an eco-industrial park. The criteria identified were evaluated using the ANP method, which is one of the MCDM methods. The flow chart of the study is shown in Figure 1. The criteria and their description are found in Table 2. Table 2 also shows the criteria categorized as main and sub-criteria.

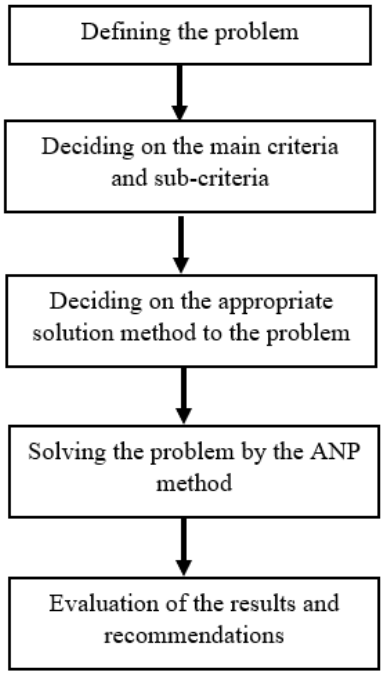

Figure 1. The flow chart of the study

Table 2. Criteria and descriptions

Main Criteria	Sub-Criteria	Explanation
Organizational Barriers (OB)	Competition	Inter-company races with similar aspects, decoupling.
	Distrust Between Firms	The state of trust between firms that do not know each other decently or know each other incorrectly.
	Location of the Park	It is the geographical location of the current or upcoming park.
	Transportation Facilities	The transportation facilities of the park are such facilities as the surrounding land road, sea road, air road.
Legal Barriers (LB)	Lack of Information	Lack of knowledge about IS, recycling, eco-industrial parks and laws.
	Compliance with International Standards	Compliance with the necessary standards for the installation of an eco-industrial park.
Economic Barriers (EB)	Financial Problems	Financial support will be provided to companies that will establish an IS network.
	Infrastructure Expenditures	Necessary infrastructure costs for park installation or recycling works.
Technological Barriers (TB)	Lack of Infrastructure	The lack of requirements for the installation of an IS network and an eco-industrial park.
	Lack of Hardware	It is the lack of equipment that enterprises or the park have.
Institutional Barriers (IB)	Available Recycling Facilities	These are recycling facilities that companies own, cooperate with other enterprises, or produce by recycling.
	Disbelief in the Usefulness of the System	It is the idea of not being able to benefit institutionally from the concept of EIP.
	Non-Compliance with the Concept	If there is a concept of a park that exists or is planned to be established; this is a case of non-compliance with the concept.

5.2. Solving The Problem

The problem was solved by the ANP method. The ANP method, developed by Thomas L. Saaty, is a decision-making method that considers the relationships between the criteria at the decision stage and eliminates the need for one-way modeling of the problem. Because it considers the relationships between the criteria and facilitates the solution of complex problems, this method was preferred when analyzing the problems experienced in installing an eco-industrial park. By examining the literature, the criteria that were effective on the problem were determined. The network structure was created by considering these criteria' relationships, interactions, and feedback [30]. Pairwise comparison matrices were established according to the network structure and relations. In paired comparison matrices, how effective the criteria are relative to each other was determined using Saaty's 1-9 [31] scale.
Figure 2 shows the network structure established in the study.

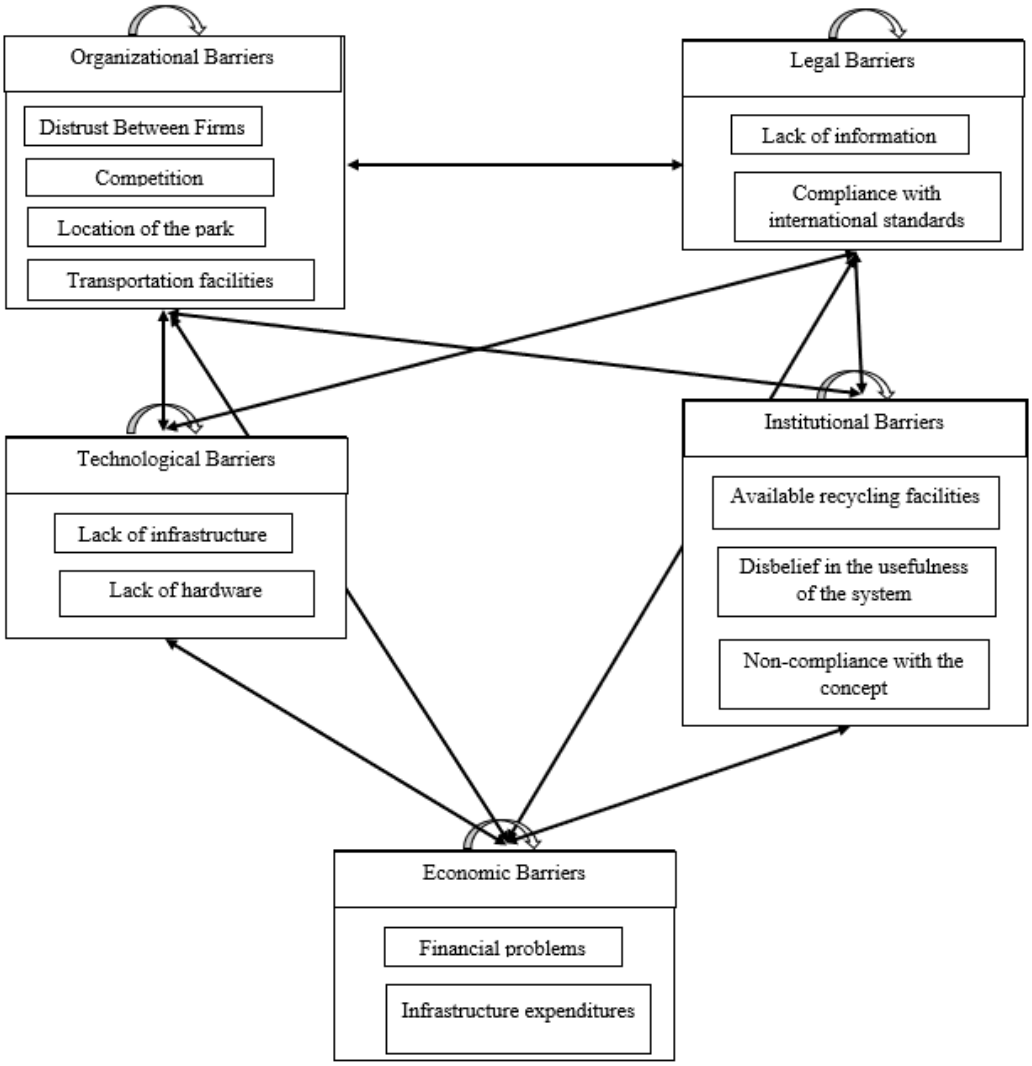

Figure 2. Network structure established according to the ANP method

5.3. Evaluation of the Solution Method

In the ANP method, pairwise comparison matrices are created between the criteria in a relationship. Table 3 shows the pairwise comparison matrix of the main criteria, the legal barriers criterion, as an example. Table 4 shows the criteria weights obtained from the evaluations of all pairwise comparison matrices. Table 4 shows the priority values calculated for the criteria.

Table 3. Comparisons for the main criterion of legal barriers

EB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	IE
EB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	OB
EB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	TB
EB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	LB
IB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	OB
IB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	TB
IB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	LB
OB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	TB
OB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	LB
TB	>=9.5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	>=9.5	LB

Table 4. Calculated priority values for the criteria

Main Criterias	Criteria Weights	Sub-Criteria	Sub-Criteria Weights
Organizational Barriers (OB)	0.195	Competition	0.153
		Distrust Between Firms	0.545
		Location of the Park	0.172
		Transportation Facilities	0.130
Legal Barriers (LB)	0.470	Lack of Information	0.460
		Compliance with International Standards	0.540
Economic Barriers (EB)	0.122	Financial Problems	0.673
		Infrastructure Expenditures	0.327
Technological Barriers (TB)	0.136	Lack of Infrastructure	0.635
		Lack of Hardware	0.365
Institutional Barriers (IB)	0.077	Available Recycling Facilities	0.483
		Disbelief in the Usefulness of the System	0.229
		Non-Compliance with the Concept	0.288

According to the priority values resulting from the ANP method, the most important criteria/problems are financial problems, lack of infrastructure, distrust between companies, compliance with international standards, and existing recycling facilities. The five most important sub-criteria also belong to different main criteria. These main criteria are, respectively: economic barriers, technological barriers, organizational barriers, legal barriers, and institutional barriers. If these main criteria are also sorted by their degree of importance, respectively, it is seen that there are legal barriers, organizational barriers, technological barriers, economic barriers, and institutional barriers. In this case, the solution to problems should start from the main criteria with the highest priority value and the most important sub-criteria of these main criteria.

6. CONCLUSIONS

IS is based on the principle that the output of one company can be used as production input by other companies. Eco-industrial parks, one of the applications of IS, coexist on common property and are defined as a community of production and service industries that can exchange waste with each other, allowing enterprises to increase their social and individual benefits.

When literature studies are examined, IS strategies are determined, criterion weights for EIP installation are calculated, EIP potential calculations are performed, and different IS applications are observed. This study differs from other studies in identifying and analyzing problems that may occur in installing EIP.

This study identifies problems likely to occur during the installation process of eco-industrial parks. These problems have been solved with ANP from MCDM methods. The ANP method supports the study in terms of establishing a relationship between criteria, and the problems should be addressed in accordance with the results obtained from the method. Organizational barriers, legal, economic, technological, and institutional barriers, including 5 of 13 covered by these criteria, the main criteria and sub-criteria, and priority of the relations established between the ANP method by calculating the values of the solution have been reached. The results from this study; EIP was taken for a region that

will be set up; the problems identified to prevent possible problems, speed up the installation process, eliminate the costs of subsequent projects, and aims to be a reference for error. Therefore, before establishing an eco-industrial park in a region, possible problems should be examined. Thus, a smooth installation can be achieved. It contributes to sustainable production and the protection of natural resources and provides benefits and expected benefits in enterprises' economic and social development.

These problems consist of the sub-criteria used in the solution of the ANP method. The solution results show that legal barriers are the main criteria. Financial problems, lack of infrastructure, and distrust between companies are the criteria with the highest priority values. Priority should be given to the sub-criteria under the main criterion of legal barriers, and firms should have information about IS and EIP. In addition, international standards should be investigated and made compliant with the standards. Other important sub-criteria also indicate the improvements and innovations the enterprise must make before an eco-industrial park is established. Since being located in an eco-industrial park means a large environmental investment, enterprises need to minimize their financial problems and prepare for the necessary infrastructure. Eco-industrial parks require cooperation between companies, so the necessary attention should be paid to competition, which is one of the most important. The distrust between companies should also be eliminated. In future studies, these criteria can be evaluated using fuzzy multi-criteria decision-making methods. In addition, the parks established in the light of these criteria can be evaluated.

CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

AUTHORSHIP CONTRIBUTIONS

Edanur Sonel: Formal analysis, Writing - original draft, Visualization. Şeyda Gür: Formal analysis, Investigation. Tamer Eren: Supervision, Visualization, Conceptualization.

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ESKİŞEHİR TEKNİK ÜNİVERSİTESİ BİLİM VE TEKNOLOJİ DERGİSİ C- YAŞAM BİLİMLERİ VE BİYOTEKNOLOJİ

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EVALUATION OF HEAVY METALS CONCENTRATIONS OF *Verbascum diversifolium* AND *Alcea calvertii* PLANTS

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ABSTRACT

Depending on atmospheric and industrial pollution, heavy metals can accumulate in the soil and affect the ecosystem. Plants are important biological controllers of environmental pollution. Elemental analysis in plants is among the alternative effective methods used for ecological research. In this study, the usability of plant species such as *Verbascum diversifolium* and *Alcea calvertii*, whose heavy metal content was determined, as biomonitors was investigated. The mineral content measurements of the extracts prepared from the leaves and flowers of the examined plant species were made with an Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES). Heavy metal (Cd, Pb, Cr, As, Zn, Ni) concentrations in plant extracts were determined. In our study, it was determined that the heavy metal tolerance of these two plant species was high. It is thought that it will be important to determine plant species resistant to heavy metals, to clean nature and to prevent human-induced heavy metal pollution from becoming a major problem for all living things in the future.

Keywords: Heavy Metal, *Verbascum diversifolium*, *Alcea calvertii*

1. INTRODUCTION

The problem of urbanization due to rapid population growth in the world has caused heavy metal pollution and brought various problems over time [1-3]. In our age, environmental problems are one of the most important dangers that threaten the natural balance and living things. Heavy metals are a group of non-biodegradable environmental chemicals [4]. Heavy metals are metals with a density greater than 5 g/cm3. Heavy metals that are not absolutely necessary for living things in nature; cadmium (Cd), chromium (Cr), mercury (Hg) and lead (Pb). They have toxic effects even in trace amounts. Heavy metals such as copper (Cu), chromium (Cr^{+3}), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn) and nickel (Ni) are necessary for living things up to a certain level. These elements, which are intensely present in living things, can cause serious diseases and even death when they reach effective doses [5,6].

There are many factors that affect the accumulation of heavy metals in the plant structure. The interaction of many factors such as plant-related factors such as plant species and genetic structure, plant organ-related factors, heavy metal-related factors such as type of heavy metal, interaction with the plant, exposure time, etc. play a role in the entry and accumulation of heavy metals into the plant. [7,8].

However, the possible interactions of these chemicals with each other in the ecosystem are not fully known. For a long time, traditional methods and chemical analysis methods have been used to determine environmental pollution [9,10]. Plants contribute to the reduction of air pollution by accumulating heavy metals, and in this way, the use of plants is an important source of choice for reducing air pollution [11,12]. Recent studies have increased on “bioindicator” or “biomonitor” living things that accumulate toxic substances. However, these methods do not give much information about the effects of pollutants on living things in the environment. Thus, it is possible to have an idea about their concentrations in different ecosystems by analyzing toxic substances in various organs of living things with biomonitoring

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properties [13]. Analyzing the contaminants accumulated in the tissues of living things, evaluating the effects of these substances that cause environmental pollution on the environment where living things live, and representing potential pollution are the most important reasons for using biomonitors. Especially in environmental pollution, pollution caused by radioactive materials is an important problem today. Plants are important biological controllers of environmental pollution [14]. The concept of metal accumulation by plants has aroused great interest as it can be used economically to clean metal-contaminated soils. Detoxifying metal-contaminated soils with plants may represent a low-cost eco-friendly technique [15].

Study material *Verbascum diversifolium* Hub. – Purple, is an endemic specie for our country. Verbascum L. is one of the largest genera of the Scrophulariaceae family. Verbascum genus, which is represented by more than 360 species in the world, usually grows in the temperate regions of the Northern Hemisphere [16]. In our country, the Malvaceae family is represented by 14 genera. One of these genera, Alcea, is represented by 20 species in our country and 2 of these species are endemic to our country. It mostly spreads in the whole of Europe except the north, in North America, in the north of Africa, in parts of the Caucasus and Southern Russia, and in the part from Anatolia to Afghanistan [17].

Heavy metal accumulation may vary according to plant species and plant organs. [18-20]. The most suitable plant species and organ should be determined separately for the monitoring of each heavy metal. In the study, heavy metal contents of medicinal plant species such as *Verbascum diversifolium* and *Alcea calvertii* were evaluated.

2. MATERIALS and METHODS

2.1. Collection of Plant Materials

Verbascum diversifolium Hochst., *Alcea calvertii* Boiss. species were collected from the roadside of the Gözeli plain during the flowering period of the plants. The region where it was collected is shown in Figure 1. The above-ground parts of the collected plant materials were dried in the shade. The aerial parts of the dried plant samples were extracted with a soxlet device using ethanol as a solvent [21]. Extraction was continued until the final extract was colorless. The ethanol content of the extracts obtained from the Soxlet device was removed in the evaporator and the dry extracts formed were stored at +4 ℃.

Figure 1. Distribution areas of plants and the region where they are collected in Turkey

2.2. ICP-OES Heavy Metal Analysis

For solubilization process with microwave oven, 0.5 g of sample was transferred to Teflon solubilization vessel and 6 mL of 65% HNO_3 and 2 mL of 30% H_2O_2 were added and teflon bombs were placed in the microwave oven. The program of the microwave device was adjusted to go up to 200°C for 15 minutes and stay at 200°C for 15 minutes (Table 1). After the incineration process, the samples that were in solution were taken into balloons and made up to 50 ml with ultrapure water. The plasma of the ICP device is burned and ultrapure water is passed through the system for 15 minutes to stabilize it. According to the elements to be analyzed, mixture standard solutions were prepared and a calibration chart was created. After the calibration chart was created, the samples were given to the system and the reading process was performed. According to the results of the analysis that did not fall into the calibration graph, different calibration graphs were created at ppm or ppb level and re-reading was performed.

Table 1. Microwave program

Step	Time	T1	T2[(1)]	Power
1	00:15:00	200℃	110℃	Maxpower*
2	00:15:00	200℃	110℃	Maxpower*

[(1)]Optionalsensor, *MaxPower: 1500W forEthosand 1200W for Start units. Useupto 500 Wattforoperationswith 3 orlessvesselssimultaneously.

3. RESULTS AND DISCUSSION

The mineral content of the extracts prepared from the leaves and flowers of the studied endemic plants *Verbascum diversifolium*, *Alcea calvertii* were measured by Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES). Concentrations of toxic minerals (Cd, Pb, Cr, As, Al and Ni) in plant extracts were compared in Table 2.

Table 2. Heavy metal limit values accepted by FAO/WHO in plants [22,23].

Heavy Metal	VDF (mg kg^{-1})	VDL (mg kg^{-1})	ACF(mg kg^{-1})	ACL(mg kg^{-1})	FAO/WHO (mg kg^{-1})
Pb	31.864	3.633	2.441	5.134	10
As	6.165	6.989	5.573	11.346	3
Cd	0.4278	0.4604	0.261	0.4814	0.3
Cr	29.094	32.077	1.161	48.146	2.0
Ni	28.746	0.0027	16.824	45.774	1.63
Zn	13.390	17.907	29.605	55.643	27.4

Verbascum diversifolium flower (VDF), *Verbascum diversifolium* leaf (VDL), *Alcea calvertii* flower (ACF), *Alcea calvertii* leaf (ACL).

Pb, one of the toxic minerals, was found to be highest in the leaves of *A. calvertii* when all plants were evaluated. However, when all the data were compared with the FAO/WHO data, it was determined that it was not above the toxic limits, but below the consumable limits. When the As concentrations of the plants were examined, it was found that the As values in all plants were above the FAO/WHO limits, but the highest concentration was in the leaves of *A. calvertii*. Cd and Cr values in plants were found to be above the FAO/WHO accepted limits in all plants except the flowers of *A. calvertii*. Another Ni element was found to be above the specified limits only in the flowers of *V.diversifolium* and the leaves

of *A. calvertii*. It was determined that Zn was below the limits in *V.diversifolium* and above the specified limits in the flowers and leaves of *A. calvertii*.

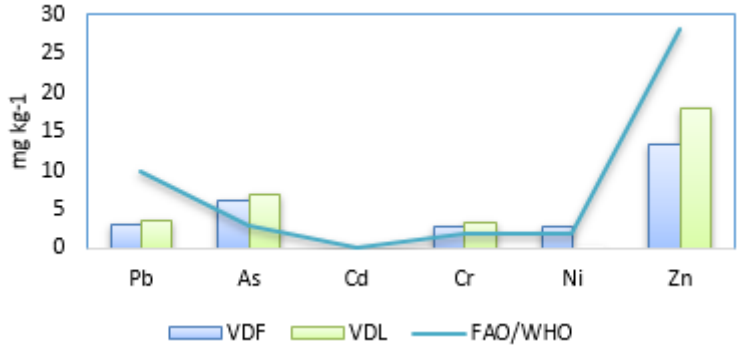

Figure 2. Comparison of VDL and VDF Heavy metal results with WHO values

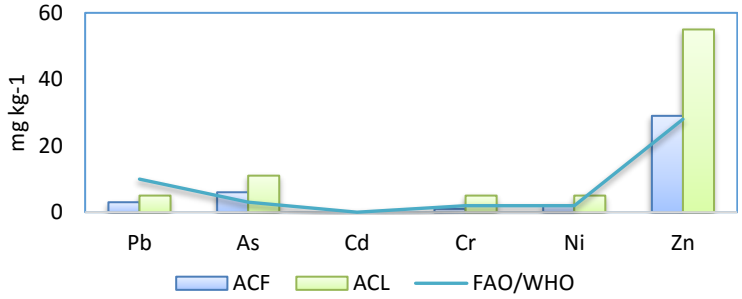

Figure 3. Comparison of ACL and ACF Heavy metal results with WHO values

In terms of usability as a biomonitor, the plant species we studied here, were not found in the literature research. However, findings obtained from different species in similar studies were compatible with the results of our study. Kaya and Gülser (2018) investigated the heavy metal (Fe, Mn, Cu, Zn, Cd, Cr, Ni and Pb) contamination potential in the leaves of the *Alcea rosea* (L.) plant grown in roadside soils. Significant differences were found in the heavy metal concentrations of the leaves. They found that the Fe, Cu, Cr, Ni, and Pb contents of the leaves decreased significantly ($P<0.05$). The highest average content of Fe, Mn, Cu, Zn, Cd, Cr, Ni, and Pb is 810.20 mg kg^{-1}, 63.01 mg kg^{-1}, 34.02 mg kg^{-1}, 29.12 mg kg^{-1}, 25.08 mg kg^{-1}, 14.47 mg kg^{-1}, the lowest average heavy metal content 7.42 mg kg^{-1}, and roadside sampling in leaves, respectively 7.00 mg kg^{-1} 157.75 mg kg^{-1}, 30.49 mg kg^{-1}, 8.20 mg kg^{-1}, 13.89 mg kg^{-1} , 0.01 mg kg^{-1}, 0.76 mg kg^{-1}, 0.57 mg kg^{-1} and 0.70 mg kg^{-1}. Fe, Cu, Zn, Mn, and Ni averages of *A. rosea* seeds were reported to be 24.38, 0.016, 0.179, 0.526, and 0.004 mg kg^{-1}, respectively [24]. In a study conducted by Yener (2007), as a result of the measurements carried out to determine whether *Alcea pallida* can be used as a biomonitor or not, it was stated that the highest value of Zn and Cd accumulation in *A. pallida* was found in the leaf and the lowest value in the flower [25]. When we compared this study with the results we obtained, Pb and Cd were found in the leaf extract of *Alcea calvertii*, and Zn was found to be high in the flower extracts of *Alcea calvertii*. The results obtained are consistent with our findings.

Idrees et al. (2018) analyzed the toxic metal contents of common medicinal plants. All selected metals were found to be higher than the WHO allowed limits in most plants. It was reported that the highest Cr (5.10 mg kg^{-1}), Ni (4.78 mg kg^{-1}) and Fe (129.04 mg kg^{-1}) concentrations were detected in *Verbascum thapsus*. It has also been reported that the Co concentration is found at 4.40 mg kg^{-1} in *Verbascum thapsus* [26]. When we compared the results of the *Verbascum diversifolium* plant that we used in our

study, it was found that the Cr and Ni concentrations were close. In their study, Chaplygin et al. (2022) determined the levels of Mn, Cr, Ni, Cu, Zn, Pb, Cd for *Verbascum thapsus*. Zn, Pb, Cr and Cd and polyelement contamination were detected in *V. thapsus* plants. While the accumulation of Zn by plants mostly occurred in the root system, most of the other accepted heavy metals were found in the vegetative parts of the plants [27]. In our study, higher amounts of Pb Cr Ni Zn were detected for *Verbascum diversifolium*, especially in flower extracts. In a study by Tuncturk et al., (2018) in which they studied *Verbascum orientale* L., which grows naturally around Lake Van in the Eastern Anatolia Region, the heavy metal contents of Cr 0.05 mg kg^{-1}, Cd 0.14 mg kg^{-1}, Co 1.54 mg kg^{-1}, Zn was determined as 29.81 mg kg^{-1} and Pb as 0.04 mg kg^{-1}[28]. When compared with our study, it was determined that the Pb, Cr and Cd values were lower than the concentrations we obtained, and the Ni concentration was much higher than the data we obtained Eren and Mert (2017), in their study; According to the findings obtained from rhododendron (*Inula helenium*), lantern grass (*Physalis angulata*) and mullein (*Verbascum thapsus*) plants in soils contaminated with Ni, Cd and Cu, it was determined that the Ni, Cd and Cu concentrations accumulated in the tissues of the plants did not reach levels that would cause toxicity. The highest Ni content was obtained from 400 mg kg^{-1} application of lantern grass, the highest Cd content was obtained from 10 mg kg^{-1} application in lantern and mullein plants, and the highest Cu concentration was obtained from 200 mg kg^{-1} application of lantern plant As a result of the experiment, it was determined that lantern grass and mullein plants have the potential to be used in the cleaning of soils contaminated with heavy metals [29]. Although the species we used in our study were different from the species used in these studies, the results obtained as shown in Figure 2 were parallel to these results due to their structural features. Güleryüz et al. (2005) analyzed the element contents (Cu, Fe, Mn, Ni, Pb and Zn) to determine the index value of *Verbascum olympicum* Boiss. They also examined the element values in different organs of the plants. The maximum values of all the metals examined were determined at a very high level in the organs. Metal content in different organs of *V. olympicum* showed differences [30]. These results show that the metal content in the organs is reflected in the soils of the regions. Many factors such as differences in plant physiology, soil properties, agricultural management practices, ecological interaction can explain the different metal accumulation in plants. The accumulation capacities and biomonitoring properties of other Verbascum species were supported by our findings and previous studies on heavy metal. When we compare the data obtained as a result of our study with the heavy metal limit values accepted by FAO/WHO in plants, the acceptable limit values for As are reported as 1.63 mg kg^{-1} for 3 mg kg^{-1} Ni, 0.3 mg kg^{-1} for Cd, and 2.0 mg kg^{-1} for Cr [31]. According to Table 2, As; in all plant extracts studied; Cd and Cr in other plant extracts except flower extracts of *Alcea calvertii*; Ni was found above the reference value in other plant extracts except the leaf extracts of *Verbascum diversifolium.*

As a result of the study, it was determined that most of the elements in the leaf and flower extracts were at different levels. Different heavy metal concentrations have been reported in different organs in studies conducted to date [32, 33, 12]. Therefore, the structure and characteristics of the organ can significantly affect heavy metal uptake [34, 35].

As a result of the data obtained, as shown in Figure 3, it was found that the Pb, As, Cd, Cr, Ni, Zn results of the leaf extracts of *Alcea calvertii* were much higher than the reference values. As a result of the determination of the metals in the flower and leaf extracts of the plants, it was determined that some of them could be considered as metal accumulators. The collected plant samples were found to be acceptable as metal accumulators, although they had different deposition abilities for each metal. According to the results, the best accumulator was found to be *Alcea calvertii*. It was determined that the heavy metal accumulation of *Alcea calvertii* was higher when compared to the other studied species. Bioaccumulator plants are expressed as plant species that accumulate pollutants at higher concentrations than the living things in their environment [36]. Therefore, *Alcea calvertii* can be considered as a good bioaccumulator plant.

The use of some plant species commonly found in natural vegetation in the cleaning of ecosystems polluted with heavy metals is gaining increasing importance today. As a result of all the evaluations, the

studied *Verbascum diversifolium*, *Alcea calvertii* species show that the plant species has high tolerance to heavy metals. Identifying plant species resistant to heavy metals will be important in cleaning nature and preventing heavy metal pollution caused by humans from becoming a major problem for all living things in the future. Measures are needed to prevent contamination of agricultural lands. One of the methods that can be applied in such problematic or potentially problematic areas is the use of tolerant plant species and varieties.

4. CONCLUSION

The results obtained, the heavy metal content of the plants we studied can be evaluated as a biomonitor. It is important to find plant species resistant to heavy metals, which is one of the factors that pollute the nature. The results of the analysis on the examined plant species show that they can be used as an important source for further studies.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

AUTHORSHIP CONTRIBUTIONS

Tuba TÜRKOĞLU: Writing - original draft, Visualization. **Semra TÜRKOĞLU:** Formal analysis, Investigation, Conceptualization, Supervision, Visualization, Conceptualization.

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ESKİŞEHİR TEKNİK ÜNİVERSİTESİ BİLİM VE TEKNOLOJİ DERGİSİ C- YAŞAM BİLİMLERİ VE BİYOTEKNOLOJİ

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RESEARCH ARTICLE

ECOLOGICAL FOOTPRINT CONCEPT: A CASE STUDY FROM ANADOLU UNIVERSITY

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ABSTRACT

Quantifying the impact of humans on the environment is very difficult due to its complex nature. An ecological footprint is an effective tool and indicator that quantitatively reveals the impact of human beings on the world while maintaining their vital activities, the cost of living or their burden on nature. In this study, the ecological footprints of 179 teacher candidates studying at Anadolu University Faculty of Education were determined by using an international scale. 34.1% of teacher candidates were in the department of primary school education, 35.2% in the department of pre-school education and 30.7% in the department of special education. The ecological footprint results were given in the categories of date, necessary world, land type, consumption categories, ecological footprint, a carbon footprint and percentage effect of carbon footprint on ecological footprint. According to the results, no significant difference was found between the ecological footprints of teacher candidates based on department and gender (except services footprint). However, the ecological footprint values of the teacher candidates were above the average of Türkiye ($p<0.05$). Since teachers, who are one of the most important elements of education, have a great responsibility in raising individuals/society who are conscious and sensitive to environmental problems, teacher education on this issue is very important. It is believed that this study will contribute to the studies to be carried out on the subject.

Keywords: Ecological footprint, Teacher candidates, Anadolu University, Türkiye

1. INTRODUCTION

With the rapid increase in the world population and industrialization, the demand for natural resources and the increase in pressure on these resources have revealed the necessity of questioning the continuity of wealth and production-consumption activities on a global scale. In this context, the concept of sustainable development, which is a multidimensional concept that combines economic, social and environmental elements, has been put forward in order to ensure the continuity of the development of societies [1]. However, in the last period, the emphasis on the concept of ecological sustainability has increased, along with sustainable development, due to the pressure placed on the planet by industrialization and the increasing population, and human beings consuming more than they produce.

Meeting the needs of the present without compromising the capacity of future generations to meet their needs is defined as ecological sustainability [2]. The understanding of the limitations of natural resources has led to an increase in the sensitivity of societies and scientists to the environment. Due to the complex nature of human and environmental relations, it is very difficult to quantify the impact on a global, country, institutional and even personal scale. In order to overcome this difficulty and to determine ecological sustainability quantitatively, Wackernagel and Rees [3] first introduced the concept of ecological footprint in 1996.

The ecological footprint is an indicator that quantitatively reveals the impact of human beings on the world while maintaining their vital activities, the cost of living or their burden on nature [4]. The main emphasis in the concept of ecological footprint is that for the sustainability of life, individuals should

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organize their living conditions and economic activities by taking into account the carrying capacity of the planet. Ecological footprint, which is on an international scale, consists of built-up land, forest products, cropland, grazing land, fishing ground and carbon footprint components in terms of land types. When considered on an individual basis, the effects on nature during a person's vital activities are calculated on the basis of these components and the results are given in terms of global hectares. The global hectare area represents the productive capacity of 1 hectare of land over the world's average productivity [2]. Then, using these values, the global hectares corresponding to the consumption categories of the person including food, shelter, transportation, goods and services and finally the ecological footprint are calculated. In short, a metric of sustainability, the ecological footprint transforms consumption and waste generation into units of the equal land area [5]. An exciting way to make society aware of some of the less obvious but essential aspects of human ecology and to familiarize people with some of the environmental effects of a consumer society is through ecological footprinting. Since the calculation of the ecological footprint reveals how, by whom, and to what extent natural resources are used, making these calculations is very important in creating the balance of use of natural resources [6].

Another concept that should be considered together with the ecological footprint is the concept of biocapacity. Biocapacity is defined as the supply of natural resources and ecological services. In other words, it is the quantity of productive areas used in the world to produce natural resources. By comparing the ecological footprint and biocapacity values, the minimum sustainability criterion is defined. Accordingly, in order to ensure sustainability, the total ecological footprint should be less than the total biological capacity [7]. When the ecological footprint is greater than the total biocapacity, a biocapacity deficit arises [8-10].

Ecological footprints, biocapacities and related values of countries are reported in studies carried out periodically based on all countries around the world. Türkiye's Ecological Footprint Report prepared by World Wildlife Fund in 2012 is one of them [2]. According to the report, Türkiye's ecological footprint is 50% above its global biocapacity. In other words, Türkiye needs 1.5 planets to continue in this way and this situation is not sustainable for our country. It is predicted that the gap between biocapacity and ecological footprint will continue to increase in favor of ecological footprint and this situation will continue to be a problem in the future [2, 11]. Clearly, efforts are needed in this regard.

In Türkiye, as in the world, the largest of the ecological footprint components is personal consumption with a rate of 82% [2]. Therefore, it is extremely important to determine the ecological footprint values on an individual basis and to raise awareness. For this reason, it is seen that studies on ecological footprints have increased in Türkiye, especially since the beginning of the 2000s [12-22].

Although there is the potential use of communication tools such as TV programs, social media, etc. to raise awareness on the ecological footprint on an individual basis, their effectiveness of them is often controversial [23]. In this sense, getting effective results can only be possible with the total education of society. Teachers, who are one of the most important elements of education, have a great responsibility in raising individuals who are conscious and sensitive to environmental problems [24]. In order for teachers to be sufficient in this regard, they must complete their education with the necessary equipment. For this, the concept of ecological footprint firstly needs to be learned by teacher candidates before they start teaching [1]. It has been demonstrated by research that tools such as the ecological footprint calculation tool will be used in teacher education and that it will be effective in increasing sustainability by raising more sensitive and conscious individuals towards the environment [25]. Few research, however, have examined the relationship between environmental footprint assessment and the value of education for national sustainability in Türkiye [26-35].

Therefore, this study aims to determine the ecological footprints of teacher candidates in different branches based on various variables and to raise awareness about this subject in teacher candidates,

based on the belief that the first group to have knowledge about sustainable development should be teacher/teacher candidates.

2. MATERIALS AND METHODS

2.1. Research Group

179 teacher candidates studying at Anadolu University Faculty of Education participated in the research during the spring term of 2021-2022. When the distribution of teacher candidates according to their gender, it could be seen that 67.6% of them were female and 32.4% of them were male students. 34.1% of teacher candidates studied in the department of primary school education, 35.2% in the department of pre-school education and 30.7% in the department of special education. Information about the research group was summarized in Table 1.

Table 1. Distribution of the research group according to some variables

Department	Gender	Frequency	%
Primary School Education	Male	22	12.3
	Female	39	21.8
Pre-school Education	Male	12	6.7
	Female	51	28.5
Special Education	Male	24	13.4
	Female	31	17.3
	TOTAL	**179**	**100**

2.2. Data Collection and Tools

There are many scales used to calculate the ecological footprint of individuals. In this study, the "Ecological Footprint Scale", a web-based scale with international standards, was used (http://www.footprintcalculator.org/). The scale consists of 16 questions in total. Two of the questions are related to food, six of them are related to shelter, 1 of them are related to goods/services and 7 of them are related to transportation components. The questions in the questionnaire were adapted to Turkish and applied to the participants in the spring term of 2021-2022 in a digital environment. Then, the answers of the participants who answered the scale to questions were entered into the system. When the data is entered into the system, the system calculates and summarizes the ecological footprints of the participants in the date, necessary world, land type, consumption categories, ecological footprint, carbon footprint and percentage effect of the carbon footprint on the ecological footprint, with the algorithm it contains. Thus, based on the automatic calculation of the program, it provides an idea about the consumption patterns of each participant who answered the survey, and due to the comprehensible nature of the data, awareness is created on the subject. Values related to the ecological footprint and its components obtained from the answers given by the participants to the questions were expressed in global hectares (gha).

In addition, through a personal information form developed, the participants were asked whether they had heard of the concept of ecological footprint before, if they had knowledge, whether they consciously applied the principles of ecological footprint in their daily lives and other thoughts they wanted to express, in addition to questions about gender and branch. All the answers given by the participants were recorded and then statistical evaluations were made.

2.3. Data Analyses

When the literature was examined, it was seen that studies on the subject do not include data and comparisons related to the sub-variables of the land type category, which is one of the ecological

footprint components, and comparisons were made mainly based on the values in the consumption category (food, shelter, transportation, goods and services) [1, 26-35]. For this reason, the data related to the land type variable were given over the average values, and the other data were compared statistically.

In this context, firstly, the data were examined in terms of normal distribution, later, ln transformation was applied to the world necessary, food, shelter, transportation and carbon footprint values that were determined not to show normal distribution, and log10 transformation was applied to the ecological footprint data. Analyzes were performed by using these transformed data.

In the evaluations of gender variables, independent samples t-test was used. For branch variable, One-way ANOVA analysis was used and for comparison of the data with Türkiye's average, one sample t test was used. The data were analyzed using the SPSS 21.0 program.

3. RESULTS AND DISCUSSIONS

3.1. Date Data

In the ecological footprint scale, the first value given as a result of entering the data on an individual basis and calculating the ecological footprint value is the "date" data. Date data, based on the calculated footprint value, defines the date when the person consumed all of the world's resources for his/her share for that year. This is very important data in terms of raising awareness about the ecological footprint. Table 2 summarises the average date data of the participants in this study. When Table 2 is evaluated, it is seen that, on average, as of 28 May, teacher candidates used their share of the world resources of that year, and in the following part of the year, they used resources that did not belong to them, and thus a biocapacity deficit emerged. On the basis of gender, it is observed that the critical date for men is 23 May, while for women it is 30 May. It is seen that female teacher candidates of the special education department have the best value in this sense (4 Jun), while male teacher candidates of the primary school teaching department have the worst value (24 May). However, it is a remarkable result that all teacher candidates consume their share of the world's resources before almost half of the year is over. It is desirable that this date falls as far as possible at the end of the year or even on 31 December [2]. In other studies, conducted in our country, no study evaluating ecological footprint and date data together has been found [26-35].

Table 2. Average date data of participants by departments and gender

Department	Gender	Date	Average
Primary School Education	Male	24 May	25 May
	Female	25 May	
Pre-school Education	Male	4 May	26 May
	Female	31 May	
Special Education	Male	31 May	3 June
	Female	4 June	
TOTAL	Male	23 May	28 May
	Female	30 May	

3.2. World Necessary

In the ecological footprint scale, the second value given is the "world necessary" data. The necessary world data of an individual is a data that defines how many worlds are needed if everyone in the world lives like that individual. This is also very important data in terms of raising awareness about the ecological footprint. The expected situation is that the load that everyone creates on the earth during their vital activities is equivalent to 1 earth at most [2]. Table 3 summarises the average necessary world

data of the participants in this study. When Table 3 is analysed, it is seen that the average number of required worlds of all participants in the study is 2.62. When the required world data is analysed by the department, it is seen that primary school teacher candidates have the highest value with 2.72 while special education teacher candidates have the lowest value with 2.49. When compared in terms of gender variable, it is seen that male teacher candidates in the department of pre-school education have the highest value (3.03) and female teacher candidates in the department of special education have the lowest value (2.47). When all teacher candidates are compared together in terms of the required world data, it is seen that male teacher candidates have a higher value (2.73) than female teacher candidates (2.57). In all evaluations made on the basis of both departments and gender, it is clear that it is far above the required value (one world).

Table 3. Average world necessary data of participants by departments and gender

Department	Gender	World Necessary	Average
Primary School Education	Male	2,79	2.72
	Female	2,69	
Pre-school Education	Male	3,03	2.63
	Female	2,54	
Special Education	Male	2,52	2.49
	Female	2,47	
TOTAL	Male	2,73	2.62
	Female	2,57	

When evaluated on the basis of departments, it was determined that the difference between departments in terms of the number of world necessary was not statistically significant (F: 1.714, $p>0.05$). Similarly, there is no statistically significant difference on the basis of gender variable (t: 1.478, $p>0.05$).

The last report on Türkiye's ecological footprint was published by WWF in 2012 [2]. According to the report, Türkiye's ecological footprint exceeds the global biocapacity by 50%. In other words, if everyone in the world consumed as much as a citizen of Türkiye, we would need 1.5 planets. The data obtained in this study were compared with this critical number by means of one-sample t test. Accordingly, the number of worlds needed for the consumption of teacher candidates is statistically different from both the average of Türkiye (t: 29.128, $p<0.05$) and the desired average of 1 world (t: 51.506, $p<0.05$). In other studies, conducted in our country, no study evaluating ecological footprint and necessary world data together has been found [26-35].

3.3. Land Types Footprint

In the ecological footprint scale, the third value given is the “land types footprint” data. The land type footprint data gives the size of the different land types required to meet the world resources consumed by an individual in terms of global hectares. It has some subcomponents. Built-up land footprint data refers to the area covered by infrastructure and superstructure to meet human needs, including transport networks, housing, industrial buildings and hydroelectric power plants. Forest products footprint data refers to the area of forest required to produce wood, pulp, timber, industrial wood and firewood for human consumption. Cropland footprint data refers to the agricultural area required for the production of food, fibre, animal feed, oil crops and rubber for human consumption. Grazing land footprint refers to the grazing area required to produce the products people demand, such as meat, milk, leather and wool. Fishing ground footprint refers to the estimated area of marine and freshwater required to sustain the fish and seafood consumed. Carbon footprint refers to the area of forest required to sequester emissions from fossil fuel consumption, land use changes and chemical processes, with the exception of CO_2 emissions sequestered by the oceans [2]. Table 4 summarises the average land type data (gha) of participants by departments and gender in this study. Table 4 shows that cropland has the highest average value (1.13 ± 0.38), while grazing land (0.10 ± 0.04) and fishing ground (0.11 ± 0.06) have the

lowest average values The average value of carbon footprint related to land type was determined as 2.36+0.81.

Table 4. Average land type data (gha) of participants by departments and gender

		Built-Up Land (gha±SD)	**Forest Products** (gha±SD)	**Cropland** (gha±SD)	**Grazing Land** (gha±SD)	**Fishing Ground** (gha±SD)	**Carbon Footprint** (gha±SD)
Primary School Edu.	Male	0.15±0.06	0.46±0.13	1.07±0.36	0.10±0.04	0.11±0.05	2.54±1.04
	Female	0.15±0.05	0.45±0.11	1.05±0.32	0.1±0.03	0.1±0.06	2.37±0.74
Pre-school Edu.	Male	0.18±0.05	0.48±0.09	1.38±0.48	0.13±0.05	0.15±0.07	2.64±0.78
	Female	0.15±0.05	0.44±0.09	1.07±0.33	0.09±0.04	0.1±0.05	2.27±0.75
Special Edu.	Male	0,15±0.05	0.46±0.14	1.15±0.38	0.1±0.05	0.11±0.05	2.15±0.6
	Female	0.15±0.06	0.45±0.13	1.04±0.4	0.08±0.05	0.1±0.05	2.18±0.78
Average		**0.15±0.06**	**0.46±0.12**	**1.13±0.38**	**0.10±0.04**	**0.11±0.06**	**2.36±0.81**

According to Türkiye's ecological footprint report, 46% (1.24-1.36 gha per capita) of Türkiye's ecological footprint components are carbon footprint, 35% (about 1 gha per capita) agricultural land, 11% (0.29 gha per capita) forest products, 3% (0.05 gha per capita) grassland, 3% (0.08 gha per capita) built-up area and 2% (0.06 gha per capita) fishing ground footprint components [2]. Although the results are proportionally quite similar to this study, the average values are about twice the average per capita footprint components of Türkiye. This is also an important result. Since these data give less insight to ordinary people who are not experts in the field, most articles in Türkiye do not include data on this topic at all [1, 26-35].

3.4. Final Comsumption Categories

In the ecological footprint scale, the fourth value given as is the "consumption categories" data. Consumption categories data is the more visible component of the ecological footprint value. It has some subcomponents such as food, shelter, mobility, goods and services. These values, given in gha, represent the world resources used to meet an individual's needs for food, shelter, transport, goods and services. Table 5 summarises the average consumption categories data (gha) of participants by departments and gender in this study. When Table 5 is analysed, it is seen that teacher candidates received the highest value from the food category in terms of consumption categories, followed by goods, services, shelter and mobility. When the components of Türkiye's ecological footprint by consumption categories according to Türkiye's ecological footprint report are analysed, it is seen that the food category takes the first place with 52% (1.18 gha per capita), followed by products with 21% (0.47 gha per capita), transport with 15%, (0.33 gha per capita) services with 6% (nearly 0.13 gha per capita) and housing with 6% (nearly 0.13 gha per capita) [2]. In this study, the rates are 30% for food (1.28 gha per capita), 22% for goods (0.95 gha per capita), 19% for services (0.8 gha per capita), 16% for shelter (0.68 gha per capita), 13% for transport (0.56 gha per capita). As can be seen, in all items, the footprint values of teacher candidates are higher than Türkiye's average.

When the consumption categories are evaluated on the basis of departments, it is seen that there is no significant difference in terms of food variable (F: 0.52, $p>0.05$), shelter variable (F: 0.147, $p>0.05$), transport variable (F: 1.228, $p>0.05$), goods variable (F: 0.342, $p>0.05$) and services variable (F: 0.543, $p>0.05$). When consumption categories are evaluated on the basis of gender, it is determined that there is no statistically significant difference between food variable (t: 0.192, $p>0.05$), shelter variable (t: -0. 235, $p>0.05$), transport variable (t: 0.192, $p>0.05$) and goods variable (t: 0.214, $p>0.05$) variables. In the services variable, the gender-based difference (male $_{average}$: 0.83 gha, female $_{average}$: 0,77 gha) is statistically significant (t: 2.283, $p<0.05$).

Table 5. Average comsumption categories data (gha) of participants by departments and gender

		Food (gha±SD)	**Shelter** (gha±SD)	**Mobility** (gha±SD)	**Goods** (gha±SD)	**Services** (gha±SD)
Primary School Edu.	Male	1.18±0.61	0.65±0.34	0.77±0.19	0.96±0.45	0.77±0.16
	Female	1.13±0.52	0.60±0.27	0.59±0.1	1.03±0.66	0.79±0.14
Pre-school Edu.	Male	1.70±0.75	0.6±0.44	0.78±0.18	0.93±0.57	0.91±0.14
	Female	1.22±0.54	0.64±0.41	0.5±0.37	0.99±0.48	0.75±0.13
Special Edu.	Male	1.36±0.59	0.82±0.27	0.28±0.08	0.88±0.34	0.81±0.17
	Female	1.11±0.6	0.77±0.40	0.42±0.1	0.90±0.56	0.79±0.16
Average		**1.28±0.6**	**0.68±0.36**	**0.56±0.17**	**0.95±0.51**	**0.80±0.15**

In the study conducted by Özyürek et al. (2022) statistically significant difference was found between departments in the goods and services item, while no difference was observed in other components. In the same study, a difference was determined on the basis of gender only in the shelter item, no difference was determined between the other components [26]. In a study conducted by Keleş and Aydoğdu (2010), similar results were found in terms of consumption categories (1.7 gha for food, 1.03 gha for goods and services, 1.01 gha for shelter and 0.17 for mobility), [33]. In a study conducted by Keleş et al. (2008), a gender-based difference was mentioned only in the food item and no significant difference was found among other items. In this study, pre-service teachers from different branches were studied, but there was no evaluation on the basis of department [35].

3.5. Ecological Footprint and Carbon Footprint

The most important output of the international ecological footprint scale applied in this study is the ecological footprint data. The last data in this scale is the carbon footprint data and the percentage effect of a carbon footprint on ecological footprint value. All data belonging to these three variables are summarized in Table 6. When Table 6 is analysed, it is seen that the highest ecological footprint value is found in male teacher candidates in the department of pre-school education and the lowest value is found in female teacher candidates in the department of special education. The average ecological footprint value of the research group was determined as 4.29 gha. When the carbon footprint values are compared, it is seen that male teacher candidates in the department of pre-school education have the highest value, while male teacher candidates of special education have the lowest value. The average carbon footprint value of the research group was determined as 6.7 tonnes/year. It is seen that the carbon footprint is responsible for 53.9% of the average ecological footprint value.

Table 6. Average ecological and carbon footprint data of participants by departments and gender

		Ecological Footprint (EF) (gha±SD)	**Carbon Footprint (CF)** (ton/per year±SD)	**% CF in EF value** (±SD)
Primary School Edu.	Male	4.40±1.48	7.37±3.05	56.86±6.98
	Female	4.22±1.02	6.88±2.13	55.28±6.40
Pre-school Edu.	Male	4.93±1.06	7.68±2.22	53.25±8.57
	Female	4.13±1.00	6.58±2.13	52.37±11.41
Special Edu.	Male	4.14±0.92	6.25±1.76	51.92±7.60
	Female	4.02±1.17	6.37±2.23	54.29±7.17
Average		**4.29±1.10**	**6.7±2.25**	**53.9±8.63**

The difference in ecological footprint values is not statistically significant for both departments (F: 0.763, $p>0.05$) and gender (t: 1.567, $p>0.05$). However, according to Türkiye's ecological footprint report, Türkiye's estimated ecological footprint size is 3.3 gha for 2023 [2]. The data obtained in this

study were compared with this critical number by means of one-sample t test. Accordingly, the ecological footprints of teacher candidates are significantly different from the expectation of Türkiye's ecological footprint (t: 11.568, $p<0.05$).

In some other studies conducted on pre-service teachers in Türkiye, it was reported that ecological footprint values were above the average of Türkiye [1, 12, 33, 35, 36]. Yıldız and Selvi (2015) found that the average ecological footprint of pre-service science teachers was higher than the average footprint of Türkiye [1]. Keleş et al. (2008) and Keleş and Aydoğdu (2010) determined that the ecological footprint values of teacher candidates in different branches were above the world and Türkiye averages [33, 35]. Ağaç and Yalçın (2018) determined in their study that the average ecological footprint of science teacher candidates among teacher candidates was higher [36]. These findings are similar to the findings of this study.

3.6. Other Informations

In addition to the ecological footprint scale, through a personal information form developed, the participants were asked whether they had heard of the concept of ecological footprint before, if they had knowledge, whether they consciously applied the principles of ecological footprint in their daily lives and other thoughts they wanted to express. It was determined that a total of 89 teacher candidates (primary school 33, pre-school 30, special 26) had heard of the concept of ecological footprint before (49.7%), while the remaining 90 teacher candidates (primary school 28, pre-school 32, special 29) had never heard of it (50.3%). A total of 47 (26.2%) teacher candidates (primary school 14, pre-school 18, special 15) stated that they consciously apply ecological footprint principles in their daily lives, while the rest (73.8%) did not. However, it is seen that the ecological footprints of the teacher candidates who stated that they consciously apply ecological footprints are above the average of Türkiye. In a study conducted by Yıldız and Selvi (2015), it is revealed that even a large proportion (75%) of pre-service science teachers, who are perhaps the group that should have the most knowledge about the subject, have heard the concept of ecological footprint for the first time [1].

When all analyses were evaluated together, it was determined that there was no difference between the ecological footprints of teacher candidates studying in the departments of primary school, pre-school and special education at Anadolu University Faculty of Education on the basis of both department and gender (except services footprint). One of the main reasons for this is thought to be related to Eskişehir province. Most of the students live in what is considered to be a student district in the province, which is very close to the university. They stay in houses with similar characteristics and live in similar conditions. Due to the close location of the university, walking to and from classes reduces the mobility footprint values. However, the intercity routes they make to visit their families increase the mobility footprint. Food constitutes the highest component of the consumption-related footprint of teacher candidates. It is thought that this can be explained by the fact that students who are away from their families mostly consume ready-made food.

In this study, it was determined that the ecological footprint values of teacher candidates on the basis of both department and gender were considerably higher than the average of Türkiye. This situation shows that these teacher candidates, who are educated in different branches, do not have sufficient knowledge in terms of ecological footprint and sustainability concepts. When the relevant departments of Anadolu University Faculty of Education are evaluated in terms of curriculum, it is seen that there is a course called environmental education ("Çevre Eğitimi" in Turkish) only in the department of primary school education. When the course content is examined, it is seen that there is standard information about environmental education, but not specifically about ecological footprint and sustainability. In this context, it is thought that it would be useful to open a course in all departments of education faculties or to make the necessary content updates/improvements in existing courses.

Another advantage of this study is that the interests of teacher candidates in these departments are orientated towards relatively young age groups. Because, as in many subjects, environmental adaptations can be acquired more effectively at early ages.

In our country, the number of studies in which ecological footprint and university students are evaluated together is not very high. While some of these studies used the international ecological footprint scale used in this study [1, 26, 35], many other studies used scales developed by researchers [27, 28, 29, 30]. Due to the different scales used, it is seen that the results and reporting of the results are also different. For this reason, it is seen that the data of some variables such as date, world necessary and land types provided in the international standard ecological footprint scale are not given in other studies. Similarly, it is seen that some data provided in other studies are not provided on an international scale. Of course, the best way is to use a specific scale developed for our country throughout the whole country. In this regard, there are news about the development of a Türkiye-specific ecological footprint calculation tool developed by Keleş and Özsoy and even studies using this scale [37], but it is not widely used. The development of this and similar specialised scales will enable more reliable assessments across the country.

The total ecological footprint of production in Türkiye exceeded the national biological capacity for the first time in 1972, and by 2007, it exceeded the biological capacity by approximately 1.6 doubled (2.1 gha), [2, 8]. It is clear that something must be done about the issue. In many studies, it has been concluded that the use of ecological footprint as an educational tool positively increases the awareness of the individuals participating in the research towards sustainable life, improves their attitudes moderately positively and is effective in gaining responsible behaviors towards sustainable life [37]. Considering that teachers play a key role in the development of value judgements and lifestyles necessary for sustainable development, it is clear that there is a need for training on these issues for teacher candidates in Türkiye. It is believed that this study will raise awareness on this issue and contribute to the studies to be conducted on this subject.

4. CONCLUSIONS

The following suggestions can be made.

- Courses on ecological footprint should be added to the curriculum of teacher candidates or existing course contents should be updated.
- Seminars, symposiums, etc. can be held together with public and non-governmental organisations that raise awareness in the direction of reducing the ecological footprint values of teacher candidates.
- It can be ensured that teacher candidates take part in project studies that will lead to the reduction of ecological footprint values.
- Informative training on ecological footprint can be added to the in-service training programmes of existing teachers.
- In order to increase the level of awareness in the social dimension, ecological footprint practices appropriate to the characteristics of each period should be included in all stages of education, including higher education, starting from pre-school age.

CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

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REVIEW

CORONATINE: A POTENTIAL PHYTOTOXIN FOR INCREASING THE TOLERANCE OF PLANTS TO DROUGHT STRESS

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ABSTRACT

Drought and water deficiency are the leading factors that negatively threaten plant growth and development, resulting in significant yield losses in agricultural production. Severe drought events expected because of global warming reveal that serious steps should be taken to enhance the drought tolerance of agricultural crops. Coronatine (COR), a chlorosis-inducing and non-host-specific phytotoxin secreted by the pathogen *Pseudomonas syringae*, is structurally and functionally similar to jasmonates, but it is far more active as a plant growth regulator. Therefore, many studies have been conducted to understand the positive effect of COR application on drought stress tolerance in plants. This review assesses the potential of COR for improving plant drought tolerance by examining previous studies that investigated the effect of exogenously applied COR on antioxidant enzyme activities of plants exposed to osmotic stress simulated by polyethylene glycol PEG application or by not providing water. In addition, it was evaluated whether COR could have a dose-dependent effect on the antioxidant enzyme activities of plants under drought stress. According to the findings of the reviewed studies, COR treatment enhanced the plant drought tolerance by increasing the activity of antioxidant enzymes.

Keywords: Antioxidant enzymes, Coronatine, Drought Stress

1. INTRODUCTION

1.1. Plants' Drought Stress Defence Mechanism

Plants are exposed to various environmental stresses throughout their lives that reduce their biosynthetic capacity and affect their productivity and growth. The main environmental stressor is drought, with the highest percentage of 26%, defined as a dry period long enough to cause a serious decrease in soil moisture content, as well as plant growth, development, and yield; therefore, these environmental factors should be recognized as the major issues of future climate change [1]. In recent years, with the emergence of the adverse effects of climate change, increasing food production demands and drought stress-related yield losses have attracted more attention [2].

Exposure to drought stress results in many biochemical and physiological alterations that disrupt normal growth and development. Drought stress generally causes growth suppression, stomatal closure, leaf senescence, disruption of the main components of photosynthesis, and inhibition of cell elongation and expansion. Furthermore, drought stress can enhance respiration while reducing the photosynthetic rate [3–4]. Osmotic stress caused by drought is a crucial damage factor that can cause dehydration of plant cells, degradation of photosynthetic pigments, and accumulation of active oxygen species (AOS) [5]. Plants can have methods to survive in their changing habitats by increasing their tolerance to drought stress, which mainly affects plants according to duration and severity [6–8]. One of the survival strategies is the antioxidant defence mechanism in plants. Plant antioxidant mechanisms, both enzymatic and non-enzymatic, are responsible for preventing or reducing the damage caused by AOS. In enzymatic systems, superoxide radicals (O_2) are detoxified to H_2O_2 and O_2 by superoxide dismutase (SOD), and

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then catalase (CAT) and ascorbate peroxidase (APX) can destroy H_2O_2. Glutathione reductase (GR) can also detoxify H_2O_2 through the ascorbate–glutathione cycle [8]. For plants without CAT, H_2O_2 could be detoxified by ascorbate peroxidase (APX) and glutathione reductase (GR) through the ascorbate–glutathione cycle within the chloroplasts [9]. However, drought stress causes a dysfunction of the scavenger enzyme system, leading to increased lipid peroxidation and, ultimately damage to the membrane [10]. Therefore, antioxidant enzymes efficiently convert H_2O_2 to H_2O_2 and O_2, which occur when plants are subjected to drought-induced water deficiency [11].

The internal molecules of plant hormones, produced in low concentrations, are the main controllers of plant development and growth, defined as the main molecules that coordinate a wide variety of signalling pathways in the responses to abiotic and biotic stress in plants [12]. Abscisic acid (ABA), auxin, brassinosteroid, cytokinin, ethylene, gibberellin, jasmonate, salicylic acid, and strigolactone are well-known plant hormones that function as growth regulators and facilitate environmental adaptations in plants [13–14]. Along with the detection of the stress signal, phytohormones are able to activate various adaptation processes in plants, as an example, stimulation of root growth, stomatal closure, and accumulation of osmolytes to deal with drought-induced stress [15]. In addition to controlling the growth and development of plants, JA and its active derivative products, recognized as jasmonates, are related to plant defence. They are also important in regulating plant stress responses to a variety of abiotic and biotic stresses, including drought. [16]. As a phytohormone, JA promotes tolerance to drought in plants in a variety of ways, including minimizing water loss by controlling stomatal closure and opening, also scavenging reactive oxygen species (ROS) by activating the enzymatic antioxidative system, and regulating root development [17-18]. Several studies have found that exogenous application of JA increased plant antioxidant activity under drought-stressed conditions. The study on wheat seedlings exposed to drought stress is an example of how exogenously applied JA enhanced dehydroascorbate reductase (DHAR), monodehydroascorbate reductase (MDHAR), APX and GR [19].

1.2. Phytotoxin Coronatine as a Plant Growth Regulator

Coronatine (COR) is a polyketide and a nonhost-specific phytotoxin that induces chlorosis in a wide range of species of plants. It is produced by numerous strains of the plant bacteria *Pseudomonas syringae*, including maculicola, tomato, glycinea, and atropurpurea [20–21]. COR is composed of two parts: coronamic acid (CMA), derived from isoleucine, and polyketide coronafacic acid (CFA). CMA and CFA are synthesized in different ways and bind via an amide bond to form the coronatine phytotoxin. Tamogami and Kodama (2000) reported that COR is an analog of jasmonic acid (JA) [22]. COR has structures and functions similar to those of jasmonates, so its activities are similar but not identical. Furthermore, it is known that the coronatine insensitive 1 receptor of plants is shared by both COR and jasmonates [22–24]. Previous research has shown that COR is approximately 1000 times more active than jasmonates, even at very low concentrations [25]. Although it is a phytotoxin, COR affects plant biology in multiple ways such as hypertrophy, inhibition of root elongation, cell wall thickening, tendril coiling, leaf senescence, chloroplast structure alteration, chlorosis, and accumulation of protease inhibitor for defence, and, as an elicitor, induces secondary metabolites in plants, such as volatiles, nicotine, and alkaloids [11, 20, 24, 25, 26, 27, 28, 29].

Several research findings have shown that COR has an important role as a plant growth regulator to improve tolerance or resistance to abiotic stress during the plant growth process through modulation of metabolism, inducing anthocyanin production, stomatal opening, the elicitation of plant defences, and hormone synthesis and transport [25–29]. Research shows that applying micro doses of COR to plants can alleviate the response of the plant to abiotic stresses, including salinity-induced stress in cotton [30], drought-induced stress in soybeans and cauliflower [31-32], heat-induced stress in wheat [33], and chilling stress in cucumber [34]. Previous research has demonstrated that COR improves resistance to plant stress by maintaining high photosynthetic performance and increasing antioxidant enzyme activities [31-35], as well as whether exogenously applied COR can alleviate or exacerbate the negative

effects of drought stress in plants by influencing the response to plant stress. The purpose of this review was to assess previous studies that examined the effect of COR application on plant response under drought stress conditions, and to update the literature on the subject.

1.3. The Effect of COR on Plant Antioxidant Enzyme Systems Under Drought-Induced Stress

Wang et al. (2008) studied the antioxidant activities of maize seedlings under conditions of drought stress, depending on the application of COR [36]. They simulated drought stress by supplementing the nutrition solution with PEG-6000 (15%) after 24 hours of COR treatment. The application of COR revealed that the leaves had a high-water content. In addition to that, the activity of antioxidant enzymes increased significantly. As a result, 20 nmol L^{-1} of COR application was determined to reduce the negative consequences of drought stress in maize seedlings.

Ai et al. (2008) investigated the role of COR in helping to improve drought resistance of two different rice varieties. The first cultivar, Handao 297, has tolerance to drought stress, and the second cultivar, Yuefu, has a sensitivity to drought stress. Different amounts of COR were applied to each variety to achieve the same effect on the tolerance to drought of both rice cultivars. In preliminary experiments, three-leaf seedlings were treated for 24 hours with COR at concentrations of 0.01 μM and 0.1 μM, which were found to be effective against the application of PEG 6000 (20%). Drought tolerance is increased similarly in two rice cultivars by applying COR, but optimal concentrations differ: a low concentration of 0.01 μM for the drought-tolerant variety and a high concentration of 0.1 μM for the drought-sensitive variety is required to mitigate the negative effects of drought-induced stress by activating antioxidant enzymes and trying to prevent membrane peroxidation and denaturation of biological molecules. Ai et al. (2008) defined the accumulation of proline, H_2O_2, and malondialdehyde (MDA) as drought-induced stress markers. Based on this, Wu et al. (2012) discussed how the application of COR and methyl jasmonate (*MeJA*) exogenously affects defence-related metabolism under drought-induced stress conditions in cauliflower. In this research, when the seedlings expanded to the fourth leaf stage, 0.1 μM COR, and 10 μM MeJA were applied with foliar spray for 24 hours. Then, water deficit stress was applied to the seedlings by not giving them water for 8 days.

Treatment with COR and MeJA increased the activity of CAT, SOD, APX, peroxidase (POD) and GR. According to the findings of this study, both COR and MeJA play a positive role in increasing the activity of non-enzymatic and enzymatic antioxidants, as well as in reducing the production of lipid peroxide in cauliflower seedlings. Both can reduce the negative effects of drought stress and improve resistance to water stress in cauliflower seedlings by promoting defence-related metabolism.

Like the previous study by Ai et al. (2008), Li et al. (2010) also worked on two different winter wheat cultivars, ChangWu134 as drought tolerant and Shan253 as drought sensitive, but unlike the other study, they applied the same concentration of COR (0.1 μM) to both cultivars at the three-leaf stage. COR application increased CAT activity in both cultivars during drought conditions. Furthermore, APX, POD and SOD activities increased in the ChangWu134 variety. Contrary to the findings of the previous study, APX, POD, and SOD activities in the drought sensitive Shan253 cultivar were not affected by COR treatment except for GR activity. According to the results, COR effects on the root / shoot ratio and dry weights, relative water content, ABA, and CAT activity were observed under drought stress. In this case, they were unable to define a significant difference in the improvement of stress tolerance by applying 0.1 μM COR between the two cultivars. Finally, they have revealed that the enhancement of stress tolerance with COR should be independent of genotype.

We also studied to determine whether pretreatment with COR improves the tolerance of chickpea roots (*Cicer arietinum* L. ICC 4958 cultivar) under conditions of osmotic and heat stress, or both stresses combined. This was the first report on stress combinations studied. Depending on preliminary experiments, we decided to apply 0.01 μM COR for 24 h and then 6% PEG (PEG-6000) to inducing

osmotic stress or heat stress (35°C–44°C; the temperature is gradually increased by 1°C every 15 minutes and held for 1 hour) for 3 days. COR enhanced the activities of H_2O_2-scavenging enzymes, including POD under osmotic stress, CAT under heat stress, and CAT and POD under both stresses when applied together. We reported that 0.01 M COR pre - treatment significantly reduced the negative effects of all stress conditions on the roots of cultivar ICC 4958 by decreasing H_2O_2 production and increasing antioxidant enzyme activity [37]. Another study by Hao et al. (2013) discussed the function of exogenously applied COR in coping with the adverse effects of drought stress in soybean, which is drought sensitive. 0.1 μM COR was applied to soybean seedlings in three stages of the leaf by foliar spray. After 24 hours, the seedlings were kept without water for 7 days for drought-stress applications.

When COR-applied plants were compared with control plants under drought stress, it was determined that the activities of CAT, POD, SOD, and APX were much higher in the leaves of COR-treated plants. Furthermore, in these plants, the amount of proline increased and the accumulation of malondialdehyde and hydrogen peroxide decreased with the application of COR. This means that exogenously pre-treating soybeans with COR can reduce the negative consequences of drought stress. In a similar study by Xu et al. (2020), the effect of exogenously applied COR on the antioxidant enzyme levels of tobacco (sensitive to drought stress) under PEG-induced drought conditions was investigated. Tobacco was pretreated with 0.001 μM COR in Hoagland nutrient solution for 24 hours, then the seedlings were subjected to PEG-6000 (20%). All drought-exposed plants have been shown to show higher antioxidant enzyme activities, while those treated with COR showed 25.36%, 27.33%, 47.61% and 20.91% higher SOD, CAT, APX, and GR activities in response to PEG-induced drought stress, respectively. According to the findings, COR-induced stress tolerance decreased the adverse effects of drought on tobacco by enhancing antioxidant enzyme activities.

Another study to discuss tolerance developed by the application of COR to drought-stressed plants includes winter wheat seeds (*Triticum aestivum* L.) from JiMai22 (drought-tolerant) and LiangXing99 (drought-sensitive). When the seedlings grew two leaves, unlike previous studies, they were first treated with PEG-6000 (20%) within a Hoagland nutrient solution to simulate drought stress, and then COR was applied by spraying in the amount of 1 μM COR. Although COR was performed after the PEG application, no considerable differences in the results were observed. The water stress alleviating capacity of JiMai22 (moisture-insensitive) was greater than that of LiangXing99 (moisture-sensitive) due to the higher activity of defence-related antioxidant enzymes and reduced accumulation of MDA [38].

Another research by Yu et al. (2021) aimed to determine how COR affects the homeostasis of reactive oxygen species (ROS), water balance, and antioxidant regulation in detached maize plants to mitigate the effects of drought stress. After being treated for 12 hours each with 0.001 M COR and distilled water, the maize plants were subsequently exposed to 10% (w/v) polyethylene glycol (PEG 6000) for 5 hours. Compared to the control, the SOD and POD activity increased by 19.1 and 14.6% under well-watered conditions, respectively, while the CAT activity was slightly different, although the difference was not statistically significant. Furthermore, PEG treatment markedly increased SOD, POD, and CAT activities in all plants, and SOD, POD, and CAT activities were also higher in plants treated with COR under drought stress compared to control plants. These findings suggested that COR could enhance maize drought tolerance by controlling ROS homeostasis to maintain water loss rate and antioxidant enzyme activity [39].

The study by Wang et al. (2023) examined the changes in physiological and transcriptome abundance that COR regulates in C. leucochlora seedling leaves from plants that have been subjected to drought. According to their research, COR increased drought resistance by preserving osmotic adjustment, decreasing membrane lipid peroxidation, preserving photosynthetic capability, and improving the antioxidant defence system under water deficiency stress. Activity of antioxidant enzymes compared to the well-watered control; drought stress significantly increased the activity of antioxidant enzymes.

However, compared to untreated plants under drought stress, 0.1 nmol L^{-1} COR treatment significantly increased SOD, POD, CAT, and APX activities. Compared to drought stress, D+COR treatment increased SOD activity by 17.23%. A similar rising trend in activity was seen in POD, CAT, and APX. Compared to the drought stress treatment, D+COR improved the three characteristics by 14.92%, 13.36%, and 21.95%, respectively. When plants were under drought stress, COR had a significant impact on antioxidant enzyme activities, increasing tolerance to drought in C. leucochlora seedlings by scavenging ROS and minimizing oxidative damage [40]. The dose-dependent effect of COR on the antioxidant enzyme activities of various species of plants under drought stress is summarized in Table 1.

Table 1. The dose-dependent effect of COR on antioxidant enzyme activities of varied species of plants under drought stress conditions.

PLANT	COR	TREATMENT	PEG6000 (%)/DAY WITHOUT WATER	RESULTS OBTAINED	REFERENCES
Maize	20 nmol L^{-1}	24 hours nutrient solution	15%	Enhanced the PEG induced drought tolerance by increasing the antioxidant activity.	Wang et al. (2008)
Two Rice Cultivars Handao 297 (tolerant)/ Yuefu (sensitive)	0.01 µM / 0.1 µM	24 hours nutrient solution	20%	Applied concentrations are the optimal for each cultivar to activate antioxidant enzymes.	Ai et al. (2008)
Cauliflower (Brassica oleracea L.)	0.1 µM	Foliar spray	8 days	Both MeJA and COR enhanced the activity of antioxidant enzymes such as SOD, POD, CAT, APX, and GR.	Wu et al. (2011)
Winter Wheat Seedlings ChangWu134 (tolerant) Shan253 (sensitive)	0.1 µM	24 hours nutrient solution	20%	COR increased CAT activity for both cultivars, also increased the activities of SOD, POD and APX in the ChangWu134 variety.	Xiangwen et al. (2010)
Chickpea (Cicer arietinum L. cv ICC 4958)	0.01 µM	24 hours nutrient solution	6 %	COR enhanced the activities of H_2O_2 scavenger enzymes such as catalase (CAT) under heat stress, ascorbate peroxidase (POD) under PEG stress, and CAT and POD under combined stresses.	Arıkan et al. (2013)
Soybean	0.1 µM	Foliar spray	7 days	Exogenously applied COR can alleviate drought stress; therefore, SOD, POD, CAT and APX activities were higher in plants applied COR compared to controls.	Hao et al. (2013)
Tobacco (Nicotiana tabacum L.) (sensitive)	0.001µM	24 hours nutrient solution	20%	COR- treated ones showed 25.36%, 27.33%, 47.61% and 20.91% more higher SOD, CAT, APX, and GR activities in response to PEG-induced drought stress, respectively.	Xu et al. (2020)
Winter wheat (Triticum aestivum L) JiMai22 (insensitive) LiangXing99 (sensitive)	1 µM	Foliar spray	20%	COR applicated after PEG-induced drought conditions but no significant difference was observed. Water stress alleviating ability of JiMai22 (insensitive) was greater than that of LiangXing99 (sensitive) by activating higher defence related antioxidant enzymes activity.	Wang et al. (2020)
Maize	0.001 M	5 hours	10%	Activities of SOD, POD, CAT in leaves of maize seedlings under 10% PEG treatment were enhanced by COR pretreatment.	Yu et al. (2021)
C. leucochlora seedling	0.1 nmol L^{-1}	Foliar spray	15 days	Compared to untreated plants under drought stress, COR treatment significantly increased SOD, POD, CAT and APX activity in C. leucochlora seedlings.	Wang et al. (2023)

2. CONCLUSION

Drought stress is a serious constraint that limits plant development and growth. Although COR has been identified as a new plant growth regulator, its effect on defence-related mechanisms in plants, especially tolerance, to drought has not yet been clarified. The objective of this review was to summarize studies on the effects of COR on the ability of various plant species to respond to drought stress. All studies show that the application of COR influences the drought resistance capacity of plants, although the amount and method of application vary. However, different concentrations of COR should be applied under the same drought conditions to achieve the same effect on improving drought tolerance in drought-sensitive and tolerant species. Studies investigating the application of COR with different amounts and methods under drought stress show that COR is effective in developing tolerance against drought, but this effect may be directly proportional to its amount. When the studies are examined, it can be determined that a higher concentration of COR is applied in the spraying method compared to the addition of the nutrient solution. However, it cannot be said that a high dose of COR always stimulates the antioxidant enzyme mechanism of the plant and increases the plant's tolerance to stress. For example, the lowest amount of COR (0.001 μM) was studied in tobacco under 20% induced drought stress PEG-6000, and it was determined that even this amount could increase the activity of antioxidant enzymes. Therefore, further studies should be conducted to determine the optimal concentration that should be applied to obtain the maximum benefit from COR.

CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

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