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Editorial

About life sciences and related technologies

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Abstract

The life sciences include the branches of science that are concerned with scientific studies of living organisms' such as human beings, animals, plants and microorganisms. In fact, all life sciences are biology based sciences and from the beginning of the scientific and technological researches up to date, the obtained scientific data, especially in agriculture, medicine, engineering, as well as molecular biology and biotechnology, led to an escalating specializations in interdisciplinary fields. Some life sciences focus on a specific type of life. For instance, botany is the study of plants and has different branches such as anatomy, genetics, biochemistry, biophysics, taxonomy, physiology, molecular biology and paleobotany etc. of plants. On the other hand, zoology is the study of animals that branches out anatomy, cytology, ecology, embryology, genetics, geology, histology, morphology, neonatology, paleontology, physiology, taxonomy and many others. Also, microbiology is the study of microorganisms that may exist in its single-celled form or in a colony of cells, and branches out to bacteriology, mycology, protozoology, phycology, parasitology, immunology, virology and nematology and related sciences. The branches of these life sciences have their own specific sub-branches related to the studied and mastered subjects. Recently, multidisciplinary new branches like bioengineering have been formed, especially in conjunction with life sciences and engineering sciences, and these branches contribute to the development of science. Life sciences are very useful in improving people's life quality and standards. They have applications in agriculture, health, medicine, food and drug science industries as well as environmental sciences. In this article, information is given about the branches of "life sciences and related technologies" for better understanding of life sciences.

Keywords: *Agriculture; biology; engineering; medicine; inanimate; living*

1. Introduction

Before getting into the topic of what life sciences are, we need to know that what life is, what living and non-living (inanimate), and finally what are the differences between the beings called living and non-living. Although we use these terms many times in our everyday lives, giving the answers of these questions with a few sentences have been very difficult for people from the beginning to human life to today. Instead of making a definition, so many scientists and thinkers have presented some criteria for life, living and non-livings. Nobel laureate Erwin Schrödinger, who is an Austrian physicist tried to answer this (still-unresolved) question as life is differentiated by a"code-script" that regulates cellular organization and genetic endowment, while obviously enabling living beings to defer the second law of thermodynamics.

Life is a feature, which separates physical object that with biological processes, such as life signaling and self-sustaining, as living things (organisms), from those do not have or become unable to perform these functions (died) after a certain time are classified as inanimate.

Simply, we can understand from the above definition, only two properties are required for us to determine whether a physical object is alive or not is metabolism (life functions of an organism, biomass increase and reproduction) and motion (McKay, 2004). Also the simplest requirements of life are

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energy, water, in addition to C, H, O, N, P, S, K, other macro and micro elements such as B, Mg, Ca, Cl, Mo, Cu, Fe, Mn, Zn and a few Al, Co, Na, Ni, Si and V that varies from one organism to another (McKay 1991; Ozyigit et al., 2018).

Seven features of life were listed by Koshland (2002) as **(1)** program (DNA), **(2)** improvisation (response to environment), **(3)** compartmentalization, **(4)** energy, **(5)** regeneration, **(6)** adaptability, and **(7)** seclusion (chemical control and selectivity). After the finding non-coding RNA's, today we can add RNA into the program together with DNA.

2. Living and non-living things

Since there are many different definitions, in order to separate the living from the non-living, the following properties are accepted that a living system must have; **(1)** the ability to encapsulate its components in an enclosed boundary, in order to distinguish itself from the environment, **(2)** the ability to transfer information from one generation to the next generation and finally, **(3)** the ability to accrue variations (mutations) between successive generations (Tauber and Podolsky, 1994; Rodriguez Garcia, 2016).

Here, the encapsulating ability takes us to the cell formation and naturally to "the cell theory". As it is known, Matthias Schleiden, the German botanist and Theodor Schwann, a British zoologist were formally articulated in this historic scientific theory, in 1839 and up to now, it is universally accepted whit minor revisions (Ribatti, 2018). According to this theory, "all living things are made up of cells and cell is the basic structural and functional unit of life". 14 years later, Rudolf Virchow published an important extension of cell theory, based on his observations statement that "all living cells arise from pre-existing cells" (Omnis cellula e cellula) (Epozturk and Gorkey; 2018).

Recently, the theory has modernized. Today, the "modern cell theory" includes the followings editions **(1)** energy flow occurs within cells, **(2)** cells contain hereditary information (DNA) which is passed from cell to cell **(3)** all cells have basically the same chemical composition (Kumar and Mina, 2015).

Nevertheless, this theory includes cellular organisms. Noncellular organisms like viruses do not obey the cell theory (Marcus, 2012). Possibly, non-cellular or acellular life forms could be hiding out in anywhere like beneath the deep oceans or inside the glaciers in Antarctica and waiting for the moment when it will come out and meet us as a result of global warming and/or with the soil samples brought to Europe by a South Pole explorer.

Cells function differently in unicellular and multicellular organisms. Related to above mentioned information, an organism refers to a living thing that has an organized structure, can react to stimuli, reproduce, grow, adapt, and maintain homeostasis (Folse and Roughgarden, 2010; Díaz-Muñoz et al., 2016; Demarest and Wolfe, 2017). A unicellular organism depends upon just one cell, however that cell can be tremendously complex and realizes all of its functions. A multicellular organism has cells different from each other that specialized to perform different functions that collectively support the organism (Huang et al., 2005; Schulze-Makuch and Bains, 2017; Tetz and Tetz, 2020). Although many cells have differentiated to perform various functions, there are two types of cells as prokaryotic and eukaryotic. Simply, a prokaryotic cell is a type of cell or a unicellular organism that lacks a membrane-bound nucleus, mitochondria, or any other membrane-bound organelle. However, a eukaryotic cell and/or organism have a nucleus that enclosed by membrane and membrane-bound organelles specialized to perform different functions (Martin, 2017; Urry et al., 2020).

Some organisms, like bacteria (*Agrobacterium tumefaciens*, *Eschericia coli*, *Thermus aquaticus*), cyanobacteria (*Chroococcus turgidus*), alga (*Chlamydomonas reinhardtii*, *Chlorella vulgaris*), protozoa (*Paramecium caudatum*, *Plasmodium vivax*, *Trypanosoma brucei*), yeast (*Candida albicans*, *Saccharomyces cerevisiae*), diatoms (*Achnanthes fimbriata*, *Hippodonta arctica*) etc. are unicellular-consisting of a single cell. Other organisms, such as human (*Homo sapiens*), animals (*Danio rerio*, *Drosophila melanogaster*, *Xenopus laevis*), plants (*Arabidopsis thaliana*, *Gossypium hirsutum*, *Helianthus annuus*) and fungi (*Amanita phalloides*, *Armillaria solidipes*) are some samples of multicellular organisms (Kusber and Jahn, 2002; Moore et al., 2019; Urry et al., 2020).

The above unicellular and multicellular organisms are first classified by Linnaeus, 1735 as a 2-kingdom (vegetabilia and animalia) system. As a result of the technological developments related to biological sciences, there have been many changes in following 280 years, and today a 7-kingdom system has been accepted including bacteria, archaea, protozoa, chromista, plantae, fungi and animalia by Ruggiero et al., 2015.

Life sciences cover all scientific studies that are related to the above mentioned groups in direct or indirect ways. Also, all life sciences are related to biology. Biology has a rich history of interactions with many other sciences such as agriculture, chemistry, engineering, food sciences, mathematics, medicine, pharmaceutical sciences and physics etc. Below, some definitive information are given about some selected branches of life sciences.

3. Life science branches

3.1. Basic life science branches and related concepts

Anatomy: Study of structure and relationship of body parts of organisms such as humans, animals, plants and others, especially as revealed by dissection and the separation of parts (Barnes-Svarney and Svarney, 2016; McConnell and Hull, 2020).

Astrobiology: Study of the origins, formation, early evolution, distribution, presence and future of life in the universe. It is formerly known as exobiology (Cottin et al., 2017; Cockell, 2020).

Biotechnology: Study of combination of both the living organism or their parts and a group of technologies to develop or make different products to improve the quality of human life (Ribeiro et al., 2016; Glick and Patten, 2017; Bettencourt, 2020).

Biochemistry: Study of the physico-chemical processes and substances required for life to exist and function, and of the changes they undergo during development and life at the cellular and molecular level (McKee and McKee, 2019; Rodwell et al., 2019).

Bioinformatics: Study of developing and/or using of methods or software tools for obtaining, storing, retrieving, interpreting, organizing and analyzing large amounts of biological information to generate useful biological knowledge (Hogeweg, 2011; Filiz et al., 2017).

Biolinguistics: Study of the biology and development of language related to or derived from the biological characteristics of an organism, especially human (Demirezen, 1988; Martins and Boeckx, 2016; Pleyer and Hartmann, 2019).

Biological anthropology: Study of mostly humans, non-human primates and hominids, their origin, development, biological variation and adaptation to environmental stresses. It is also known as physical anthropology (Jurmain et al., 2013; Ellison, 2018).

Biological oceanography: Study of the distribution, population dynamics and abundance of different types of marine life and their interaction with the physics, chemistry, and geology of the oceanographic system (Lalli and Parsons, 1997; Miller and Wheeler, 2012).

Biology: Study of life and living organisms, including their origin, distribution, classification, chemical processes, physical structure, function, physiological mechanisms, molecular interactions, development, behavior and evolution (Raven et al., 2019; Urry et al., 2020).

Biomechanics: Study of the structure, function and motion of the mechanical aspects of living beings at any level from whole organisms to organs, cells and cell organelles (Alexander, 2005; Arus, 2012; Fung, 2013).

Biophysics: Study of biological processes by using physics-based methods or based on physical principles from molecules, to cells, tissues, organisms and populations (Zhou, 2011; Andersen, 2016; Tabacchi and Termini, 2017).

Botany: Study of plants including their structure, properties, physiological and biochemical processes genetics, ecology, distribution, classification, and economic importance. It is also known as plant science(s), plant biology or phytology (Berg, 2008; Mauseth, 2014; Lüttge et al., 2016)

Cell biology: Study of the cell (Both prokaryotic and eukaryotic) as a fundamental unit of life, structure and functions, molecular and chemical interactions such as cell metabolism, cell communication, cell cycle, and cell composition that occur within and/or between living cells. It is also called as cellular biology, or cytology (Gupta, 2005; Alberts et al., 2013a; Cibas and Ducatman, 2013).

Developmental biology: Study of the processes by which animals and plants grow and develop forms, from zygote to full structure and is synonymous with ontogeny (Pua, 2010; Slack, 2012; Carlson, 2018).

Ecology: Study of the interactions among living organisms and their non-living biophysical environment (Townsend et al., 2003; Sharma and Sharma, 2012; Rana, 2013).

Ethology: Study of both animal and human behavior, with emphasis on the behavioral patterns that occur in natural environments, and viewing behavior as an evolutionarily adaptive trait (Holland and Ball, 2003; Warnock and Allen, 2003; Gomez-Marin, et al., 2014).

Evolutionary biology: Study of the origin and descent of species that produced the diversity of life on earth (Dukas, 2004; Johnson and Stinchcombe, 2007; Futuyma and Agrawal, 2009).

Genetics: Study of genes which is a sequence of nucleotides in DNA or RNA that encodes the synthesis of a gene product, either RNA or protein, genetic variation and heredity in organisms (Griffiths et al., 2005; Elston et al., 2012; Tseng and Yang, 2013; Snustad and Simmons, 2015, Carlberg and Molnár, 2016).

Histology: Study of plant and animal cells and tissues using microscopes to look at specimens of tissues that have been carefully prepared in relation to their specialized functions. It is also called as microscopic anatomy or microanatomy (Kierszenbaum and Tres, 2015; Gartner, 2018; Mescher, 2018).

Immunology: Study of the immune system in all organisms (Bellanti, 2013; Villani et al., 2018).

Microbiology: Study of microscopic organisms (microorganisms) those being unicellular (single cell), multicellular (cell colony), or acellular (lacking cells) and their interactions with other living organisms and the environment (Madigan et al., 2010; Carr, 2017).

Molecular biology: Study of molecular basis of biological activities in and between cells, including molecular synthesis, modification, mechanisms with biochemistry, genetics and microbiology (Cox et al., 2012; Michal and Schomburg, 2012; Alberts et al., 2013b).

Neuroscience: Study of the nervous system and human brain to understand the fundamental and emergent properties of neurons and neural circuits (Hudspeth et al., 2013; Ogawa and Oka, 2013).

Paleontology: Study of prehistoric organisms, their evolution, interactions with each other and natural environment in formergeologic periods as based on fossils (Turner, 2011; Louys, 2012).

Physiology: Study of the functioning of living organisms and the organs and parts of living organisms from the basis of cell function at the ionic and molecular level to the integrated behavior of the whole body and the influence of the external environment (Raff et al., 2014; Hall, 2016).

Population biology: Study of groups of conspecific organisms that how they interact with their environment. It is an application of mathematical models to population genetics, community ecology, and population dynamics (Hastings, 2013; Thieme, 2018).

Quantum biology: Study of quantum mechanics and theoretical chemistry in organisms (Brookes, 2017; Waring, 2018).

Structural biology: Study of molecular biology, biochemistry, and biophysics concerned with the molecular structure of biological macro-molecules (especially proteins and nucleic acids at a molecular level) which are essential for all life forms. How they acquire their structures and how alterations in their structures affect their functions Karplus and McCammon, 2002; Liljas et al., 2009).

Synthetic biology: Study of creating new biological parts, devices and systems. Design and construction of new biological entities such as enzymes, genetic circuits and cells, or the redesign of existing biological systems that are already found in nature (Keasling, 2012; Bueso and Tangney, 2017; El Karoui et al., 2019).

Systems biology: Study of the relationships between various components within a biological system, using computational and mathematical analysis with particular focus upon the role of cell-signaling strategies and metabolic pathways in physiology. (Breitling, 2010; Saetzler et al., 2011; Tavassoly and Iyengar, 2018).

Theoretical biology: Study of using abstractions and mathematical models to understand biological phenomena of the living organisms, their structure, development and behavior of the systems, as opposed to experimental biology (Hogeweg, 2011; Krakauer et al., 2011; Longo and Soto, 2016).

Toxicology: Study of the nature, effects, and detection of poisons chemical substances on living organisms (Hodgson, 2010; Smart and Hodgson, 2018).

Virology: Study of viruses, which are submicroscopic, parasitic particles of genetic material contained in a protein coat, their characteristics, classification, and the relationship with their respective hosts, and virus-like agents (Cann, 2001; Carter et al., 2007).

As seen, all these above life science branches are primarily related with biology. The below ones are consisted of some other sciences, especially engineering, medicine, pharmacology, food and agriculture. Here are some samples of applied life science branches and related concepts.

3.2. Applied life science branches and related concepts

Biocomputers: Process of building computers that use the information of biologically developed molecules (DNA, RNA and proteins) to perform computational analysis involving data storage, retrieving, and data processing (Ausländer et al., 2012; Kuo et al., 2017; Lin et al., 2018).

Biocontrol: A method of controlling pests such as insects, mites, weeds and plant diseases using other living organisms. It is also called as biological control (Flint and Dreistadt, 1998; Follett and Duan, 2012; Bhargava et al., 2020).

Bioengineering: Application of principles of biology with an emphasis on applied knowledge and the tools of engineering to generate functional, palpable and economically feasible products. It is also called as biological engineering (Pasotti and Zucca, 2014; Wintle et al., 2017; Goyal, 2018).

Bioelectronics: Study of electrical state of biological matter that significantly affects its structure and function, like membrane potential, signal transduction, isoelectric point etc (Rivnay et al., 2014; Birkholz et al., 2016).

Biomaterials: Any matter, surface, substance or construct to interact with biological systems. Biomaterials can be found and/or derived in nature and can be synthesized for different purposes in bioengineering (Williams, 1987; Vert et al., 2012; Habibovic and Barralet, 2011; Ratner and Castner, 2020).

Biomedical science: A set of scientific disciplines applying the rules of natural science and/or formal science, to develop knowledge, inventions, or technology that are being used in healthcare or public health from cells to organs and systems in the human body (Marshall and Williams, 2002; Bernstam et al., 2010; Subbiah et al., 2010).

Biomonitoring: Measurement of the body burden of elements or compounds having toxic effects, or the metabolites, in various biological materials such as hair, nails, saliva, urine, meconium, faeces, semen, blood, breast milk, teeth and bones (in human/animal) and root, shoot, ring, bark, branch, leaf and flower (in plant) (Angerer et al., 2007; Akguc et al., 2008; Yasar and Ozyigit, 2009; Yener and Yarci, 2010).

Biopolymers: They are natural polymers produced by living organisms such as polynucleotides (RNA and DNA), polypeptides (collagen, actin, and fibrin, etc.) and polysaccharides (starch, cellulose and alginate, etc.) it can also be said that they are polymeric biomolecules, which derived from cellular or extracellular matter (Mohanty et al., 2005; Kumar et al., 2007).

Conservation biology: Protecting and restoring the Earth's biodiversity with the aim of protecting species, their habitats, and ecosystems for the intrinsic value of these systems Morris and Doak, 2002; Hunter and Gibbs, 2006; Berger-Tal and Lahoz-Monfort, 2018).

Fermentation technology: Study of use of micro-organisms for industrial fabrication of commercial products like antibiotics, amino acids, vitamins, beer, wine, etc by using fermentation, which is a metabolic process that produces chemical changes in organic substrates through the action of enzymes (Hui and Evranuz, 2015; Choudhary et al., 2018; Joshi et al., 2018).

Genomics: Application of recombinant DNA, DNA sequencing methods, and bioinformatics to sequence, assemble, and analyze the function and structure, evolution, mapping, and editing of genomes (Xia, 2013; Pevsner, 2015; Chakravorty et al., 2018).

Kinesiology: The scientific study of human or non-human body movement and its mechanics and how they impact on health and wellbeing. It scrutinizes the dynamic principles of physiology and biomechanics, and mechanisms of their action (Gall et al., 2008; Twietmeyer, 2012).

Metabolomics: The comprehensive analysis of metabolites, which can collectively be referred to as the metabolome in a biological specimen (Clish, 2015; Liu and Locasale, 2017).

Optogenetics: A special neuromodulation technique in neuroscience which uses the principles and techniques of both optics and genetics to control and monitor the activities of individual neurons in living tissue (Eugenin et al., 2006; Deisseroth, 2011).

Pharmacogenomics: It is the study of the drug-genome interactions and the role of the genome in drug response. On the other hand, it is a technology that analyses how genomic variation affects an individual's response to drugs (Johnson, 2003; Wang, 2010).

Population dynamics: It is the study of size and age composition of populations in both short- and long-term, and the biological and environmental factors involved in their maintenance, decline, or expansion such as birth and death rates, immigration and emigration (Saccheri and Hanski, 2006; Leigh and Van Emden, 2017; Wade, 2018).

Proteomics: It is the large-scale study of proteins, which are the vital parts of living organisms, particularly their structures and functions (Anderson and Anderson, 1998; Blackstock and Weir, 1999; McArdle and Menikou, 2020).

Transcriptomics: Study of an organism's transcriptome, the sum of all of its RNA, the set of all RNA transcripts, including coding and non-coding (Schirmer et al., 2010; Chambers et al., 2019).

New discoveries in life sciences help people to improve their quality of life standards. In addition to biology, life sciences have applications in some agriculture, engineering, human and animal health/medicine, pharmaceutical and food science and industries. Some examples about these scientific fields are given below.

3.3. Agricultural sciences-related life sciences and related concepts

They are mainly, agricultural engineering, agricultural education, agricultural chemistry, agricultural economics, agricultural communication, agricultural policy, agricultural philosophy, agronomy, horticulture, agricultural soil science and agroecology. Some selected ones are given below.

Agricultural engineering: This study area covers from agricultural machinery to food engineering, from farming equipment to bioprocess engineering and the management of natural resources (Field and Long, 2018; Heldman et al., 2018)

Agricultural policy: This study area covers agricultural economics and agricultural engineering, agrophysics, animal science including animal breeding/animal nutrition/fisheries science/poultry science, aquaculture, biological engineering (genetic engineering/microbiology), environmental science (conservation/resources management/wildlife management) and food science (human nutrition/food technology) (Allen and Singh, 2016; Kovács, 2018; Browman et al., 2019; Baldi et al., 2020).

Agricultural production: Cash crop and agricultural products (food, natural fibers, lumber, paper, medicine and biofuels) (Poltronieri and D'Urso, 2016; Elevitch et al., 2018; Kamani et al., 2019; Kuma et al., 2019; Shogren et al., 2019).

Agricultural soil science: This study area covers agrogeology, agrology, land degradation and improvement, soil chemistry (soil amendment/soil erosion/soil life/soil type/soils retrogression) (Pimentel et al., 1987; Bai et al., 2008; Calzolari, 2013).

Agroecology: This study area covers problems of agroecosystem and analysis of agrophysics, biodiversity, climate change and agricultural adaptation, composting, valuation of ecosystems and environmental economics, green manure, recycling, soil science, valuation of natural resources and wildculture (Thomas and Kevan, 1993; Oteros-Rozas et al., 2014; Snapp and Pound, 2017; Mirsayapov et al., 2019).

Agronomy: This study area covers plant science (crop science/forestry/plant pathology/wood science), horticulture, plant breeding, theoretical production ecology and the correct use of fertilizers (Narwal et al., 2000; Hansen et al., 2007; Bhargava and Srivastava, 2019).

Farming: Aquaculture, mariculture, organic farming, alligator farming, dairy farming, pig farming, poultry farming, sheep husbandry, sericulture and viticulture (Hermansen et al., 2004; Nickum et al., 2018; Oyinlola, 2019; Raju et al., 2020; Squire, 2020).

Farming methods and practices: Aeroponics, aquaponics, artificial selection, field day, grazing, hydroponics, intercropping, irrigation, permaculture, pollination management, and sustainable agriculture (Daimon, 2002; Krebs and Bach, 2018; Martin-Guay et al., 2018; Randall and Smith, 2019).

Forestry: Agroforestry, analog forestry, forest gardening and forest farming (Michon and de Foresta, 1998; Senanayake, 2000; Elevitch et al., 2018).

3.4. Engineering sciences-related life sciences and related concepts

Agricultural engineering: Although most of the disciplines are covered by the agricultural science, engineering technology makes different agricultural engineering. Its subdisciplines and related concepts are; aquaculture engineering, biomechanical engineering, bioprocess engineering, biotechnical engineering, ecological engineering (ecosystem engineering), food engineering, forest engineering, health and safety engineering, information and electrical systems engineering, natural resources engineering and machinery systems engineering (Michon and de Foresta, 1998; Fescemyer and Smith, 2006; Ferreira and Van Loggerenberg, 2011; Gholamrezai and Bahadori, 2013; Browman, et al., 2019; Mirsayapov et al., 2019).

Biological engineering: Subdisciplines and related concepts cover bioacoustics, biochemical engineering, biomedical engineering, biomolecular engineering, bioresource engineering, bioprocess engineering, biosystems engineering, biotechnical engineering, cellular engineering, genetic engineering, food and biological process engineering, health and safety engineering, microbiological engineering, molecular engineering, protein engineering, systems biology, synthetic biology (Dooley, 2003; Johnson and Schreuders, 2003; Ferentinos, 2005; Heldman and Moraru, 2010; Goyal, 2018).

Biomedical engineering: Bioinstrumentation, bioinformatics, biomechanics, biomaterial, biomedical optics, biosignal processing, biotechnology, clinical engineering, medical imaging, neural engineering, and pharmaceutical engineering and tissue engineering (Bronzino, 2000; Saltzman, 2009; Enderle and Bronzino, 2012; Bronzino and Peterson, 2014).

Biomolecular engineering: Genetic engineering (of whole genes and genomes), biomolecular/biochemical engineering, DNA, RNA and protein engineering (related to genetic engineering) (Ryu and Nam, 2000; He et al., 2006; Rees et al., 2017).

Environmental engineering: Ecological engineering, sanitary engineering, wastewater engineering (blackwater, greywater and irrigation water) and municipal/urban engineering (Aitken et al., 2004; Abiko, 2010; Allen et al., 2010).

3.5. Medical sciences-related life sciences and related concepts

Basic medical sciences: Anatomy, biochemistry, biomechanics, biophysics, biostatistics, cytology, embryology, endocrinology, epidemiology, genetics, histology, immunology, medical physics, microbiology, molecular biology, neuroscience, nutrition science, pathology, pharmacology, photobiology, physiology, radiobiology and toxicology (Stetten, 1964; Easterbrook, 2005; Laake and Benestad, 2015; Ozturk and Gencturk 2018).

Diagnostic medical sciences: Clinical laboratory sciences (transfusion medicine, cellular pathology, clinical chemistry, hematology, clinical microbiology and clinical immunology), pathology, diagnostic radiology, nuclear medicine and clinical neurophysiology (Culling et al., 2014; Murphy et al., 2017; Ozturk and Gencturk, 2018; Marshall et al., 2020).

Interdisciplinary medical fields: Aerospace medicine, addiction medicine, biomedical engineering, pharmacology, conservation medicine, diving or hyperbaric medicine, disaster medicine, evolutionary medicine, forensic medicine, gender-based medicine, hospice and palliative medicine, hospital medicine, laser medicine, medical ethics and medical humanities, health informatics, nosology, nosokinetics, occupational medicine, pain management (pain medicine/algiatry), pharmacogenomics, podiatric medicine, sexual medicine, sports medicine, therapeutics, travel medicine, tropical medicine, urgent care, veterinary medicine and wilderness medicine (Payne-James et al., 2003; Daszak et al., 2004; Eddleston et al., 2005; Hüttmann et al., 2005; Davis et al., 2008; Porst and Buvat, 2008; Quest et al., 2009; Ries et al., 2009; Doukas et al., 2012; Kumar and Gandhimathi, 2012; Kumar and Sivakumar, 2012; Oriani et al., 2012; Kling et al., 2016; Auerbach et al., 2018).

Internal medical sciences: Angiology/vascular medicine, cardiology, critical care medicine, endocrinology, gastroenterology, geriatrics, hematology, hepatology, infectious disease, nephrology, neurology, oncology, pediatrics, pulmonology/pneumology/respirology/chest medicine, rheumatology and sports medicine (Kumar and Gandhimathi, 2012; Ficalora and Mueller, 2013; Ozturk and Gencturk, 2018; Abdi and Bektas, 2019).

Surgical medical sciences: General surgery, breast surgery, eye surgery, cardiovascular surgery, colorectal surgery, cosmetic surgery, dermatologic surgery, gynecologic surgery, hand surgery, neurosurgery, oral and maxillofacial surgery, oncologic surgery, ophthalmic surgery, oral and maxillofacial surgery, orthopedic surgery, otolaryngology, plastic surgery, podiatric surgery, skull-base surgery, transplant surgery, trauma surgery, urologic surgery, vascular surgery and pediatric surgery (Stegman and Tromovitch, 1982; Trokel et al., 1983; Lundborg, 2000; Sullivan, 2001; Grillo, 2004; Lanfranco et al., 2004; O'Malley and Weinstein, 2007; Vitug and Newman, 2007; Shaw et al., 2010; Kumar and Gandhimathi, 2012; Mulholland et al., 2012; Lawrence et al., 2013; Ozturk and Gencturk, 2018). Methodologically, endoscopic surgery, laparoscopic surgery, laser surgery and robotic surgery etc. (Hüttmann et al., 2005; Nezhat et al., 2006; Schleef, 2008).

Other major medical sciences: Anesthesiology (anesthetics), dermatology, emergency medicine, family medicine, obstetrics and gynecology (Obs and Gynae), medical genetics, neurology, ophthalmology, pediatrics, pharmaceutical medicine, physical medicine and rehabilitation (physiatry), podiatric medicine and psychiatry (Stegman and Tromovitch, 1982; Nezhat et al., 2006; Kumar and Gandhimathi, 2012; Turnpenny and Ellard, 2016; Cuccurullo, 2019; Rogers and Stavosky, 2019).

3.6. Other sciences-related life sciences and related concepts

Food sciences: Food chemistry and food engineering, food microbiology, food technology, molecular gastronomy, quality control and sensory analysis (Carpenter et al., 2012; Burke et al., 2016; Carr, 2017; Gillibert et al., 2018; Heldman et al., 2018; Laganà and Avventuroso, 2018).

Forestry sciences: Aesthetically appealing landscapes, biodiversity management, employment, erosion control and forest replanting, fuel wood, landscape and community protection, natural water quality management, recreation, timber provision, watershed management and wildlife habitat (Pimentel et al., 1987; Sim and Nykvist, 1991; Thorne and Huang, 1991; Umans, 1993; Cude, 2001; Hillring, 2006; Khatun, 2011; Browman et al., 2019; Randall and Smith, 2019).

Pharmacy: Pharmaceutics (pharmaceutical formulation, pharmaceutical manufacturing, dispensing pharmacy, physical pharmacy), medicinal chemistry, pharmacognosy, pharmacy practice (clinical interventions, pharmaceutical care, communication skills and patient care) and pharmacology (Lachman et al., 1986; Remington, 2006; Bond and Raehl, 2007; Holdford and Brown, 2010; Shiksha, 2020).

Veterinary sciences: Anesthesia, animal welfare, behavior, dentistry, dermatology, emergency and critical care, internal medicine (cardiology, neurology, oncology), laboratory animal medicine, microbiology, nutrition, ophthalmology, pathology, pharmacology, poultry veterinarians, preventive medicine, radiology, sports medicine and rehabilitation, surgery (orthopedics, soft tissue surgery), theriogenology, toxicology, veterinary practitioners (avian practice, equine practice, beef cattle practice, feline practice, canine/feline practice, exotic companion mammal practice, food animal practice, dairy practice, reptile and amphibian practice and swine health management) and zoological medicine (Singh et al., 2006; Lawhead and Baker, 2016; Ettinger et al., 2017; Studdert et al., 2020; Veterinary, 2020).

4. Future Perspective

All authorities consider biology as the center of life sciences and being as the science of the future. Today, new inventions in biological sciences are mostly being implemented through biotechnology and genetic engineering applications. Biological sciences exploit the developments in technological applications in terms of trying to solve problems related with many fields including health, environment, animal husbandry, food and agriculture. As known, life sciences are mostly related with biological sciences and study "life" in all its forms, past and present. The study of every living entity in the universe is a complicated task. Of course, the branches of life sciences were being limited as the result of low level and slow scientific developments in the past. As advancements in science increasingly becomes more complex in the past 20 years, the interdisciplinary research involving researchers from multiple academic disciplines is quickly adopted as the rule rather than the exception. Interdisciplinary researches provide opportunities for synthesis of ideas and the synthesis of peculiarities from many disciplines. As well, it addresses researchers' individual differences and helps to develop important, transferable skills. For instance, geneticists use the techniques from the fields of molecular biology and chemistry, chemists use information from molecular biology and genetics, plant pathologists have to be equipped with knowledge on molecular biology to study disease resistance. For these reasons, hundreds of new disciplines will be created in the next ten years in life sciences; thus, new scientific studies and inventions will be multiplied.

References

Abdi, E., & Bektas, F. (2019). *Current research in internal medical sciences*. (pp. 1-147). Livre de Lyon.

Abiko, A. (2010). Urban Engineering: Concepts and Challenges. *Methods and Techniques in Urban Engineering*, 1-13.

Aitken, M. D., Novak, J. T., Characklis, G. W., Jones, K. L., & Vikesland, P. J. (2004). The evolution of environmental engineering as a professional discipline. *Environmental Engineering Science*, *21*(2), 117-123.

Akguc, N., Ozyigit, I. I., & Yarci, C. (2008). *Pyracantha coccinea* Roem. (Rosaceae) as a biomonitor for Cd, Pb and Zn in Mugla province (Turkey). *Pakistan Journal of Botany*, *40*(4), 1767-1776.

Alberts, B., Bray, D., Hopkin, K., Johnson, A. D., Lewis, J., Raff, M., ... & Walter, P. (2013a). *Essential cell biology*. (pp. 1-864). Garland Science, New York.

Alberts, B., Johnson, A., Lewis, J., Morgan, D., Raff, M., Roberts, K., & Walter, P. (2013b). *Molecular biology of the cell*. (pp. 1-1464). Garland Science, New York.

Alexander, R. M. (2005). Mechanics of animal movement. *Current Biology*, *15*(16), 616- 619.

Allen, A. M., & Singh, N. J. (2016). Linking movement ecology with wild life management and conservation. *Frontiers in Ecology and Evolution*, *3*(155), 1-13.

Allen, L., Christian-Smith, J., & Palaniappan, M. (2010). Overview of greywater reuse: the potential of greywater systems to aid sustainable water management. *Pacific Institute*, *654*(1), 19-21.

Andersen, O. S. (2016). Introduction to biophysics week: what is biophysics? *Biophysical Journal*, *110*(5), E01-E03.

Anderson, N. L., & Anderson, N. G. (1998). Proteome and proteomics: new technologies, new concepts, and new words. *Electrophoresis*, *19*(11), 1853-1861.

Angerer, J., Ewers, U., & Wilhelm, M. (2007). Human biomonitoring: state of the art. *International Journal of Hygiene and Environmental Health*, *210*(3-4), 201-228.

Arus, E. (2012). *Biomechanics of human motion: applications in the martial arts*. (pp. 1-559). CRC Press.

Auerbach, P. S., Constance, B. B., & Freer, L. (2018). *Field guide to wilderness medicine e-book*. (pp. 1-1000). Elsevier Health Sciences.

Ausländer, S., Ausländer, D., Müller, M., Wieland, M., & Fussenegger, M. (2012). Programmable single-cell mammalian biocomputers. *Nature*, *487*(7405), 123-127.

Bai, Z. G., Dent, D. L., Olsson, L., & Schaepman, M. E. (2008). *Global assessment of land degradation and improvement: 1. identification by remote sensing (No. 5)*. (pp. 1-69). ISRIC-World Soil Information.

Baldi, A., Paolo Macciotta, N. P., Pulina, G., & Ronchi, B. (2020). Perspectives for the future in Italy: animal science higher education, employment, and research. *Animal Frontiers*, *10*(3), 24-29.

Barnes-Svarney, P., & Svarney, T. E. (2016). *The handy anatomy answer book*. (pp. 1-385) Visible Ink Press.

Bellanti, J. (2013). *Immunology*. Vol. 6. (pp. 1-347). Springer Science & Business Media.

Berg, L. R. (2008). *Introductory botany: plants, people, and the environment.* (pp. 1-649). Thomsom Brooks/Cole Corporation, Belmont, CA.

Berger-Tal, O., & Lahoz-Monfort, J. J. (2018). Conservation technology: the next generation. *Conservation Letters*, *11*(6), e12458.

Bernstam, E. V., Smith, J. W., & Johnson, T. R. (2010). What is biomedical informatics?. *Journal of Biomedical Informatics*, *43*(1), 104-110.

Bettencourt, A. L. (2020). What is biotechnology?. *Microreviews in Cell and Molecular Biology*, *7*(2), 1-3.

Bhargava, A., & Srivastava, S. (2019). *Participatory plant breeding: concept and applications*. (pp. 1-247). Springer Singapore.

Bhargava, P., Gupta, N., Kumar, R., & Vats, S. (2020). Plants and microbes: bioresources for sustainable development and biocontrol. In: Varma, A., Tripathi, S., Prasad, R. (eds) *Plant Microbe Symbiosis* (pp. 153-176). Springer, Cham.

Birkholz, M., Mai, A., Wenger, C., Meliani, C., & Scholz, R. (2016). Technology modules from micro-and nano-electronics for the life sciences. *Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology*, *8*(3), 355-377.

Blackstock, W. P., & Weir, M. P. (1999). Proteomics: quantitative and physical mapping of cellular proteins. *Trends in Biotechnology*, *17*(3), 121-127.

Bond, C. A., & Raehl, C. L. (2007). Clinical pharmacy services, pharmacy staffing, and hospital mortality rates. *Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy*, *27*(4), 481-493.

Breitling, R. (2010). What is systems biology?. *Frontiers in Physiology*, *1*(9), 159-164.

Bronzino, J. D. (2000). *Biomedical engineering handbook 2*. Vol. 2. (pp. 1-1512). Springer Science & Business Media.

Bronzino, J. D., & Peterson, D. R. (2014). *Biomedical engineering fundamentals*. (pp. 1-1180). CRC press.

Brookes, J. C. (2017). Quantum effects in biology: golden rule in enzymes, olfaction, photosynthesis and magnetodetection. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *473*(2201), 20160822.

Browman, H. I., Cooke, S. J., Cowx, I. G., Derbyshire, S. W., Kasumyan, A., Key, B., ... & Watson, C. A. (2019). Welfare of aquatic animals: where things are, where they are going, and what it means for research, aquaculture, recreational angling, and commercial fishing. *ICES Journal of Marine Science*, *76*(1), 82-92.

Bueso, Y. F., & Tangney, M. (2017). Synthetic biology in the driving seat of the bioeconomy. *Trends in Biotechnology*, *35*(5), 373-378.

Burke, R., This, H., & Kelly, A. L. (2016). Molecular gastronomy: an introduction. *Reference Module in Food Science*, 1.

Calzolari, C. (2013). Research in pedology: a historical perspective. In: Costantini, E., Dazzi, C. (eds) *The Soils of Italy* (pp. 1-17). Springer, Dordrecht.

Cann, A. J. (2001). *Principles of molecular virology*. Std ed., (pp. 1-339). Academic Press.

Carlberg, C., & Molnár, F. (2016). Overview: what is gene expression?. In: Carlberg, C., Molnár, F. (eds) *Mechanisms of Gene Regulation* (pp. 3-16). Springer, Dordrecht.

Carlson, B. M. (2018). *Human embryology and developmental biology e-book.* (pp. 1-496). Elsevier Health Sciences.

Carpenter, R. P., Lyon, D. H., & Hasdell, T. A. (2012). *Guidelines for sensory analysis in food product development and quality control*. (pp. 1-210). Springer Science & Business Media.

Carr, F. J. (2017). Microbiology: a fundamental introduction. *EC Microbiology*, *8*(3), 123-183.

Carter, J., Saunders, V., & Saunders, V. A. (2007). *Virology: principles and applications*. (pp. 1-382). John Wiley & Sons.

Chakravorty, D., Banerjee, K., & Saha, S. (2018). Integrative omics for interactomes. In: Singh, S. (ed) *Synthetic Biology* (pp. 39-49). Springer, Singapore.

Chambers, D. C., Carew, A. M., Lukowski, S. W., & Powell, J. E. (2019). Transcriptomics and single-cell RNA-sequencing. *Respirology*, *24*(1), 29-36.

Choudhary, M., Joshi, S., Bhagyawant, S. S., & Srivastava, N. (2018). Advances in fermentation technology: principle and their relevant applications. In: Sharma, V., Kuila, A. (eds) *Principles and Applications of Fermentation Technology* (pp. 53-63). Wiley Online Library.

Cibas, E. S., & Ducatman, B. S. (2013). *Cytology e-book: diagnostic principles and clinical correlates*. (pp. 1-576). Elsevier Health Sciences.

Clish, C. B. (2015). Metabolomics: an emerging but powerful tool for precision medicine. *Molecular Case Studies*, *1*(1), a000588.

Cockell, C. S. (2020). *Astrobiology: understanding life in the universe*. (pp. 1-632). John Wiley & Sons.

Cottin, H., Kotler, J. M., Bartik, K., Cleaves, H. J., Cockell, C. S., De Vera, J. P. P., ... & Pascal, R. (2017). Astrobiology and the possibility of life on earth and elsewhere…. *Space Science Reviews*, *209*(1-4), 1-42.

Cox, M. M., Doudna, J. A., & O'Donnell, M. (2012). *Molecular biology: principles and practice* (p. 1-809). New York, NY. USA: WH Freeman and Company.

Cuccurullo, S. J. (2019). *Physical medicine and rehabilitation board review*. (pp. 1-1152). Springer Publishing Company.

Cude, C. G. (2001). Oregon water quality index a tool for evaluating water quality management effectiveness 1. *JAWRA Journal of the American Water Resources Association*, *37*(1), 125-137.

Culling, C. F. A., Allison, R. T., & Barr, W. T. (2014). *Cellular pathology technique*. (pp. 1-650). Elsevier.

Daimon, H. (2002). Understanding of various traits of crops needed for sustainable production system and their utilization for farming methods and practices. *Japanese Journal of Crop Science*, *71*(Supplement2), 310-313.

Daszak, P., Tabor, G. M., Kilpatrick, A. M., Epstein, J. O. N., & Plowright, R. (2004). Conservation medicine and a new agenda for emerging diseases. *Annals of the New York Academy of Sciences*, *1026*(1), 1-11.

Davis, J. R., Johnson, R., & Stepanek, J. (2008). *Fundamentals of aerospace medicine*. (pp. 1-754). Lippincott Williams & Wilkins.

Deisseroth, K. (2011). Optogenetics. *Nature Methods*, *8*(1), 26-29.

Demarest, B., & Wolfe, C. T. (2017). The organism as reality or as fiction: buffon and beyond. *History and Philosophy of the Life Sciences*, *39*(1), 2-22.

Demirezen, M. (1988). Behaviorist theory and language learning. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi*, *3*(3), 135-140.

Díaz-Muñoz, S. L., Boddy, A. M., Dantas, G., Waters, C. M., & Bronstein, J. L. (2016). Contextual organismality: beyond pattern to process in the emergence of organisms. *Evolution*, *70*(12), 2669-2677.

Dooley, J. H. (2003). Biological engineering definition. *Encyclopedia of Agricultural Food and Biological Engineering, New York: Marcel Dekker*, 60-63.

Doukas, D. J., McCullough, L. B., & Wear, S. (2012). Perspective: medical education in medical ethics and humanities as the foundation for developing medical professionalism. *Academic Medicine*, *87*(3), 334-341.

Dukas, R. (2004). Evolutionary biology of animal cognition. *Annual Review of Ecology, Evolution, and Systematics*, *35*, 347-374.

Easterbrook, P. J. (2005). *Basic medical sciences for MRCP part 1.* (pp. 1-436). Elsevier/Churchill Livingstone.

Eddleston, M., Pierini, S., Wilkinson, R., & Davidson, R. (2005). *Oxford handbook of tropical medicine*. 2nd ed., (pp. 1-686). Oxford University Press.

El Karoui, M., Hoyos-Flight, M., & Fletcher, L. (2019). Future trends in synthetic biology-a report. *Frontiers in Bioengineering and Biotechnology*, *7*, 175-184.

Elevitch, C. R., Mazaroli, D. N., & Ragone, D. (2018). Agroforestry standards for regenerative agriculture. *Sustainability*, *10*(9), 3337.

Ellison, P. T. (2018). The evolution of physical anthropology. *American Journal of Physical Anthropology*, *165*(4), 615-625.

Elston, R. C., Satagopan, J. M., & Sun, S. (2012). Genetic terminology. In: Elston, R., Satagopan, J., Sun, S. (eds) *Statistical Human Genetics* (pp. 1-9). Humana Press.

Enderle, J., & Bronzino, J. (2012). *Introduction to biomedical engineering*. (pp. 1-1272). Academic press.

Epozturk, K., & Gorkey, S. (2018) Yaşadığı çağda efsane olmuş bir tıp insanın işyeri hekimi olarak çalışması: Rudolf Virchow ve Troya. *Mersin Üniversitesi Tıp Fakültesi Lokman Hekim Tıp Tarihi ve Folklorik Tıp Dergisi*, *8*(3), 167-171.

Ettinger, S. J., Feldman, E. C., & Cote, E. (2017). *Textbook of veterinary* *internal medicine-ebook*. (pp. 1-2736). Elsevier Health Sciences.

Eugenin, E. A., Osiecki, K., Lopez, L., Goldstein, H., Calderon, T. M., & Berman, J. W. (2006). CCL2/monocyte chemoattractant protein-1 mediates enhanced transmigration of human immunodeficiency virus (HIV)-infected leukocytes across the blood–brain barrier: a potential mechanism of HIV-CNS invasion and NeuroAIDS. *Journal of Neuroscience*, *26*(4), 1098-1106.

Ferentinos, K. P. (2005). Biological engineering applications of feedforward neural networks designed and parameterized by genetic algorithms. *Neural Networks*, *18*(7), 934-950.

Ferreira, E., & Van Loggerenberg, F. (2011). Perceptions on safety management within South African small and medium enterprises (SMEs): research and theory. *African Safety Promotion*, *9*(2), 25-42.

Fescemyer, K., & Smith, H. (2006). Agricultural and food engineering. *Routledge Studies in Library and Information Science*, *1*, 62-83.

Ficalora, R. D., & Mueller, P. S. (2013). *Mayo clinic internal medicine board review*. (pp. 1-802). Oxford University Press.

Field, H. L., & Long, J. M. (2018). *Introduction to agricultural engineering technology: a problem solving approach*. (pp. 1-456). Springer.

Filiz, E., Vatansever, R., & Ozyigit, I. I. (2017). Bioinformatics database resources for plant transcription factors. In: Hakeem, K., Malik, A., Vardar-Sukan, F., Ozturk, M. (eds) *Plant Bioinformatics* (pp. 161-177). Springer, Cham.

Flint, M. L., & Dreistadt, S. H. (1998). *Natural enemies handbook: the illustrated guide to biological pest control*. Vol. 3386. (pp. 1-154). Univ of California Press.

Follett, P. A., & Duan, J. J. (2012). *Nontarget effects of biological control*. (pp. 1-316). Springer Science & Business Media.

Folse III, H. J., & Roughgarden, J. (2010). What is an individual organism? A multilevel selection perspective. *The Quarterly Review of Biology*, *85*(4), 447-472.

Fung, Y. C. (2013). *Biomechanics: mechanical properties of living tissues*. (pp. 1-568). Springer Science & Business Media.

Futuyma, D. J., & Agrawal, A. A. (2009). Evolutionary history and species interactions. *Proceedings of the National Academy of Sciences*, *106*(43), 18043-18044.

Gall, J., Rosenhahn, B., & Seidel, H. P. (2008). An introduction to interacting simulated annealing. In: Rosenhahn, B., Klette, R., Metaxas, D. (eds) *Human Motion* (pp. 319-345). Springer, Dordrecht.

Gartner, L. P. (2018). *BRS cell biology and histology*. (pp. 1-448). Lippincott Williams & Wilkins.

Gholamrezai, S., & Bahadori, M. (2013). Mechanisms for employing the forestry alumni by agricultural and natural resources engineering organization. *Iranian Journal of Agricultural Economics and Development Research (IJAEDR)*, *44*(1), 143-151.

Gillibert, R., Huang, J. Q., Zhang, Y., Fu, W. L., & de la Chapelle, M. L. (2018). Food quality control by surface enhanced Raman scattering. *TrAC Trends in Analytical Chemistry*, *105*, 185-190.

Glick, B. R., & Patten, C. L. (2017). *Molecular biotechnology: principles and applications of recombinant DNA*. Vol. 34. (pp. 1-740). John Wiley & Sons.

Gomez-Marin, A., Paton, J. J., Kampff, A. R., Costa, R. M., & Mainen, Z. F. (2014). Big behavioral data: psychology, ethology and the foundations of neuroscience. *Nature Neuroscience*, *17*(11), 1455-1462.

Goyal, M. R. (2018). *Scientific and technical terms in bioengineering and biological engineering*. (pp. 1-634). CRC Press.

Griffiths, A. J., Wessler, S. R., Lewontin, R. C., Gelbart, W. M., Suzuki, D. T., & Miller, J. H. (2005). *An introduction to genetic analysis*. (pp. 1-868). Macmillan.

Grillo, H. C. (2004). *Surgery of the trachea and bronchi*. (pp. 1-872). PMPH USA.

Gupta, P. K. (2005). *Cell and molecular biology*. (pp. 1-942). Rastogi Publications.

Habibovic, P., & Barralet, J. E. (2011). Bioinorganics and biomaterials: bone repair. *Acta Biomaterialia*, *7*(8), 3013-3026.

Hall, J. E. (2016). *Guyton and hall textbook of medical physiology*. 1st ed., (pp. 1-1168). Jordanian Edition E-Book. Elsevier.

Hansen, N., Ward, S., Khosla, R., Fenwick, J., & Moore, B. (2007). What does undergraduate enrollment in soil and crop sciences mean for the future of agronomy?. *Agronomy Journal*, *99*(4), 1169-1174.

Hastings, A. (2013). *Population biology: concepts and models*. (pp.1-220). Springer Science & Business Media.

He, L., Dexter, A. F., & Middelberg, A. P. (2006). Biomolecular engineering at interfaces. *Chemical Engineering Science*, *61*(3), 989-1003.

Heldman, D. R., & Moraru, C. I. (2010). *Encyclopedia of agricultural, food, and biological engineering*. (pp. 1-2120). Crc Press.

Heldman, D. R., Lund, D. B., & Sabliov, C. (2018). *Handbook of food engineering*. (pp. 1-1194). CRC press.

Hermansen, J. E., Strudsholm, K., & Horsted, K. (2004). Integration of organic animal production into land use with special reference to swine and poultry. *Livestock Production Science*, *90*(1), 11-26.

Hillring, B. (2006). World trade in forest products and wood fuel. *Biomass and Bioenergy*, *30*(10), 815-825.

Hodgson, E. (2010). *A textbook of modern toxicology*. (pp. 1-672). John Wiley & Sons.

Hogeweg, P. (2011). The roots of bioinformatics in theoretical biology. *PLoS Computational Biology*, *7*(3), e1002021.

Holdford, D. A., & Brown, T. R. (2010). *Introduction to hospital and health-system pharmacy practice*. (pp. 1-416). ASHP.

Holland, P. C., & Ball, G. F. (2003). The psychology and ethology of learning. *Handbook of Psychology*, 457-497.

Huang, S., Yuan, S., Dong, M., Su, J., Yu, C., Shen, Y., ... & Zhang, S. (2005). The phylogenetic analysis of tetraspanins projects the evolution of cell-cell interactions from unicellular to multicellular organisms. *Genomics*, *86*(6), 674-684.

Hudspeth, A. J., Jessell, T. M., Kandel, E. R., Schwartz, J. H., & Siegelbaum, S. A. (2013). *Principles of neural science*. (pp. 1- 1705). McGraw-Hill, Health Professions Division.

Hui, Y. H., & Evranuz, E. O. (2015). *Handbook of vegetable preservation and processing*. (pp. 1-772). CRC Press.

Hunter Jr, M. L., & Gibbs, J. P. (2006). *Fundamentals of conservation biology*. (pp. 1-516). John Wiley & Sons.

Hüttmann, G., Yao, C., & Endl, E. (2005). New concepts in laser medicine: towards a laser surgery with cellular precision. *Medical Laser Application*, *20*(2), 135-139.

Johnson, A., & Schreuders, P. (2003). Bringing life to engineering: biological engineering at the graduate level. *European Journal of Engineering Education*, *28*(1), 37-46.

Johnson, J. A. (2003). Pharmacogenetics: potential for individualized drug therapy through genetics. *Trends in Genetics*, *19*(11), 660-666.

Johnson, M. T., & Stinchcombe, J. R. (2007). An emerging synthesis between community ecology and evolutionary biology. *Trends in Ecology & Evolution*, *22*(5), 250-257.

Joshi, R., Sharma, V., & Kuila, A. (2018). Fermentation technology: current status and future prospects. In: Sharma, V., Kuila, A. (eds) *Principles and Applications of Fermentation Technology* (pp. 1-13). Wiley Online Library.

Jurmain, R., Kilgore, L., Trevathan, W., & Ciochon, R. L. (2013). *Introduction to physical anthropology, 2013-2014 edition*. (pp. 1-576). Cengage Learning.

Kamani, M. H., Eş, I., Lorenzo, J. M., Remize, F., Roselló-Soto, E., Barba, F. J., ... & Khaneghah, A. M. (2019). Advances in plant materials, food by-products, and algae conversion into biofuels: use of environmentally friendly technologies. *Green Chemistry*, *21*(12), 3213-3231.

Karplus, M., & McCammon, J. A. (2002). Molecular dynamics simulations of biomolecules. *Nature Structural Biology*, *9*(9), 646-652.

Keasling, J. D. (2012). Synthetic biology and the development of tools for metabolic engineering. *Metabolic Engineering*, *14*(3), 189-195.

Khatun, K. (2011). Reconciling timber provision with carbon sequestration opportunities in the tropical forests of Central America. *Environmental Science & Policy*, *14*(8), 1091-1102.

Kierszenbaum, A. L., & Tres, L. (2015). *Histology and cell biology: an introduction to pathology e-book*. (pp. 1-752). Elsevier Health Sciences.

Kling, J. M., Rose, S. H., Kransdorf, L. N., Viggiano, T. R., & Miller, V. M. (2016). Evaluation of sex-and gender-based medicine training in post-graduate medical education: a cross-sectional survey study. *Biology of Sex Differences*, *7*(1), 38, 48-103.

Koshland, D. E. (2002). The seven pillars of life. *Science*, *295*(5563), 2215-2216.

Kovács, K. (2018). Managerial challenges in hungarian agricultural enterprises. In: Bryła, P. (ed) *Managing Agricultural Enterprises* (pp. 225-239). Palgrave Macmillan, Cham.

Krakauer, D. C., Collins, J. P., Erwin, D., Flack, J. C., Fontana, W., Laubichler, M. D., ... & Stadler, P. F. (2011). The challenges and scope of theoretical biology. *Journal of Theoretical Biology*, *276*(1), 269-276.

Krebs, J., & Bach, S. (2018). Permaculture-Scientific evidence of principles for the agroecological design of farming systems. *Sustainability*, *10*(9), 3218.

Kuma, T., Dereje, M., Hirvonen, K., & Minten, B. (2019). Cash crops and food security: Evidence from Ethiopian smallholder coffee producers. *The Journal of Development Studies*, *55*(6), 1267-1284.

Kumar, A., Srivastava, A., Galaev, I. Y., & Mattiasson, B. (2007). Smart polymers: physical forms and bioengineering applications. *Progress in Polymer Science*, *32*(10), 1205-1237.

Kumar, K. S., & Sivakumar, R. (2012). History of medicine - a review. *International Journal of Current Pharmaceutical & Clinical Research*, *2*(2), 61-69.

Kumar, P., and Mina, U. (2015). Life Sciences Fundamentals and Practice - I, Fifth edition, Chapter 3, Cell Structure and Functions, Pathfinder Publication, New Delhi, India, pp: 236-347.

Kumar, S., Gandhimathi, C., Venugopal, J., Tay, S., & Ramakrishna, S. (2015). Simultaneous electrospun-electrosprayed biocomposite nanostructured substrates for bone tissue engineering. *The FASEB Journal*, *29*(1_supplement), 876-914.

Kuo, T. Y., Lin, C. L., Charoenkit, N., Chen, Y. Y., & Preuksakarn, C. (2017). Toward theoretical synthesis of biocomputer. *IET Systems Biology*, *11*(1), 36-43.

Kusber, W. H., & Jahn, R. (2002). *Annotated list of diatom names by Horst Lange-Bertalot and co-workers*. (pp. 1-62). AlgaTerra.

Laake, P., & Benestad, H. B. (2015). *Research in medical and biological sciences: from planning and preparation to grant application and publication*. (pp. 1-584). Academic Press.

Lachman, L., Lieberman, H. A., & Kanig, J. L. (1986). *The theory and practice of industrial pharmacy*. (pp. 1-902). Lea & Febiger.

Laganà, P., & Avventuroso, E. (2018). *Chemistry and hygiene of food additives*. (pp. 1-46). Springer.

Lalli, C., & Parsons, T. R. (1997). *Biological oceanography: an introduction*. 2nd ed., (pp. 1-320). Elsevier.

Lanfranco, A. R., Castellanos, A. E., Desai, J. P., & Meyers, W. C. (2004). Robotic surgery: a current perspective. *Annals of Surgery*, *239*(1), 14-21.

Lawhead, J., & Baker, M. (2016). *Introduction to veterinary science*. (pp. 1-448). Cengage Learning.

Lawrence, P. F., Bell, R. M., Dayton, M. T., & Hebert, J. (2013). *Essentials of general surgery*. (pp. 1-586). Lippincott Williams & Wilkins.

Leigh, S., & Van Emden, H. F. (2017). *Population dynamics: cycles and patterns* (pp. 262-279). Wallingford, UK: CAB International.

Liljas, A., Liljas, L., Piskur, J., Nissen, P., & Kjeldgaard, M. (2009). *Textbook of structural biology*. (pp. 1-572). World Scientific Publishing Company.

Lin, C. L., Kuo, T. Y., & Li, W. X. (2018). Synthesis of control unit for future biocomputer. *Journal of Biological Engineering*, *12*(1), 14-30.

Linnaeus, C. (1735). Systemae Naturae, sive regna tria naturae, systematics proposita per classes, ordines, genera & species, Haak, Levden, str. 1-12.

Liu, X., & Locasale, J. W. (2017). Metabolomics: a primer. *Trends in Biochemical Sciences*, *42*(4), 274-284.

Longo, G., & Soto, A. M. (2016). Why do we need theories?. *Progress in Biophysics and Molecular Biology*, *122*(1), 4-10.

Louys, J. (2012). Paleontology in ecology and conservation: an introduction. In: Louys, J. (eds) *Paleontology in Ecology and Conservation* (pp. 1-7). Springer Earth System Sciences, Springer, Berlin, Heidelberg.

Lundborg, G. (2000). Brain plasticity and hand surgery: an overview. *The Journal of Hand Surgery: British & European Volume*, *25*(3), 242-252.

Lüttge, U., Beyschlag, W., Budel, B., Francis, D., & Berg, L. R. (2016). *Progress in botany*. (pp. 1-435). Springer-Verlag Berlin An.

Madigan, M. T., Clark, D. P., Stahl, D., & Martinko, J. M. (2010). *Brock biology of microorganisms 13th edition*. (pp. 1-1152). Benjamin Cummings.

Marcus, B. (2012). But it is only a theory. In: Marcus, B. (ed) *Evolution That Anyone Can Understand* (pp. 21-26). Springer, New York, NY.

Marshall, T., & Williams, K. M. (2002). Proteomics and its impact upon biomedical science. *British Journal of Biomedical Science*, *59*(1), 47-64.

Marshall, W. J., Lapsley, M., Day, A., & Shipman, K. (2020). *Clinical chemistry*. (pp. 1-432). Elsevier Health Sciences.

Martin, R. (2017). Basic structures of prokaryotic and eukaryotic cells. *Microreviews in Cell and Molecular Biology*, *2*(2), 1-7.

Martin-Guay, M. O., Paquette, A., Dupras, J., & Rivest, D. (2018). The new green revolution: sustainable intensification of agriculture by intercropping. *Science of the Total Environment*, *615*, 767-772.

Martins, P. T., & Boeckx, C. (2016). What we talk about when we talk about biolinguistics. *Linguistics Vanguard*, *2*(1), 1-15.

Mauseth, J. D. (2014). *Botany: an introduction to plant biology*. (pp. 1-844). Jones & Bartlett Publishers.

McArdle, A. J., & Menikou, S. (2020). What is proteomics?. *Archives of Disease in Childhood Education and Practice*, 1-4.

McConnell, T. H., & Hull, K. L. (2020). *Human form, human function: essentials of anatomy & physiology*. (pp. 1-778). Jones & Bartlett Publishers.

McKay, C. P. (1991). Urey Prize lecture: Planetary evolution and the origin of life. *Icarus*, *91*(1), 93-100.

McKay, C. P. (2004). What is life-and how do we search for it in other worlds?. *PLoS Biology*, *2*(9), e302.

McKee, J. R., & McKee, T. (2019). *Biochemistry: the molecular basis of life*. 7th ed., (pp. 1-448). Oxford University Press.

Mescher, A. L. (2018). *Junqueira's basic histology: text and atlas*. (pp. 1-570). McGraw-Hill Education.

Michal, G., & Schomburg, D. (2012). *Biochemical pathways: an atlas of biochemistry and molecular biology*. (pp. 1-416). John Wiley & Sons.

Michon, G., & de Foresta, H. (1998). 1 T Agro-Forests: Incorporating a Forest Vision in Agroforestry. *Agroforestry in Sustainable Agricultural Systems*, 381.

Miller, C. B., & Wheeler, P. A. (2012). *Biological oceanography*. 2nd ed., (pp. 1-474). John Wiley & Sons.

Mirsayapov, R. R., Asylbaev, I. G., Kurmasheva, N. G., Lukmanov, R. A., & Miftakhov, I. R. (2019). Agroecological assessment of soils in the system of agricultural land use. *Bulgarian Journal of Agricultural Science*, *25*(S2), 187-190.

Mohanty, A. K., Misra, M., & Drzal, L. T. (2005). *Natural fibers, biopolymers, and biocomposites*. (pp. 1-896). CRC Press.

Moore, L. R., Huang, T., Ostrowski, M., Mazard, S., Kumar, S. S., Gamage, H. K., ... & Paulsen, I. T. (2019). Unicellular cyanobacteria are important components of phytoplankton communities in Australia's northern oceanic ecoregions. *Frontiers in Microbiology*, *9*(3356), 1-16.

Morris, W. F., & Doak, D. F. (2002). *Quantitative conservation biology*. (pp. 1-480). Sinauer, Sunderland, Massachusetts, USA.

Mulholland, M. W., Lillemoe, K. D., Doherty, G. M., Maier, R. V., Simeone, D. M., & Upchurch, G. R. (2012). *Greenfield's surgery: Scientific principles & practice*. (pp. 1-2112). Lippincott Williams & Wilkins.

Murphy, M. F., Roberts, D. J., & Yazer, M. H. (2017). *Practical transfusion medicine*. (pp. 1-608). John Wiley & Sons.

Narwal, S. S., Hoagland, R. E., Dilday, R. H., & Roger, M. R. (2000). *Allelopathy in ecological agriculture and forestry*. (1-267). Springer Science & Business Media.

Nezhat, C., Saberi, N. S., Shahmohamady, B., & Nezhat, F. (2006). Robotic-assisted laparoscopy in gynecological surgery. *JSLS: Journal of the Society of Laparoendoscopic Surgeons*, *10*(3), 317-320.

Nickum, M. J., Masser, M., Reigh, R., & Nickum, J. G. (2018). Alligator (*Alligator mississippiensis*) aquaculture in the United States. *Reviews in Fisheries Science & Aquaculture*, *26*(1), 86-98.

O'Malley, B. W., & Weinstein, G. S. (2007). Robotic skull base surgery: preclinical investigations to human clinical application. *Archives of Otolaryngology-Head & Neck Surgery*, *133*(12), 1215-1219.

Ogawa, H., & Oka, K. (2013). *Methods in neuroethological research*. (pp. 1-186). Springer Science & Business Media.

Oriani, G., Marroni, A., & Wattel, F. (2012). *Handbook on hyperbaric medicine*. (pp. 1-920). Springer Science & Business Media.

Oteros-Rozas, E., Martín-López, B., González, J. A., Plieninger, T., López, C. A., & Montes, C. (2014). Socio-cultural valuation of ecosystem services in a transhumance social-ecological network. *Regional Environmental Change*, *14*(4), 1269-1289.

Oyinlola, M. A. (2019). Mariculture: perception and prospects under climate change. In: Andres, M., William, W. L. (eds) *Predicting Future Oceans* (pp. 227-239). Elsevier.

Ozturk, N., & Gencturk, M. (2018). Hekimlerin branş tercihlerinin trend analizi yöntemi ile incelenmesi, Investigation of physicians branch preferencies by trend analyse method. *Social Sciences Studies Journal*, *4*(19), 2193-2202.

Ozyigit, I. I., Yalcin, B., Turan, S., Saracoglu, I. A., Karadeniz, S., Yalcin, I. E., & Demir, G. (2018). Investigation of heavy metal level and mineral nutrient status in widely used medicinal plants' leaves in Turkey: Insights into health implications. *Biological Trace Element Research*, *182*(2), 387-406.

Pasotti, L., & Zucca, S. (2014). Advances and computational tools towards predictable design in biological engineering. *Computational and Math-*

ematical Methods in Medicine, *2014*, 1-16.
Payne-James, J., Busuttil, A., & Smock, W. (2003). *Forensic medicine: clinical and pathological aspects*. (pp. 1-840). Cambridge University Press.
Pevsner, J. (2015). *Bioinformatics and functional genomics*. (pp. 1-1168). John Wiley & Sons.
Pimentel, D., Allen, J., Beers, A., Guinand, L., Linder, R., McLaughlin, P., ... & Siebert, S. (1987). World agriculture and soil erosion. *BioScience*, *37*(4), 277-283.
Pleyer, M., & Hartmann, S. (2019). Constructing a consensus on language evolution? Convergences and differences between biolinguistic and usage-based approaches. *Frontiers in Psychology*, *10*, 2537-2556.
Poltronieri, P., & D'Urso, O. F. (2016). *Biotransformation of agricultural waste and by-products: the food, feed, fibre, fuel (4F) economy*. (pp. 1-398). Elsevier.
Porst, H., & Buvat, J. (2008). *Standard practice in sexual medicine*. (pp. 1-416). John Wiley & Sons.
Pua, E. C. (2010). *Plant developmental biology-biotechnological perspectives*. (pp. 1-497). Heidelberg; Springer.
Quest, T. E., Marco, C. A., & Derse, A. R. (2009). Hospice and palliative medicine: new subspecialty, new opportunities. *Annals of Emergency Medicine*, *54*(1), 94-102.
Raff, H., Falk-Steinmetz, M., Medhora, M., De Roo, K., & Holt, P. (2014). In Vander's human physiology: the mechanisms of body function. *Undersea & Hyperbaric Medicine: Journal of the Undersea and Hyperbaric Medical Society, Inc*, *41*(4), 331-335.
Raju, P. J., Mamatha, D. M., & Seshagiri, S. V. (2020). Sericulture industry: a bonanza to strengthen rural population in India. In: Mamatha, D. M., Seshagiri, S. V. (eds) *Environmental and Agricultural Informatics: Concepts, Methodologies, Tools, and Applications* (pp. 366-387). IGI Global.
Rana, S. V. S. (2013). *Essentials of ecology and environmental science*. (pp. 1-608). PHI Learning Pvt. Ltd.
Randall, N., & Smith, B. (2019). *The biology of agroecosystems*. (pp. 1-208). Oxford University Press, USA.
Ratner, B. D., & Castner, D. G. (2020). Surface properties and surface characterization of biomaterials. In: Wagner, W. R., Sakiyama-Elbert, S. E., Zhang, G., Yaszemski, M. J. (eds) *Biomaterials Science* (pp. 53-76). Academic Press.
Raven, P., Johnson, G., Mason, K., Losos, J., Singer, S. (2019). *Biology*. 12th ed., (pp. 1-1472). McGraw-Hill Education.
Rees, H. A., Komor, A. C., Yeh, W. H., Caetano-Lopes, J., Warman, M., Edge, A. S., & Liu, D. R. (2017). Improving the DNA specificity and applicability of base editing through protein engineering and protein delivery. *Nature Communications*, *8*(1), 1-10.
Remington, J. P. (2006). *Remington: The science and practice of pharmacy*. Vol. 1. (pp. 1-2393). Lippincott Williams & Wilkins.
Ribatti, D. (2018). An historical note on the cell theory. *Experimental Cell Research*, 364(1), 1-4.
Ribeiro, T. G., Barone, B., & Behrens, J. H. (2016). Genetically modified foods and their social representation. *Food Research International, 84*, 120-127.
Ries, R. K., Miller, S. C., & Fiellin, D. A. (2009). *Principles of addiction medicine*. (pp. 1-1570). Lippincott Williams & Wilkins.
Rivnay, J., Owens, R. M., & Malliaras, G. G. (2014). The rise of organic bioelectronics. *Chemistry of Materials*, *26*(1), 679-685.
Rodriguez Garcia, M. (2016). Engineering the transition from non-living to living matter, Doctoral Dissertation, (pp. 1-234). University of Glasgow, Scotland, UK.
Rodwell, V. W., Bender, D. A., Botham, K. M., Kennelly, P. J., Weil, P. A. (2019). *Harper's illustrated biochemistry*. 31st ed., (pp. 1-800). McGraw-Hill Education.
Rogers, L. C., & Stavosky, J. W. (2019). Hospital and surgical privileges for doctors of podiatric medicine: a position statement from the American board of podiatric medicine. *Journal of the American Podiatric Medical Association*, *109*(S1), 1-4.
Ruggiero, M. A., Gordon, D. P., Orrell, T. M., Bailly, N., Bourgoin, T., Brusca, R. C., ... & Kirk, P. M. (2015). A higher level classification of all living organisms. *PloS One*, *10*(4), e0119248.
Ryu, D. D., & Nam, D. H. (2000). Recent progress in biomolecular engineering. *Biotechnology Progress*, *16*(1), 2-16.
Saccheri, I., & Hanski, I. (2006). Natural selection and population dynamics. *Trends in Ecology & Evolution*, *21*(6), 341-347.
Saetzler, K., Sonnenschein, C., & Soto, A. M. (2011). Systems biology beyond networks: generating order from disorder through self-organization. *Seminars in Cancer Biology*, *21*(3), 165-174.
Saltzman, W. M. (2009). *Biomedical engineering: bridging medicine and technology*. (pp. 1-656). Cambridge University Press.
Schirmer, K., Fischer, B. B., Madureira, D. J., & Pillai, S. (2010). Transcriptomics in ecotoxicology. *Analytical and Bioanalytical Chemistry*, *397*(3), 917-923.
Schleef, J. (2008). Complications of endoscopic surgery in infants and children. In: Bax, K. M. A., Georgeson, K. E., Rothenberg, S. S., Valla, J. S., Yeung, C. K. (eds) *Endoscopic Surgery in Infants and Children* (pp. 61-69). Springer, Berlin, Heidelberg.
Schulze-Makuch, D., & Bains, W. (2017). The first multicellular organisms. In: Schulze-Makuch, D., Bains, W. (eds) *The Cosmic Zoo* (pp. 107-120). Springer, Cham.
Senanayake, R. (2000). Analog forestry: an alternative to'clear and simplify'. *LEISA*, *16*(3), 12-13.
Sharma, P. D., & Sharma, P. D. (2012). *Ecology and environment*. (pp. 1-640). Rastogi Publications.
Shaw, I., Kumar, C., & Dodds, C. (2010). *Oxford textbook of anaesthesia for oral and maxillofacial surgery*. (pp. 1-337). Oxford University Press.
Shiksha, (2020). Shiksha, https://www.shiksha.com/medicine-health-sciences/articles/branches-of-pharmacy-its-studies-and-applications-blogId-23227, Last accessed on July 30, 2020.
Shogren, R., Wood, D., Orts, W., & Glenn, G. (2019). Plant-based materials and transitioning to a circular economy. *Sustainable Production and Consumption*, *19*, 194-215.
Sim, B. L., & Nykvist, N. (1991). Impact of forest harvesting and replanting. *Journal of Tropical Forest Science*, 251-284.
Singh, J., Bujarbarua, D., & Singh, S. (2006). History of veterinary science in Indian context. *Indian Journal of Veterinary Surgery*, *27*(1), 66-70.
Slack, J. M. (2012). *Essential developmental biology*. (pp. 1-496). John Wiley & Sons.
Smart, R. C., & Hodgson, E. (2018). *Molecular and biochemical toxicology*. (pp. 1-1040). John Wiley & Sons.
Snapp, S., & Pound, B. (2017). *Agricultural systems: agroecology and rural innovation for development: agroecology and rural innovation for development*. (pp. 1-400). Academic Press.
Snustad, D. P., & Simmons, M. J. (2015). *Principles of genetics*. (pp. 1-784). John Wiley & Sons.
Squire, S. (2020). Climate change: The home front fight for sustainable viticulture. *Australian and New Zealand Grapegrower and Winemaker*, (674), 35-38.
Stegman, S. J., & Tromovitch, T. A. (1982). Cosmetic dermatologic surgery. *Archives of Dermatology*, *118*(12), 1013-1016.
Stetten, D. (1964). Interface between basic medical sciences and their clinical branches: views of a basic scientist. *JAMA*, *189*(3), 217-218.
Studdert, V. P., Gay, C. C., & Hinchcliff, K. W. (2020). *Saunders comprehensive veterinary dictionary e-book*. (pp. 1-1312). Saunders Limited.
Subbiah, R., Veerapandian, M., & S Yun, K. (2010). Nanoparticles: functionalization and multifunctional applications in biomedical sciences. *Current Medicinal Chemistry*, *17*(36), 4559-4577.
Sullivan, D. A. (2001). *Cosmetic surgery: The cutting edge of commercial medicine in America*. (pp. 1-233). Rutgers University Press.
Tabacchi, M. E., & Termini, S. (2017). "The human use of human beings": interdisciplinarity, transdisciplinarity and all that in biophysics and beyond. *Biophysical Chemistry*, *229*, 165-172.
Tauber, A. I., & Podolsky, S. H. (1994). Frank Macfarlane Burnet and the immune self. *Journal of the History of Biology*, *27*(3), 531-573.
Tavassoly, I., Goldfarb, J., & Iyengar, R. (2018). Systems biology primer: the basic methods and approaches. *Essays in Biochemistry*, *62*(4), 487-500.
Tetz, V. V., & Tetz, G. V. (2020). A new biological definition of life. *Biomolecular Concepts*, *11*(1), 1-6.
Thieme, H. R. (2018). *Mathematics in population biology*. Vol. 12. (pp. 1-568). Princeton University Press.
Thomas, V. G., & Kevan, P. G. (1993). Basic principles of agroecology and sustainable agriculture. *Journal of Agricultural and Environmental Ethics*, *6*(1), 1-19.
Thorne, J. F., & Huang, C. S. (1991). Toward a landscape ecological aesthetic: methodologies for designers and planners. *Landscape and Urban Planning*, *21*(1-2), 61-79.
Townsend, C. R., Begon, M., & Harper, J. L. (2003). *Essentials of ecology*. 2nd ed., (pp. 1-532). Blackwell Science.

Trokel, S. L., Srinivasan, R., & Braren, B. (1983). Excimer laser surgery of the cornea. *American Journal of Ophthalmology*, *96*(6), 710-715.
Tseng, C. C., & Yang, X. (2013). Introduction: what is genetics?. In: Tseng, C. C., Yang, X. (eds) *Learning Basic Genetics with Interactive Computer Programs* (pp. 1-18). Springer, New York, NY.
Turner, D. (2011). *Paleontology: a philosophical introduction*. (pp. 1-240). Cambridge University Press.
Turnpenny, P. D., & Ellard, S. (2016). *Emery's elements of medical genetics e-book*. (pp. 1-486). Elsevier Health Sciences.
Twietmeyer, G. (2012). What is kinesiology? Historical and philosophical insights. *Quest*, *64*(1), 4-23.
Umans, L. (1993). A discourse on forestry science. *Agriculture and Human Values*, *10*(4), 26-40.
Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., Orr, R. B., Campbell, N. A. (2020). *Campbell biology*. 12th ed., (pp. 1-1488). Pearson Education, Incorporated.
Vert, M., Doi, Y., Hellwich, K. H., Hess, M., Hodge, P., Kubisa, P., ... & Schué, F. (2012). Terminology for biorelated polymers and applications (IUPAC Recommendations 2012). *Pure and Applied Chemistry*, *84*(2), 377-410.
Veterinary, (2020). Veterinary Practice News, https://www.veterinarypracticenews.com/about-veterinary-specialists/, Last accessed on July 30, 2020.
Villani, A. C., Sarkizova, S., & Hacohen, N. (2018). Systems immunology: Learning the rules of the immune system. *Annual Review of Immunology*, *36*, 813-842.
Vitug, A. F., & Newman, L. A. (2007). Complications in breast surgery. *Surgical Clinics of North America*, *87*(2), 431-451.
Wade, P. R. (2018). Population dynamics. In: Würsig, B., Thewissen, J. G. M., Kovacs, K. (eds) *Encyclopedia of Marine Mammals* (pp. 763-770). Academic press.
Wang, L. (2010). Pharmacogenomics: a systems approach. *Wiley Interdisciplinary Reviews: Systems Biology and Medicine*, 2(1), 3-22.
Waring, S. (2018). Quantum biology: a scientific revolution in our understanding of biological systems. *Biological Systems Open Access*, *7*(185), 2-10.
Warnock, F. F., & Allen, M. (2003). Ethological methods to develop nursing knowledge. *Research in Nursing & Health*, *26*(1), 74-84.
Williams, D. F. (1987). *Definitions in biomaterials: proceedings of a consensus conference of the European Society for Biomaterials, Chester, England, March 3-5, 1986*. Vol. 4. (pp. 1-72). Elsevier Science Limited.
Wintle, B. C., Boehm, C. R., Rhodes, C., Molloy, J. C., Millett, P., Adam, L., ... & Doubleday, R. (2017). Point of View: A transatlantic perspective on 20 emerging issues in biological engineering. *Elife*, *6*, e30247.
Xia, X. (2013). What is comparative genomics?. In: Xia, X. (ed) *Comparative Genomics* (pp. 1-20). Springer, Berlin, Heidelberg.
Yasar, U., & Ozyigit, I. I. (2009). Use of human hair as a potential biomonitor for zinc in the Pendik District Istanbul Turkey. *Romanian Biotechnological Letters*, *14*(3), 4474-4481.
Yener, S. H., & Yarcı, C. (2010). *Alcea pallida* Waldst. & Kit. (Malvaceae) as a heavy metal biomonitor in Istanbul (Turkey). *Fresenius Environmental Bulletin*, *19*(5a), 1024-1030.
Zhou, H. X. (2011). Q&A: What is biophysics?. *BMC Biology*, *9*(1), 1-4.

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Review article

Cadmium in plants, humans and the environment

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Abstract

Heavy metals are the most persistent and complex pollutants in nature. They not only reduce the quality of the atmosphere, water bodies and food crops, but also pose a threat to the health and well-being of animals and people. Metals are accumulated in the tissues of living organisms since contrary to most organic compounds; they are not subject to metabolic degradation. Cadmium (Cd) is one of the heavy metals as well as one of the most important pollutants that easily transported in plants, then distributed to all plant organs, and thus easily transferred to the food chain. So far, studies have not shown any positive effects of Cd on living organisms. Cd can be harmful on human health even in low concentrations, which can cause many serious illnesses and even deaths. In this article, a literature review has been made under the topics of the general properties of Cd, its distribution in nature, its sources and usage areas, the entryways of Cd into plants, its transportation as well as importance in plant metabolism; effects on plants as a heavy metal, the antagonistic-synergistic relationship of Cd with other elements, remediation methods can be applied in soils exposed to Cd contamination, the passageways of Cd to nutrients, its entry into the body and its transportation, and finally the effects of Cd on humans and animals.

Keywords: *Heavy metal; metal accumulation; metal uptake; pollution; toxicity*

1. Introduction

Unplanned urbanization and industrialization depending on the rapid increase in the human population, increase the pollution by heavy metals and cause deterioration of ecological balance (Ozturk et al., 2017). As a result of environmental pollution soil, water and air are also polluted and the level of pollution is becoming more dangerous on living things day by day (Akguc et al., 2010). Heavy metals are, one of the most critical factors causing environmental pollution (Yang et al., 2018; Karahan et al., 2020).

The sustainability of human beings has always been dependent on plant life as a source of food, raw materials and energy. Plants can easily uptake the nutrients they need to grow and complete their physiological periods from the soil throughout their roots. These nutrients can be found in the soil in the form in which they are found in plants (Carfagna et al., 2013; Meena et al., 2020). The role of each nutrient in plant nutrition is different and thus, in agricultural practices they must be applied to the plants in a balanced way (Okcu et al., 2009; Elemike et al., 2019).

The elements necessary for the growth and survival of plants are called "plant nutrients". It is possible to find almost all elements that exist in nature in the analysis of plant tissue and organs (Hawkesford et al., 2016). However, 16 of these elements (C, H, O, N, P, S, K, B, Ca, Cl, Cu, Fe, Mg, Mn, Mo and Zn) are "essential nutrients" for all plants. Six of these elements (Al, Co, Na, Ni, Si and V) are "beneficial elements" that are considered necessary only in some plants or metabolic pathways (Ozyigit et al., 2018; Karahan et al., 2020).

Metals such as Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se and Zn, which have relatively large atomic mass, exhibit their own

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physical structure and have atomic weights are greater than 5 g cm^{-3} are called as "heavy metals". More than sixty elements are considered as heavy metals, and these metals are located in a large part of the periodic table called "transition elements" (Salzer, 1999; Duffus, 2002; Yalcin et al., 2020).

Some of the heavy metals are involved in metabolism by participating in the structure of vitamins, enzymes and hormones, while others take part in absorption and digestion (Azevedo and Lea, 2005; Pohl et al., 2011). Heavy metals such as Cu, Fe, Mn, Mo, Ni and Zn are needed for living things up to a certain dose; these elements are called "micro or trace elements". Contrarily, heavy metals such as As, Cd, Cr, Hg and Pb are not essential for living things and even small amounts of them can show toxic effects (Altay et al., 2013; Ozyigit et al., 2018; Karahan et al., 2020). Heavy metals pose a great threat to plants, animals and humans when they are released in the environment as they accumulate in organisms through the food chain, causing serious diseases and even death (Kumar et al., 2019; Sevik et al., 2019; Karahan et al., 2020). Heavy metals can easily spread around, and affect the environment negatively even in Antarctica, where the life, as well as human habitat is limited (Corsolini, 2009). Therefore, the negative effects of heavy metals on living things should not be ignored (Baryla et al., 2001; Aissa and Kéloufi, 2012). The main factors that cause heavy metals to spread to the environment are industrial activities, motor vehicle exhausts, paints, use of metals as catalysts, mineral deposits and enterprises, volcanic activities, fertilizers and pesticides used in agriculture and urban wastes (Akguc et al., 2008; Osma et al., 2012; Ozyigit et al., 2016).

Cd, which belongs to the 2B group of the periodic table, is one of the most toxic and dangerous heavy metals for living things. The importance of Cd as an industrial and environmental pollutant has become more evident in recent years (Mishra et al., 2019). Cd can be found naturally (mobilizations of cadmium from the earth's crust are volcanoes and weathering of rocks) or spread to the environment due to anthropogenic activities like agricultural and food wastes, animal wastes and manure, logging and other wood wastes, urban refuse, municipal sewage sludge, miscellaneous organic wastes, solid wastes, fertilizer metal manufacturing, coal fly and bottom fly ash, wastage of commercial products and atmospheric fall-out (WHO, 2003; Akguc et al., 2008; Sabiha-Javied et al., 2009; Osma et al., 2012; Ozyigit et al., 2016). These factors increase the importance of Cd as a pollutant.

2. Cadmium element

The chemical symbol of cadmium is "Cd" with atomic number 48, atomic weight 112.41 g mol^{-1}, density 8.7 g cm^{-3}, boiling point 766.8°C and melting point 321°C as well as a silver-colored, soft, machinable heavy metal that cannot be found alone in nature. Among Cd salts, CdS, $CdCl_2$ and $CdSO_2$ are the best known. The chemical properties of Cd are similar to Zn in terms of plant uptake and metabolic functions. However, unlike Zn, an element has a toxic effect on plants, animals and humans (Garbisu and Alkorta, 2001). One of the ways it reaches the soil is synthetic fertilizers and pesticides. It can spread easily in nature due to its water solubility feature. It is taken into biological systems by plants and sea creatures in the form of Cd^{+2} and has the property of accumulation (Kayhan, 2006; Tripathi et al., 2020).

Cd, which is frequently used for the benefit of humanity today, unfortunately, is an important contaminant for the environment and humans. Since their compounds are mostly in powder and aerosol form, they are commonly taken by inhalation. International cancer research authorities divided chemicals into five groups according to their carcinogenic effects. Cd belongs to "Group 1" among "Carcinogenic Effective Substances in Human" due to its relationship with lung cancer. Since tin (Sn) metal was not found during the First and Second World War years, Cd was used as a substitute for Sn in food and canned containers. However, it has been noticed that Cd, which passes to acidic foods, causes poisoning, and therefore, it has been discontinued in a short time (WHO, 2019; Xu et al., 2019; Aslan, 2020). Living things are often exposed to Cd directly through the respiratory tract or food chain. Depending on the route of exposure, concentration a duration, Cd can cause damage to the lung, liver, kidney, bone, testicle and placenta (Paustenbach et al., 2003; Prozialeck et al., 2006; Meravi and Prajapati, 2013).

In plants exposed to toxic amounts of Cd, shrinkage of leaf surface area, yellowing (chlorosis), necrotic spot formation, leaf growth inhibition and leaf rolling are observed. However, the lack of Cd-based Fe and/or P deficiency or inhibition of Mn transport may be the reason for the chlorosis of the leaves (Koleli et al., 2004; Benavides et al., 2005; Lombardi and Sebastiani, 2005). Cd causes a decrease in yield and quality in plant production due to its inhibitory effects on plant photosynthesis rate, enzyme activity and ion uptake (Hassan et al., 2005; Siatka et al., 2012).

3. Distribution of cadmium

Cd is on the list of priority hazardous substances of many environmental non-governmental organizations and the United States Environmental Protection Commission. Living things are often exposed to Cd directly through the respiratory tract or food chain. The World Health Organization limited the weekly tolerable amount of Cd exposure to 50 μg and recommended it as 0.007 mg kg^{-1} body weight (WHO, 2000). Industrial activities, sewage wastes, the addition of fertilizers to agricultural soils and atmospheric deposits cause Cd to pass into the soil. In addition, diesel-powered machinery, long-term purification sludge and garbage manure applications to agricultural areas and the use of pesticides cause entry of Cd into the soil (Sabiha-Javied et al., 2009; Ozyigit et al., 2016; Tabelin et al., 2018).

4. Cadmium applications, uses and resources

It is thought that the annual exposure amount of Cd is 25-30 thousand tons. Human plays a role in 13 thousand tons of this amount (Zalups and Ahmad, 2003; Sui et al., 2018). The industries where Cd is frequently used can be listed as follows: Production of Ni-Cd batteries, refining of Cu, Pb and Zn ores, electroplating and galvanizing applications in order to prevent corrosion, adding to the composition as a preservative during the preparation of metal alloys, use as a stabilizer in plastic production, glass industry, ceramic making and dye production (Jovanovic et al., 2011; Akguc et al., 2008; Osma et al., 2012). Apart from these industrial areas given above, Cd is widely used in the production of household items, automobile and truck tires, photography, agricultural tools, aircraft parts, some industrial and hand tools, bolts, screws, screw nuts and nails (Awual et al., 2018; Ishchenko, 2018; Akguc et al., 2008; Osma et al., 2012). Additionally, in many industries, Cd is released as a by-product of Cu, Pb and Zn extraction. The uptake of Cd by humans and animals is mostly through foods. All food ingredients contain

Cd, even in small amounts. Some of the foods which have high levels of Cd are liver and offal, shellfish, mussels, seaweed, mushrooms, cocoa powder. Smoking also causes a high amount of chronic Cd exposure. Hazardous waste zones, factories that release Cd through air, and the metal refining industry are also important areas of Cd exposure (Chiocchetti et al., 2017; Vizuete et al., 2018; Aslan, 2020).

5. Entry of Cd element to plants, transport and storage

Metal transport from soil to plant roots occurs through diffusion and convection. With the dissolution of metals in the soil, metal concentration increases and as a result, complex structures are formed. Even if these complex structures are not taken into the cell by plant roots, it has been determined that they increase the transports carried out by diffusion towards the plant root in an effective amount. There are many factors that affect metal accumulation in plants. Among these factors, the mobility of the elements in the soil, their absorption by the roots, their storage in the root cells, the transport of the structures through xylem to above-ground parts, and the spread of metals in these parts are the most prominent factors (Clemens et al., 2002; Song et al., 2017).

The metals taken from the soil are initially stored in the plant roots. These metals are then passed from the roots to the xylem sap and transported to the aboveground parts of the plant with the effect of respiration power (Ismael et al., 2019). Metals reaching to the leaf are spread to leaf cells through apoplast and symplast. The distribution of the elements transported to the leaf by the apoplast and symplast is due to the binding of the metals to the chelators in the tissues. Phytochelatin (PC) and metallothioneins (MT) are the main chelators involved in the retention of metals (Filiz et al., 2019a). These chelators contain large amounts of cysteine sulfhydryl groups, which can bind to heavy metal ions and store them to form stable complexes (Prasad, 2013; Dvorak et al., 2020).

The process of heavy metal uptake and transport by plants includes the retention of metal ions by the roots, their entry to the roots and subsequent translocation to the aboveground organs through mass flow and diffusion (Jabeen et al., 2009). Plants also have molecules that can eliminate or tolerate the negative effects of metals. Some of the well-known of these molecules are phytochelatins, metallothioneins, organic acids, amino acids and metal chelators (Dučić and Polle, 2005; Ahmad et al., 2019; Filiz et al., 2019a). The strongest metal binders in plants are phytochelatins, which eliminates the negative effects of heavy metals. It has been proven in many researches that phytochelatin has a peptide structure and that Cd^{+2} is the strongest metal activator of phytochelatin synthase (Balzano et al., 2020). Metallothioneins are compounds with low molecular weight, heavy metal binding capacity, high content of cysteine groups and no aromatic amino acids (Ziller et al., 2017; Filiz et al., 2019b). In addition, the amino and carboxyl groups of amino acids have the ability to bind metal ions. Organic acids such as malate, oxalate and citrate are involved in the reaction against the negative effects of metals (Tamás et al., 2018).

Plants must initially transform the metals into a mobile form in order to absorb them from the soil. They reach this mobile form by using many methods. For instance, plants can secrete into the rhizosphere to dissolve and chelate the metal present in the soil through metal-chelating molecules. The heavy metal uptake of plants can be divided into three groups (Ayhan et al., 2006; Liang et al., 2019).

1. Metal-chelating molecules can perform the siderophores function in plants via phytochelatins and metallothioneins (Navarrete et al., 2019).

2. They can reduce the ionic metals by using metal reductases present in the structure of the plasma membrane (Shou et al., 2019; Terrón-Camero et al., 2019; Huang et al., 2020).

3. They can acidify and dissolve heavy metals by throwing protons from the roots to the soil (Zandonadi et al., 2016).

These three mechanisms can also be applied by mycorrhiza or root colonized bacteria. A plant can manage the negative effects of heavy metals by preventing the entry of them into the cell, and if it cannot prevent it, by detoxifying it in the cell. Studies have shown that cadmium is stored in vacuoles together with phytochelatins (Ashraf et al., 2019; Ahmad et al., 2019; Yamaguchi et al., 2020).

6. Effects of Cd on plants, its role in metabolism

Compared to animals, plants can take higher amounts of Cd without harm. Plants are negatively affected if excessive amounts of Cd is taken (Gill et al., 2012). It causes many physiological changes in the plant by changing nitrogen and carbohydrate metabolisms.

Cd prevents photosynthesis, disrupts chlorophyll synthesis and causes stomatal closure. The most important reason why excessive Cd concentrations disrupt chlorophyll biosynthesis is the inhibition of the synthesis of protochlorophyll reductase, which is involved in chlorophyll biosynthesis and aminolevulinic acid (Per et al., 2017). In addition, like other heavy metals, Cd causes free radical formation, which is responsible for oxidative destruction of thylakoid membrane lipids (Rai et al., 2016).

Many researches showing the effects of Cd in different organisms are exist. In a study investigating Cd toxicity in tomato plants reported that there was a linear relationship between the Cd concentration in the nutrient solution and the Cd in the root and shoots of the plants. Also, it was seen that the amount of Cd accumulated in roots of tomato is approximately 15 times more than its shoots as roots (Khan et al., 2019). In another study conducted using *Picea abies*, the amount of Cd accumulation in the roots induced parallel with the increased Cd concentration in the growing medium (Ozcan and Baycu, 2005).

A study conducted on bean seedlings (*Phaseolus vulgaris* L. cv. Strike), the effects of Cd, Cu, Hg and Pb on the quantities of total protein and abscisic acid (ABA) were investigated. Obtained results demonstrated that higher heavy metal exposures of the seedlings increased ABA production. Additionally, the total protein contents ($p<0.05$ or $p<0.01$) decreased with heavy metals' concentrations (Zengin and Munzuroglu, 2006).

Recent studies have revealed that Ca has important protective effects against Cd stress in plants. Ca mediates to Cd uptake rate and physiological changes due to Cd uptake in plants. Hayakawa et al. (2011) showed the negative effects of Ca application on Cd levels in *Gamblea innovans* leaves. The application of Ca at a low concentration caused a significant decrease in Cd uptake in the roots of rice (Kim et al., 2002). Similar reductions in Cd uptake were seen in soybean and wheat roots with the application of 1-10 mM Ca (Yang and Juang, 2015).

Reports on the effects of Cd toxicity in plants have shown changes in the uptake, transport and use of various elements and water in plants (Qin et al., 2020). The absorption of nitrate was reduced by the uptake of Cd, and relatedly the transport of nitrate from the roots to the stems was limited through the inhibition of nitrate reductase activity in the stems (Singh et al., 2019). Cd, which induces an increase in lipid peroxidation, also causes some changes in the functions of membranes (Zahra et al., 2018) and by suppressing chlorophyll biosynthesis and effecting the activities of enzymes involved in CO_2 fixation (Asati et al., 2016; Sadeghipour, 2018).

Some studies with Cd have shown that stress-dependent genomic changes cause variations in RAPD band profiles. For instance, Ozyigit et al. (2016) exposed *Kalanchoe daigremontiana* clones to Cd in different concentrations and observed new band formations in RAPD band profiles in 50, 200 and 400 μM applications. In addition, a decrease in band intensities in RAPD band profiles at concentrations of 100 μM, and an increase in band intensities at concentrations of 50, 200 and 400 μM were observed.

In another study, polymorphisms were observed in DNA profiles of *Arabidopsis* plant samples exposed to 4.0 and 5.0 mg L^{-1} Cd whereas polymorphisms were not obtained in DNA profiles 0.25 and 1.0 mg L^{-1} Cd (Wang et al., 2016).

Aslam et al. (2014) used 10 RAPD primers in *Capsicum annuum* samples exposed to 5 different Cd concentrations (20, 40, 60, 80 and 100 ppm) and a total of 184 (62 polymorphic and 122 monomorphic) bands in DNA profiles were obtained.

Recently, the highest levels of changes in RAPD profiles (lost and/or formed bands) after Cd application at different concentrations in heavy metal sensitive barley (*Hordeum vulgare* L.) genotypes were obtained in 225 μM Cd application by Cenkci and Dogan, 2015.

7. Antagonistic-synergistic relationship of Cd with other elements

Due to its chemical similarities, there is an antagonism between Ca^{2+} and Cd^{2+} cations; therefore, when they co-exist, they compete with each other in the uptake process in plants. Perfus-Barbeoch et al. (2002) stated that Cd can also enter plant cells through Ca channels. Ca has a protective function on the plasma membrane, and plays a significant role in controlling Cd accumulation in plants. Ca regulates the negative membrane potential, ensuring the stability and integrity of the cell membrane. Thus, the application of Ca reduces the total negative charge on the plant cell membrane and causes a decrease in Cd accumulation (Kinraide et al., 1998).

Cd, which has a very high transition rate from soil to plant and is very mobile in the soil, can be uptaken by plants in very low concentrations, especially in Zn deficiency. The possibility of accumulation in the edible parts of the plant indicates that this metal has a great danger potential for the environment (Koleli and Kantar, 2006).

Bioaccumulation of Cd strongly depends on the chemical properties of aquatic environments. Moreover, Cd accumulation occurs in a concentration-dependent manner, and some ions such as Mg^{2+} and Ca^{2+} have protective effects on aquatic organisms against Cd toxicity (Deleebeeck et al., 2008; 2009). These ions compete with Cd ions and suppress their toxicity (Deleebeeck et al., 2009; Schlekat et al., 2010).

In addition, it has shown that Zn and Hg reduce the teratogenic effect of Cd (McCarty, 2012). In the studies conducted on frogs, it has been determined that Zn prevents the toxic effects of Cd when they are used together (Othman et al., 2012).

8. Remediation methods of Cd-contaminated soils

Cd can be removed from soils by high-cost purification technologies or by a lower cost as well as an easily applicable method of phytoextraction (remediation of soils with plants, plants uptake heavy metals from the soil (Ozyigit and Dogan, 2014; Li et al., 2017).

In this technology, natural hyperaccumulator plant species are generally used. Some genera such as *Thlaspi, Urtica, Chenopodium*, *Polygonum* and *Allyssim* are capable of accumulating Cd, Cu, Pb, Ni and Zn and therefore, the cultivation of the members of these genera is considered an indirect method for the treatment of contaminated soils. Moreover, chelating agents can be added to increase the solubility of metals with low solubility in the soil solution. It includes the uptake of pollutants by plant roots followed by accumulation in above-ground organs and the destruction of plants by harvesting (Ozyigit and Dogan, 2014). This technique can be used to remove actively taken micronutrient elements like Cu and Zn and non-nutrient elements such as Cd, Ni and Pb. Phytoextraction technology can only be applied for areas where metal pollution is low or moderate since plant growth cannot be maintained in areas that are heavily contaminated (Padmavathiamma and Li, 2007; Goyal et al., 2020).

The rhizofiltration method includes the uptake and retention of large amounts of nutrients or metal pollutants from liquid growth media by plant roots. Roots of many plant species grown in hydroponic environment such as *Brassica juncea*, *Helianthus annuus* and *Phaseolus vulgaris* can be used to remove toxic metals such as Cu, Cd, Cr, Ni, Pb, Zn and U from liquid solutions (Ozyigit and Dogan, 2014; Shakoor et al., 2017).

9. Cd in foods

Cd and its compounds are widely used in the production of dye (dyestuff and ink production), glass, textile, electricity, battery, fungicide, insecticide and synthetic polymers with metal alloys (Akguc et al., 2008; Osma et al., 2012; Ozyigit et al., 2016). It has determined that the use of Cd in various industries causes an increased risk of food contamination of this toxic metal through soil, air and water and high levels of contamination in some foods was observed (Hezbullah et al., 2016). It has demonstrated that cereals, potatoes, leafy and rooted vegetables, fruits, liquid-solid oils, meat and dairy products can be contaminated with Cd. The use of Cd in galvanized zinc-coated packaging together with Zn has shown that such packaging materials cause poisoning in foods with high acidity. It has been thought that organic acids in foods increase the solubility of Cd in the structure of the packaging wall (Filippini et al., 2018). In addition, Cd that passes to acidic foods can also cause poisoning (Mohammad et al., 2018; Aslan, 2020).

10. Transport of Cd in human body

Cd usually enters the body via oral, respiratory and skin routes. With the absorption of Cd entering the body, it binds to blood cells and albumin, and then it is carried in the blood. It is initially transported to the liver through blood and then transported from the liver to the kidneys by binding to globulins for detoxification (Zhang et al., 2019a). The Cd accumulated in the kidneys negatively affects the filtration process in the Bowman capsule. This causes many essential proteins and the necessary glucose to be excreted with urine (Bobillier et al., 2006). It is taken into the cell via carrier proteins in the membrane. While it is taken into the cell, it binds to the carrier proteins similar to essential metals such as Ca, Cu, Fe and Zn. As a result, there is a race between them in binding to receptors on the membrane.

Cd absorption has been reported to increase when people and animals are fed diets lacking in elements such as Ca, Cr, Fe and Zn are inadequate in terms of protein (Vahter et al., 2002; Bergeron and Jumarge, 2006). Cd, which is absorbed through alveoli, intestinal lumen and skin and passed into the bloodstream, are transported by binding to the proteins containing metallothionein, albumin and thiol groups. They transport Cd to the cells through receptor-mediated endocytosis (Zalups and Ahmad, 2003). Animal studies and *in vitro* researches reported that metallothionein also protects cells against the toxicity of Cd (Bobillier et al., 2006; Othman et al., 2012).

11. Effects of Cd on animals and humans

It is calculated that the atmosphere in the residential areas is polluted with an average of 0.001 g m^{-3} level of Cd. As a compulsory consequence of this, it has been determined that people take 0.02 mg of Cd daily. It has been demonstrated that high inhalation of cadmium oxide (CdO) in the form of smoke causes lung edema and eventually has lethal effects. In cases of long-term exposure to Cd, it is determined that some cancer types such as prostate cancer and especially lung cancer, can be seen (Person et al., 2013).

Cd metal or its compounds have been shown to cause sarcoma disease when they are injected intramuscularly or subcutaneously (Yongming et al., 2011). Some of the negative effects of Cd are on Ca metabolism and causes hypercalcemia (higher than normal Ca level in the blood). In experiments on the effects of Cd on bone and Ca metabolism, it was reported that the sodium-glucose transport system in cortical cells of kidneys was inhibited (Dongre et al., 2013). In addition, among the skincare products frequently used by women such as eyeliner, blush, lipstick contain Cd and can cause skin cancer (Duruibe et al., 2007; Pratinidhi et al., 2018).

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Cd quickly converts to CdO in the air. Inorganic salts such as $Cd(NO_3)_2$, $CdSO_4$ and $CdCl_2$ are water-soluble. Acute effects in respiration are observed when the Cd concentration in the air exceeds the limit of 1 mg m^{-3}. Due to the low excretion of Cd from the body and accumulation, its negative effects on health can be observed over time. Industrially, Cd poisoning occurs with alloy compounds used during welding, electrochemical coatings, dyes containing Cd and batteries with Cd (Aslan, 2020).

The earliest finding of Cd nephrotoxicity, which is common in workers exposed to Cd, is tubular dysfunction in the form of low molecular weight proteinuria. However, the degree of proteinuria varies over time. It has been suggested that Cd-induced tubular proteinuria is irreversible in many workers for at least a couple of years (Fay et al., 2018; Chen et al., 2020).

Cd can cause DNA breaks and lipid peroxidation. Studies have shown that Cd toxicity causes apoptosis in proximal tubule cells (Wang et al., 2017). One of the important nephrotoxic effects of Cd is that it causes interstitial fibrosis as a result of tubular cell necrosis and inflammation (Fujiki et al., 2019). Since Cd shows the highest concentration of liver after the kidneys, thus determination of its hepatotoxic effects is also very important (Cao et al., 2017).

It was reported that no Cd-related liver enzyme elevation or low serum albumin was detected in the case of environmental Cd exposure (Lavryshyn and Gutyj, 2019; Yaseen, 2019). One of the early signs of Cd toxicity in the liver is impaired mitochondrial function (Okoye et al., 2019). The toxic effect of Cd on mitochondria is related to the increased glutathione and decreased glutathione peroxidase activity by Cd in liver cells rather than increased permeability of mitochondrial inner membrane (Abarikwu et al., 2017).

Cd is accumulated within the cell lysosomes, disrupting the integrity of the lysosomal membrane. The release of lysosomal proteases and phospholipases initiates a series of events that cause hepatocyte cytotoxicity (Wang et al., 2019). Acute exposure to gas mixtures containing high concentrations of Cd can cause fatal acute chemical pneumonia. However, the effects of chronic Cd exposure on the respiratory system seem to be more important. Smoking in the community is the most important reason for continuous and low-dose Cd exposure (Oztoprak et al., 2020; Tao et al., 2020).

Chronically uptake of Cd with either smoking or by respiratory tract in occupational risk group workers causes harmful effects on the respiratory system. The severity and time of occurrence of this damage depend on the concentration and duration of Cd exposure and it is usually seen over the years. It has been reported that chronic inflammation in the nose, pharynx and larynx can be developed in workers of Cd industry (Hassanin et al., 2017; Prokopowicz et al., 2019). Chronic obstructive pulmonary disease (COPD) is common in workers exposed to Cd and smokers. In these patients, the presence of emphysema has been demonstrated both clinically and radiologically (Sundblad et al., 2016).

It has been suggested that Cd-mediated apoptosis is sensitive to Clara cells and type II cells, and this apoptotic effect is associated with the increase in the *p53* and *Bax* genes (Lee et al., 2016). Ca metabolism disorders and bone diseases caused by Cd exposure are seen in the Japanese community, where there is a regular environmental exposure. The main features of Itai-itai disease are osteomalacia, which tend to painful bone fractures, osteoporosis and kidney tubular dysfunction. Cd can be effective on bones by disrupting calcium phosphate and vitamin D metabolism. Bone metabolism disorders have been reported in workers exposed to Cd. Osteomalacia due to Cd can be seen in these individuals. Chronic Cd exposure has been shown to reduce bone mass and increase the incidence of bone fractures (Nishijo et al., 2017a; Browar et al., 2018; Reyes-Hinojosa et al., 2019).

In histological studies, it was found that the application of chronic Cd caused dilatation in the Havers canals in the bones, the expansion of the pericellular area and the hyperplastic bone marrow into the metaphyseal cortical bone. Studies have shown that chronic exposure to Cd causes an increased risk of osteoporosis and osteoporosis-related bone fractures in both sexes, especially in older women (Ohta et al., 2000; Nishijo et al., 2017b; Huang et al., 2019).

In addition to the kidney and liver, Cd is also stored in the heart. However, compared to kidney and liver, the Cd concentration in the heart tissue is relatively lower. It has been shown in studies that Cd, causes metabolic and structural disorders in the heart and plays a role in the etiology of hypertension even in low concentrations (Asagba ve Obi, 2004; Bobillier et al., 2006). This model of hypertension is created by applying cadmium chloride ($CdCl_2$) (1 mg kg^{-1} per day, i.p.) regularly for 2 weeks. The mechanism of the development of hypertension with the application of $CdCl_2$ is explained by the fact that Cd metal mimics the effect of Ca ion with partial agonist effect and its direct contractionary effect on the vascular smooth muscle (Rathod et al., 1997; Resitoglu et al., 2016).

As a result of many experimental studies, it has been shown that the application of Cd salts in late pregnancy causes placental damage as Cd has teratogenic effects such as exencephaly and hydrocephalus in early pregnancy. In animal embryo cultures, Cd has been reported to cause reopening of the closed neural tube (Santoyo-Sánchez et al., 2018; Geng and Wang, 2019; Kmecick et al., 2019). The human placenta is also sensitive to toxic Cd activity (Erboga and Kanter, 2016; Zhang et al., 2016; Geng and Wang, 2019).

Cd can damage the fetus by affecting the metabolism of other elements such as Cu, Fe, Se and Zn. Smoking is also responsible for Cd toxicity during pregnancy. The incidence of low birth weight has increased in infants of smoker mothers, and there is an increase in placental mass. However, Cd was not found in breast milk in smoking mothers (Bobillier et al., 2006; Moynihan et al., 2017; Ali et al., 2018).

As a result of exposure to Cd for a long time, structural and functional disorders occur, especially in the male and female reproductive system (Zhang et al., 2019b). Mammal testicles are very sensitive to Cd as it causes a decrease in sperm motility and spermatogenesis index (Acosta et al., 2016; Nna et al., 2017). Testicular necrosis caused by Cd can cause permanent infertility. Although the molecular effects of Cd on male infertility are controversial, it has been suggested that chronic Cd application causes a decrease in fertility by joining sperm chromatin (Imafidon et al., 2016; Habib et al., 2019). In recent experimental studies on female rats, the application of Cd to ovulation has been shown to inhibit ovulation (Gautam and Chaube, 2018; Yang et al., 2019). In addition, Cd has been reported to prevent the accumulation of follicle-stimulating hormone (FSH) and cAMP-induced progesterone in ovarian granulosa cells (Massanyi et al., 2005; Li et al., 2019).

12. Conclusion

Currently, the use of synthetic fertilizers in agriculture, the consumption of agricultural products grown in areas contaminated with Cd, the use of contaminated drinking water and the inclusion of fishery products in the diet have made our contact with Cd inevitable. In addition, the consumption of organs such as liver and kidneys of grazing animals in contaminated areas and the consumption of contaminated plant foods, being in environments with high Cd concentrations for a long time and smoking are the leading factors in the contamination with Cd. As mentioned above, prolonged exposure to Cd causes oxidative damage in blood and liver tissues as well as histopathological changes, especially in kidney, brain and testicular tissues. As can be seen from the literature, Cd-related diseases are recently discovered and not well-known before. Thus, it is important to create Cd awareness. Conscious choices are crucial in protecting mental and physical health as well as the health of relationships and communication between individuals. One of the measures is to monitor and reduce the Cd level existed in airborne dust particles in residential areas; creating habitats with minimal dust particles and combating dust is also a serious measure against Cd exposure. Important Cd sources that can contaminate soil and water should be determined and measures should be taken in order to prevent contamination. Furthermore, it is necessary to measure the amount of Cd in food and water regularly and avoid consuming contaminated foods. To sum up, information and awareness-raising studies about the toxic effects of Cd and other heavy metals should be made a part of education at every level. The government should inform the public in cooperation with local governments for this.

References

Abarikwu, S. O., Olufemi, P. D., Lawrence, C. J., Wekere, F. C., Ochulor, A. C., & Barikuma, A. M. (2017). Rutin, an antioxidant flavonoid, induces glutathione and glutathione peroxidase activities to protect against ethanol effects in cadmium-induced oxidative stress in the testis of adult rats. *Andrologia*, *49*(7), e12696.

Acosta, I. B., Junior, A. S. V., e Silva, E. F., Cardoso, T. F., Caldas, J. S., Jardim, R. D., & Corcini, C. D. (2016). Effects of exposure to cadmium in sperm cells of zebrafish, Danio rerio. *Toxicology Reports*, *3*, 696-700.

Ahmad, J., Ali, A. A., Baig, M. A., Iqbal, M., Haq, I., & Qureshi, M. I. (2019). Role of phytochelatins in cadmium stress tolerance in plants. In: Hasanuzzaman, M., Prasad, M. N. V., Fujita, M. (eds) *Cadmium Toxicity and Tolerance in Plants* (pp. 185-212). Academic Press.

Aissa, L., & Kéloufi, B. (2012). Determining the heavy metal pollution in Mascara (Algeria) by using *Casuarina equisetifolia*. *Ecologia Balkanica*, *4*(1), 1-7.

Akguc, N., Ozyigit, I. I., & Yarci, C. (2008). *Pyracantha coccinea* Roem.(Rosaceae) as a biomonitor for Cd, Pb and Zn in Mugla province (Turkey). *Pakistan Journal of Botany*, *40*(4), 1767-1776.

Akguc, N., Ozyigit, I., Yasar, U., Leblebici, Z., & Yarci, C. (2010). Use of Pyracantha coccinea Roem. as a possible biomonitor for the selected heavy metals. *International Journal of Environmental Science & Technology*, *7*(3), 427-434.

Ali, F., Kazi, T. G., Afridi, H. I., & Baig, J. A. (2018). Exposure of cadmium via smoking and drinking water on zinc levels of biological samples of malnutrition pregnant women: A prospective cohort study. *Environmental toxicology and pharmacology*, *63*, 48-54.

Altay, V., Ozyigit, I. I., Keskin, M., Demir, G., & Yalcin, I. E. (2013). An ecological study of endemic plant *Polygonum istanbulicum* Keskin and its environs. *Pakistan Journal of Botany*, *45*(S1), 455-459.

Asagba, S. O., & Obi, F. O. (2004). Effects of oral cadmium exposure on renal glomerular and tubular functions in the rat. *Journal of Applied Sciences and Environmental Management*, *8*, 29-32.

Asati, A., Pichhode, M., & Nikhil, K. (2016). Effect of heavy metals on plants: an overview. *International Journal of Application or Innovation in Engineering & Management*, *5*, 2319-4847.

Ashraf, S., Ali, Q., Zahir, Z. A., Ashraf, S., & Asghar, H. N. (2019). Phytoremediation: Environmentally sustainable way for reclamation of heavy metal polluted soils. *Ecotoxicology and Environmental Safety*, *174*, 714-727.

Aslam, R., Ansari, M. Y. K., Choudhary, S., Bhat, T. M., & Jahan, N. (2014). Genotoxic effects of heavy metal cadmium on growth, biochemical, cyto-physiological parameters and detection of DNA polymorphism by RAPD in *Capsicum annuum* L.-An important spice crop of India. *Saudi Journal of Biological Sciences*, *21*(5), 465-472.

Aslan, R. (2020). Zinde ve sağlıklı bir hayat için kadmiyum'a dikkat. *Ayrıntı Dergisi*, *7*(82), 51-56.

Awual, M. R., Khraisheh, M., Alharthi, N. H., Luqman, M., Islam, A., Karim, M. R., ... & Khaleque, M. A. (2018). Efficient detection and adsorption of cadmium (II) ions using innovative nano-composite materials. *Chemical Engineering Journal*, *343*, 118-127.

Ayhan B., Ekmekci Y., Tanyolac D., (2006). Bitkilerde ağır metal zararları ve korunma mekanizmaları. *Anadolu Üniversitesi Bilim ve Teknoloji Dergisi*, *7*(1), 1-16.

Azevedo, R. A., & Lea, P. J. (2005). Preface: toxic metals in plants. *Brazilian Journal of Plant Physiology*, *17*(1), 1-1.

Balzano, S., Sardo, A., Blasio, M., Chahine, T. B., Dell'Anno, F., Sansone, C., & Brunet, C. (2020). Microalgae metallothioneins and phytochelatins and their potential use in bioremediation. *Frontiers in Microbiology*, *11*, 517.

Baryla, A., Carrier, P., Franck, F., Coulomb, C., Sahut, C., Havaux, M. (2001). Leaf chlorosis in oilseed rape plants (*Brassica napus*) grown on cadmium-polluted soil: causes and consequences for photosynthesis and growtth. *Planta*, *212*, 696-709.

Benavides, M. P., Gallego, S. M., Tomaro, M. L. (2005). Cadmium toxicity in plants. *Brazilian Journal of Plant Physiology*, *17*(1), 21- 34.

Bergeron, P. M., & Jumarge, C. (2006). Characterization of cadmium uptake in human intestinal crypt cells HIEC in relation to inorganic metal speciation. *Toxicology*, *219*(1-3), 156-166.

Bobillier, S. C., Maupoil, V., & Berthelot, A. (2006). Metallothionein induction in the liver, kidney, heart and aorta of cadmium and ısoproterenol treated rats. Journal of Applied *Toxicology*, *26*, 47-55.

Browar, A. W., Koufos, E. B., Wei, Y., Leavitt, L. L., Prozialeck, W. C., & Edwards, J. R. (2018). Cadmium exposure disrupts periodontal bone in experimental animals: implications for periodontal disease in humans. *Toxics*, *6*(2), 32-42.

Cao, Z., Fang, Y., Lu, Y., Tan, D., Du, C., Li, Y., ... & Pei, L. (2017). Melatonin alleviates cadmium-induced liver injury by inhibiting the TXNIP-NLRP3 inflammasome. *Journal of Pineal Research*, *62*(3), e12389.

Carfagna, S., Lanza, N., Salbitani, G., Basile, A., Sorbo, S., & Vona, V. (2013). Physiological and morphological responses of lead or cadmium exposed *Chlorella sorokiniana* 211-8K (Chlorophyceae). *Springer Plus*, *2*(147), 1-7.

Cenkci, S., & Dogan, N. (2015). Random amplified polymorphic DNA as a method to screen metal-tolerant barley (*Hordeum vulgare* L.) genotypes. *Turkish Journal of Botany*, *39*(5), 747-756.

Chen, X., Cui, W., Duan, N., Zhu, G., Jin, T., & Wang, Z. (2020). The association between alcohol consumption and renal tubular dysfunction induced by cadmium exposure. *Biological Trace Element Research*, *194*(1), 58-65.

Chiocchetti, G., Jadan-Piedra, C., Velez, D., & Devesa, V. (2017). Metal (loid) contamination in seafood products. *Critical Reviews in Food Science and Nutrition*, *57*(17), 3715-3728.

Clemens, S., Palmgren, M. G., & Krämer, U. (2002). A long way ahead: understanding and engineering plant metal accumulation. *Trends in Plant Science*, *7*(7), 309-315.

Corsolini, S. (2009). Industrial contaminants in Antarctic biota. *Journal of Chromatography A*, *1216*(3), 598-612.

Deleebeeck, N. M., De Schamphelaere, K. A., & Janssen, C. R. (2008). A novel method for predicting chronic nickel bioavailability and toxicity to Daphnia magna in artificial and natural waters. *Environmental Toxicology and Chemistry: An International Journal*, *27*(10), 2097-2107.

Deleebeeck, N. M., De Schamphelaere, K. A., & Janssen, C. R. (2009). Effects of Mg^{2+} and H^+ on the toxicity of Ni^{2+} to the unicellular green alga Pseudokirchneriella subcapitata: Model development and validation with surface waters. *Science of the Total Environment*, *407*(6), 1901-1914.

Dongre, N. N., Suryakar, A. N., Patil, A. J., Hundekari, I. A., & Devarnavadagi, B. B. (2013). Biochemical effects of lead exposure on battery manufacture workers with reference to blood pressure, calcium metabolism and bone mineral density. *Indian Journal of Clinical Biochemistry*, *28*(1), 65-70.

Dučić, T., & Polle, A. (2005). Manganese and copper toxicity and detoxification in plants. *Brazilian Journal of Plant Physiology*, *172*, 115-122.

Duffus, J. H. (2002). "Heavy metals" a meaningless term? (IUPAC Technical Report). *Pure and Applied Chemistry*, *74*(5), 793-807.

Duruibe, J. O., Ogwuegbu, M. O. C., & Egwurugwu, J. N. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of Physical Sciences*, *2*(5), 112-118.

Dvorak, M., Schnegg, R., Niederwanger, M., Pedrini-Martha, V., Ladurner, P., Lindner, H., ... & Dallinger, R. (2020). Cadmium pathways in snails follow a complementary strategy between metallothionein detoxification and auxiliary inactivation by phytochelatins. *International Journal of Molecular Sciences*, *21*(1), 7-21.

Elemike, E. E., Uzoh, I. M., Onwudiwe, D. C., & Babalola, O. O. (2019). The role of nanotechnology in the fortification of plant nutrients and improvement of crop production. *Applied Sciences*, *9*(3), 499-531.

Erboga, M., & Kanter, M. (2016). Effect of cadmium on trophoblast cell proliferation and apoptosis in different gestation periods of rat placenta. *Biological Trace Element Research*, *169*(2), 285-293.

Fay, M. J., Alt, L. A., Ryba, D., Salamah, R., Peach, R., Papaeliou, A., ... & Stubbs-Russell, Z. (2018). Cadmium nephrotoxicity is associated with altered microRNA expression in the rat renal cortex. *Toxics*, *6*(1), 16-30.

Filippini, T., Cilloni, S., Malavolti, M., Violi, F., Malagoli, C., Tesauro, M., ... & Vinceti, M. (2018). Dietary intake of cadmium, chromium, copper, manganese, selenium and zinc in a Northern Italy community. *Journal of Trace Elements in Medicine and Biology*, *50*, 508-517.

Filiz, E., Saracoglu, I. A., Ozyigit, I. I., & Yalcin, B. (2019a). Comparative analyses of phytochelatin synthase (PCS) genes in higher plants. *Biotechnology & Biotechnological Equipment*, *33*(1), 178-194.

Filiz, E., Ozyigit, I. I., Saracoglu, I. A., Uras, M. E., Sen, U., & Yalcin, B. (2019b). Abiotic stress-induced regulation of antioxidant genes in different *Arabidopsis* ecotypes: microarray data evaluation. *Biotechnology & Biotechnological Equipment*, *33*(1), 128-143.

Fujiki, K., Inamura, H., Sugaya, T., & Matsuoka, M. (2019). Blockade of ALK4/5 signaling suppresses cadmium-and erastin-induced cell death in renal proximal tubular epithelial cells via distinct signaling mechanisms. *Cell Death & Differentiation*, *26*(11), 2371-2385.

Garbisu, C., & Alkorta, I. (2001). Phytoextraction: a cost-effective plant-based technology for the removal of metals from the environment. *Bioresource Technology*, *77*(3), 229-236.

Gautam, G. J., & Chaube, R. (2018). Differential effects of heavy metals (cadmium, cobalt, lead and mercury) on oocyte maturation and ovulation of the catfish *Heteropneustes fossilis*: an in vitro study. *Turkish Journal of Fisheries and Aquatic Sciences*, *18*(10), 1205-1214.

Genchi, G., Sinicropi, M. S., Lauria, G., Carocci, A., & Catalano, A. (2020). The effects of cadmium toxicity. *International Journal of Environmental Research and Public Health*, *17*(11), 3782-3806.

Geng, H. X., & Wang, L. (2019). Cadmium: toxic effects on placental and embryonic development. *Environmental Toxicology and Pharmacology*, *67*, 102-107.

Gill, S. S., Khan, N. A., & Tuteja, N. (2012). Cadmium at high dose perturbs growth, photosynthesis and nitrogen metabolism while at low dose it up regulates sulfur assimilation and antioxidant machinery in garden cress (*Lepidium sativum* L.). *Plant Science*, *182*, 112-120.

Goyal, D., Yadav, A., Prasad, M., Singh, T. B., Shrivastav, P., Ali, A., ... & Mishra, S. (2020). Effect of Heavy Metals on Plant Growth: An Overview. In: Naeem, M., Ansari, A., Gill, S. (eds) *Contaminants in Agriculture* (pp. 79-101). Springer, Cham.

Habib, R., Wahdan, S. A., Gad, A. M., & Azab, S. S. (2019). Infliximab abrogates cadmium-induced testicular damage and spermiotoxicity via enhancement of steroidogenesis and suppression of inflammation and apoptosis mediators. *Ecotoxicology and Environmental Safety*, *182*, 109398.

Hassan, M. J., Shao, G., & Zhang, G. (2005). Influence of cadmium toxicity on growth and antioxidant enzyme activity in rice cultivars with different grain cadmium accumulation. *Journal of Plant Nutrition*, *28*(7), 1259-1270.

Hassanin, E. S., El-Bassel, H., & El-Razek, A. (2017). Effect of Cadmium Exposure among workers in Battery Industries. *Bulletin of the National Nutrition Institute of the Arab Republic of Egypt*, *49*(1), 1-20.

Hawkesford, M. J., Kopriva, S., & De Kok, L. J. (2016). *Nutrient use efficiency in plants*. (pp. 1-279). Springer International Pu.

Hayakawa, N., Tomioka, R., & Takenaka, C. (2011). Effects of calcium on cadmium uptake and transport in the tree species *Gamblea innovans*. *Soil Science and Plant Nutrition*, *57*(5), 691-695.

Hezbullah, M., Sultana, S., Chakraborty, S. R., & Patwary, M. I. (2016). Heavy metal contamination of food in a developing country like Bangladesh: An emerging threat to food safety. *Journal of Toxicology and Environmental Health Sciences*, *8*(1), 1-5.

Huang, X., Duan, S., Wu, Q., Yu, M., & Shabala, S. (2020). Reducing cadmium accumulation in plants: structure-function relations and tissue-specific operation of transporters in the spotlight. *Plants*, *9*(2), 223-240.

Huang, X., Liu, T., Zhao, M., Fu, H., Wang, J., & Xu, Q. (2019). Protective effects of moderate Ca supplementation against Cd-induced bone damage under different population-relevant doses in young female rats. *Nutrients*, *11*(4), 849-871.

Imafidon, C. E., Olatoye, T. R., Bamidele, F. S., Ojo, O. E., & Ademoye, K. A. (2016). Cadmium-induced testicular toxicity, oxidative stress and histopathology in Wistar rats: sustained effects of polyphenol-rich extract of *Vernonia amygdalina* (Del.) leaf. *Journal of Interdisciplinary Histopathology*, *4*(3), 54-62.

Ishchenko, V. A. (2018). Environment contamination with heavy metals contained in waste. *Environmental Problems*, *3*(1), 21-24.

Ismael, M. A., Elyamine, A. M., Moussa, M. G., Cai, M., Zhao, X., & Hu, C. (2019). Cadmium in plants: uptake, toxicity, and its interactions with selenium fertilizers. *Metallomics*, *11*(2), 255-277.

Jabeen, R., Ahmad, A., & Iqbal, M. (2009). Phytoremediation of heavy metals: physiological and molecular mechanisms. *The Botanical Review*, *75*(4), 339-364.

Jovanovic, V. S., Ilic, M. D., Markovic, M. S., Mitic, V. D., Mandic, S. N., & Stojanovic, G. S. (2011). Wild fire impact on copper, zinc, lead and cadmium distribution in soil and relation with abundance in selected plants of Lamiaceae family from Vidlic Mountain (Serbia). *Chemosphere*, *84*(11), 1584-1591.

Karahan, F., Ozyigit, I. I., Saracoglu, I. A., Yalcin, I. E., Hocaoglu-Ozyigit, A., & Ilcim, A. (2020). Heavy metal levels and mineral nutrient status in different parts of various medicinal plants collected from eastern Mediterranean region of Turkey. *Biological Trace Element Research*, *197*, 316-329.

Kayhan, F. E. (2006). Su ürünlerinde Cd'un biyobirikimi ve toksisitesi. *E.U. Su Ürünleri Dergisi*, *23*, 215-220.

Khan, M. Y., Prakash, V., Yadav, V., Chauhan, D. K., Prasad, S. M., Ramawat, N., ... & Sharma, S. (2019). Regulation of cadmium toxicity in roots of tomato by indole acetic acid with special emphasis on reactive oxygen species production and their scavenging. *Plant Physiology and Biochemistry*, *142*, 193-201.

Kim, Y. Y., Yang, Y. Y., & Lee, Y. (2002). Pb and Cd uptake in rice roots. *Physiologia Plantarum*, *116*(3), 368-372.

Kinraide, T. B., Yermiyahu, U., & Rytwo, G. (1998). Computation of surface electrical potentials of plant cell membranes: correspondence to published zeta potentials from diverse plant sources. *Plant Physiology*, *118*(2), 505-512.

Kmecick, M., da Costa, M. C. V., de Oliveira Ribeiro, C. A., & Ortolani-Machado, C. F. (2019). Morphological evidence of neurotoxic effects in chicken embryos after exposure to perfluorooctanoic acid (PFOA) and inorganic cadmium. *Toxicology*, *427*, 152286.

Koleli, N., & Kantar, C. (2006). Fosforlu gübrede ağır metal tehlikesi. *Ekoloji Magazin Dergisi*, 9.

Koleli, N., Eker, S., & Cakmak, I. (2004). Effect of zinc fertilization on cadmium toxicity in durum and bread wheat grown in zinc-deficient soil. *Environmental Pollution*, *131*(3), 453-459.

Kumar, S., Prasad, S., Yadav, K. K., Shrivastava, M., Gupta, N., Nagar, S., ... & Malav, L. C. (2019). Hazardous heavy metals contamination of vegetables and food chain: Role of sustainable remediation approaches-A review. *Environmental Research*, *179*, 108792.

Lavryshyn, Y. Y., & Gutyj, B. V. (2019). Protein synthesize function of bulls liver at experimental chronic cadmium toxicity. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies. Series: Veterinary Sciences*, *21*(94), 92-96.

Lee, J. Y., Tokumoto, M., Fujiwara, Y., Hasegawa, T., Seko, Y., Shimada, A., & Satoh, M. (2016). Accumulation of p53 via down-regulation of UBE2D family genes is a critical pathway for cadmium-induced renal toxicity. *Scientific Reports*, *6*(1), 1-15.

Li, J. T., Liang, Z. W., Jia, P., Liu, J., Xu, Y. J., Chen, Y. J., ... & Shu, W. S. (2017). Effects of a bacterial consortium from acid mine drainage on cadmium phytoextraction and indigenous soil microbial community. *Plant and Soil*, *415*(1-2), 347-358.

Li, X., Guo, J., Jiang, X., Sun, J., Tian, L., Jiao, R., ... & Bai, W. (2019). Cyanidin-3-O-glucoside protects against cadmium-induced dysfunction of sex hormone secretion via the regulation of hypothalamus-pituitary-gonadal axis in male pubertal mice. *Food and Chemical Toxicology*, *129*, 13-21.

Liang, Y., Wang, X., Guo, Z., Xiao, X., Peng, C., Yang, J., ... & Zeng, P. (2019). Chelator-assisted phytoextraction of arsenic, cadmium and lead by Pteris vittata L. and soil microbial community structure response. *International Journal of Phytoremediation*, *21*(10), 1032-1040.

Lombardi, L., & Sebastiani, L. (2005). Copper toxicity in *Prunus cerasifera*: growth and antioxidant enzymes responses of in vitro grown plants. *Plant Science*, *168*(3), 797-802.

Massanyi, P., Uhrin, V., Toman, R., Pivko, J., Lukáč, N., Forgacs, Z. S., ... & Danko, J. (2005). Ultrastructural changes of ovaries in rabbits following cadmium administration. *Acta Veterinaria Brno*, *74*(1), 29-35.

McCarty, M. F. (2012). Zinc and multi-mineral supplementation should mitigate the pathogenic impact of cadmium exposure. *Medical Hypotheses*, *79*(5), 642-648.

Meena, V., Dotaniya, M. L., Saha, J. K., Meena, B. P., Das, H., & Patra, A. K. (2020). Sustainable C and N management under metal-contaminated soils. In: Datta, R., Meena, R. S., Pathan, S. I., Ceccherini, M. T. (eds) *Carbon and Nitrogen Cycling in Soil* (pp. 293-336). Springer, Singapore.

Meravi, N., & Prajapati, S. K. (2013). Effects of heavy metals/metalloids contamination of soils on micronucleus induction in *Tradescantia pallida*. *Environmental Skeptics and Critics*, *2*(2), 58-62.

Mishra, S., Bharagava, R. N., More, N., Yadav, A., Zainith, S., Mani, S., & Chowdhary, P. (2019). Heavy metal contamination: an alarming threat to environment and human health. In: Sobti, R. C., Kumar Arora, N., Kothari, R. (eds) *Environmental Biotechnology: For Sustainable Future* (pp. 103-125). Springer, Singapore.

Mohammad, A. M., Chowdhury, T., Biswas, B., & Absar, N. (2018). Food poisoning and intoxication: a global leading concern for human health. In: Grumezescu, A. M., Holban, A. M. (eds) *Food Safety and Preservation* (pp. 307-352). Academic Press.

Moynihan, M., Peterson, K. E., Cantoral, A., Song, P. X., Jones, A., Solano-González, M., ... & Téllez-Rojo, M. M. (2017). Dietary predictors of urinary cadmium among pregnant women and children. *Science of The Total Environment*, *575*, 1255-1262.

Navarrete, A., González, A., Gómez, M., Contreras, R. A., Díaz, P., Lobos, G., ... & Moenne, A. (2019). Copper excess detoxification is mediated by a coordinated and complementary induction of glutathione, phytochelatins and metallothioneins in the green seaweed *Ulva compressa*. *Plant Physiology and Biochemistry*, *135*, 423-431.

Nishijo, M., Nakagawa, H., Suwazono, Y., Nogawa, K., & Kido, T. (2017a). Causes of death in patients with Itai-itai disease suffering from severe chronic cadmium poisoning: a nested case–control analysis of a follow-up study in Japan. *BMJ Open*, *7*(7), e015694.

Nishijo, M., Nambunmee, K., Suvagandha, D., Swaddiwudhipong, W., Ruangyuttikarn, W., & Nishino, Y. (2017b). Gender-specific impact of cadmium exposure on bone metabolism in older people living in a cadmium-polluted area in Thailand. *International Journal of Environmental Research and Public Health*, *14*(4), 401.

Nna, V. U., Ujah, G. A., Mohamed, M., Etim, K. B., Igba, B. O., Augustine, E. R., & Osim, E. E. (2017). Cadmium chloride-induced testicular toxicity in male wistar rats; prophylactic effect of quercetin, and assessment of testicular recovery following cadmium chloride withdrawal. *Biomedicine & Pharmacotherapy*, *94*, 109-123.

Ohta, H., Yamauchi, Y., Nakakita, M., Tanaka, H., Asami, S., Seki, Y., & Yoshikawa, H. (2000). Relationship between renal dysfunction and bone metabolism disorder in male rats after long-term oral quantitative cadmium administration. *Industrial Health*, *38*(4), 339-355.

Okcu, M., Tozlu, E., Kumlay, A. M., & Pehluvan, M. (2009). Ağır metallerin bitkiler üzerine etkileri. *Alınteri Zirai Bilimler Dergisi*, *17*(2), 14-26.

Okoye, C. N., MacDonald-Jay, N., & Kamunde, C. (2019). Effects of bioenergetics, temperature and cadmium on liver mitochondria reactive oxygen species production and consumption. *Aquatic Toxicology*, *214*, 105264.

Osma, E., Ozyigit, I. I., Leblebici, Z., Demir, G., & Serin, M. (2012). Determination of heavy metal concentrations in tomato (*Lycopersicon esculentum* Miller) grown in different station types. *Romanian Biotechnological Letters*, *17*(1), 6963.

Othman, M. S., Khonsue, W., Kitana, J., Thirakhupt, K., Robson, M., Borjan, M., & Kitana, N. (2012). Hepatic metallothionein and Glutathione-S-Transferase responses in two populations of rice frogs, *Fejervarya limnocharis*, naturally exposed to different environmental cadmium levels. *Bulletin of Environmental Contamination and Toxicology*, *89*(2), 225-228.

Ozcan, T., & Baycu, G. (2005). Some elemental concentrations in the acorns of Turkish *Quercus* L. (Fagaceae) taxa. *Pakistan Journal of Botany*, *37*(2), 361-371.

Oztoprak, F. S., Yigitalp Rencber, S., Ceylan, A., Arica, E., Sayin Ipek, D. N., Kurt, M. E., & Yetiz, P. (2020). Assessment of lead, mercury, cadmium, chromium and total antioxidant capacity levels of employees exposed to exhaust gases in closed parking lots. *International Journal of Environmental Analytical Chemistry*, 1-13.

Ozturk, A., Yarci, C., & Ozyigit, I. I. (2017). Assessment of heavy metal pollution in Istanbul using plant (*Celtis australis* L.) and soil assays. *Biotechnology & Biotechnological Equipment*, *31*(5), 948-954.

Ozyigit, I. I., & Dogan, I. (2014). Plant-microbe interactions in phytoremediation. In: Rehman Hakeem K., Sabir M., Ozturk M., Mermut A. (eds)

Soil Remediation and Plants-Prospects & Challenges (pp. 255-285). Elsevier B.V. Amsterdam.

Ozyigit, I. I., Yalcin, B., Turan, S., Saracoglu, I. A., Karadeniz, S., Yalcin, I. E., & Demir, G. (2018). Investigation of heavy metal level and mineral nutrient status in widely used medicinal plants' leaves in Turkey: Insights into health implications. *Biological Trace Element Research*, *182*(2), 387-406.

Ozyigit, I. I., Yilmaz, S., Dogan, I., Sakcali, M. S., Tombuloglu, G., & Demir, G. (2016). Detection of physiological and genotoxic damages reflecting toxicity in kalanchoe clones, *Global Nest Journal*, *18*, 223-232.

Padmavathiamma, P. K., & Li, L. Y. (2007). Phytoremediation technology: hyper-accumulation metals in plants. *Water, Air, and Soil Pollution*, *184*(1-4), 105-126.

Paustenbach, D., Finley, B., Mowat, F., & Kerger, B. (2003). Human health risk and exposure assessment of chromium (VI) in tap water. *Journal of Toxicology and Environmental Health, Part A*, *66*(14), 1295-1339.

Per, T. S., Masood, A., & Khan, N. A. (2017). Nitric oxide improves S-assimilation and GSH production to prevent inhibitory effects of cadmium stress on photosynthesis in mustard (*Brassica juncea* L.). *Nitric oxide*, *68*, 111-124.

Perfus-Barbeoch, L., Leonhardt, N., Vavasseur, A., & Forestier, C. (2002). Heavy metal toxicity: cadmium permeates through calcium channels and disturbs the plant water status. *The Plant Journal*, *32*(4), 539-548.

Person, R. J., Tokar, E. J., Xu, Y., Orihuela, R., Ngalame, N. N. O., & Waalkes, M. P. (2013). Chronic cadmium exposure in vitro induces cancer cell characteristics in human lung cells. *Toxicology and Applied Pharmacology*, *273*(2), 281-288.

Pohl, C., Croot, P. L., Hennings, U., Daberkow, T., Budéus, G., & vd Loeff, M. R. (2011). Synoptic transects on the distribution of trace elements (Hg, Pb, Cd, Cu, Ni, Zn, Co, Mn, Fe, and Al) in surface waters of the Northern-and Southern East Atlantic. *Journal of Marine Systems*, *84*(1-2), 28-41.

Prasad, M. N. V. (2013). *Heavy metal stress in plants: from biomolecules to ecosystems*. (pp. 1-462). Springer Science & Business Media.

Pratinidhi, S. A., Sagare, A. A., & Patil, A. J. (2018). Heavy metal levels in commonly used cosmetic products in Asia. *MIMER Medical Journal*, *2*(2), 31-36.

Prokopowicz, A., Sobczak, A., Szuła-Chraplewska, M., Ochota, P., & Kośmider, L. (2019). Exposure to cadmium and lead in cigarette smokers who switched to electronic cigarettes. *Nicotine and Tobacco Research*, *21*(9), 1198-1205.

Prozialeck, W. C., Edwards, J. R., & Woods, J. M. (2006). The vascular endothelium as a target of cadmium toxicity. *Life Sciences*, *79*(16), 1493-1506.

Qin, S., Liu, H., Nie, Z., Rengel, Z., Gao, W., Li, C., & Zhao, P. (2020). Toxicity of cadmium and its competition with mineral nutrients for uptake by plants: a review. *Pedosphere*, *30*(2), 168-180.

Rai, R., Agrawal, M., & Agrawal, S. B. (2016). Impact of heavy metals on physiological processes of plants: with special reference to photosynthetic system. In: Singh, A., Prasad, S., Singh, R. (eds) *Plant Responses to Xenobiotics* (pp. 127-140). Springer, Singapore.

Rathod, S. P., Shah, N., & Balaraman, R. (1997). Antihypertensive effect of dietary calcium and diltiazem, a calcium channel blocker on experimentally induced hypertensive rats. *Indian Journal of Pharmacology*, *29*(2), 99-104.

Resitoglu, M. T., Guden, D. S., & Firat, S. S. (2016). Hipertansiyon araştırmalarında kullanılan deneysel modeller. *Clinical and Experimental Health Sciences*, *6*(1), 35-43.

Reyes-Hinojosa, D., Lozada-Pérez, C. A., Cuevas, Y. Z., López-Reyes, A., Martínez-Nava, G., Fernández-Torres, J., ... & Martínez-Flores, K. (2019). Toxicity of cadmium in musculoskeletal diseases. *Environmental Toxicology and Pharmacology*, *72*, 103219.

Sabiha-Javied, T., Mehmood, M., Chaudhry, M., & Tufail, I. (2009). Heavy metal pollution from phosphate rock used for the production of fertilizer in Pakistan. *Microchemical Journal*, *91*, 94-99.

Sadeghipour, O. (2018). Enhancing cadmium tolerance in common bean plants by potassium application. *Philippine Agricultural Scientist*, *101*(2), 167-175.

Salzer, A. (1999). Nomenclature of organometallic compounds of the transition elements (IUPAC Recommendations 1999). *Pure and Applied Chemistry*, *71*(8), 1557-1585.

Santoyo-Sánchez, M., Thévenod, F., & Barbier, O. (2018). Cadmium handling, toxicity and molecular targets involved during pregnancy: lessons from experimental models. *Metal Metabolism in Animals*, *18*, 272.

Schlekat, C. E., Van Genderen, E., De Schamphelaere, K. A., Antunes, P. M., Rogevich, E. C., & Stubblefield, W. A. (2010). Cross-species extrapolation of chronic nickel Biotic Ligand Models. *Science of the Total Environment*, *408*(24), 6148-6157.

Sevik, H., Ozel, H. B., Cetin, M., Özel, H. U., & Erdem, T. (2019). Determination of changes in heavy metal accumulation depending on plant species, plant organism, and traffic density in some landscape plants. *Air Quality, Atmosphere & Health*, *12*(2), 189-195.

Shakoor, A., Abdullah, M., Sarfraz, R., Altaf, M. A., & Batool, S. A. (2017). A comprehensive review on phytoremediation of cadmium (Cd) by mustard (*Brassica juncea* L.) and sunflower (*Helianthus annuus* L.). *Journal of Biological and Environmental Sciences*, *10*(3), 88-98.

Shou, H., Li, L., Ye, L., & Kong, Q. (2019). A vacuolar membrane ferric-chelate reductase, OsFRO1 alleviates Fe toxicity in rice (*Oryza sativa* L.). *Frontiers in Plant Science*, *10*, 700.

Siatka, T., Kašparová, M., & Spilková, J. (2012). Effects of zinc and cadmium ions on cell growth and production of coumarins in cell suspension cultures of *Angelica archangelica* L. *Ceska a Slovenska Farmacie: Casopis Ceske Farmaceuticke Spolecnosti a Slovenske Farmaceuticke Spolecnosti*, *61*(6), 261-266.

Singh, P., Singh, I., & Shah, K. (2019). Reduced activity of nitrate reductase under heavy metal cadmium stress in rice: an in silico answer. *Frontiers in Plant Science*, *9*, 1948.

Song, Y., Jin, L., & Wang, X. (2017). Cadmium absorption and transportation pathways in plants. *International Journal of Phytoremediation*, *19*(2), 133-141.

Sui, F., Zuo, J., Chen, D., Li, L., Pan, G., & Crowley, D. E. (2018). Biochar effects on uptake of cadmium and lead by wheat in relation to annual precipitation: a 3-year field study. *Environmental Science and Pollution Research*, *25*(4), 3368-3377.

Sundblad, B. M., Ji, J., Levänen, B., Midander, K., Julander, A., Larsson, K., ... & Lindén, A. (2016). Extracellular cadmium in the bronchoalveolar space of long-term tobacco smokers with and without COPD and its association with inflammation. *International Journal of Chronic Obstructive Pulmonary Disease*, *11*, 1005.

Tabelin, C. B., Igarashi, T., Villacorte-Tabelin, M., Park, I., Opiso, E. M., Ito, M., & Hiroyoshi, N. (2018). Arsenic, selenium, boron, lead, cadmium, copper, and zinc in naturally contaminated rocks: A review of their sources, modes of enrichment, mechanisms of release, and mitigation strategies. *Science of the Total Environment*, *645*, 1522-1553.

Tamás, M. J., Fauvet, B., Christen, P., & Goloubinoff, P. (2018). Misfolding and aggregation of nascent proteins: a novel mode of toxic cadmium action in vivo. *Current genetics*, *64*(1), 177-181.

Tao, C., Pei, Y., Zhang, L., & Zhang, Y. (2020). Microbial communities respond to microenvironments in lungs of mice under simulated exposure to cadmium aerosols. *Science of The Total Environment*, *710*, 136300.

Terrón-Camero, L. C., Peláez-Vico, M. Á., Del-Val, C., Sandalio, L. M., & Romero-Puertas, M. C. (2019). Role of nitric oxide in plant responses to heavy metal stress: exogenous application versus endogenous production. *Journal of Experimental Botany*, *70*(17), 4477-4488.

Tripathi, S., Srivastava, P., Devi, R. S., & Bhadouria, R. (2020). Influence of synthetic fertilizers and pesticides on soil health and soil microbiology. In: Prasad, M. N. V. (ed) *Agrochemicals Detection, Treatment and Remediation* (pp. 25-54). Butterworth-Heinemann.

Vahter, M., Berglund, M., Åkesson, A., & Liden, C. (2002). Metals and women's health. *Environmental Research*, *88*(3), 145-155.

Vizuete, J., Pérez-López, M., Míguez-Santiyán, M. P., & Hernández-Moreno, D. (2018). Mercury (Hg), lead (Pb), cadmium (Cd), selenium (Se), and arsenic (As) in liver, kidney, and feathers of gulls: A review. In: de Voogt, P. (ed) *Reviews of Environmental Contamination and Toxicology Volume 247* (pp. 85-146). Springer, Cham.

Wang, H., He, L., Song, J., Cui, W., Zhang, Y., Jia, C., ... & Hui, X. (2016). Cadmium-induced genomic instability in *Arabidopsis*: molecular toxicological biomarkers for early diagnosis of cadmium stress. *Chemosphere*, *150*, 258-265.

Wang, L. Y., Fan, R. F., Yang, D. B., Zhang, D., & Wang, L. (2019). Puerarin reverses cadmium-induced lysosomal dysfunction in primary rat proximal tubular cells via inhibiting Nrf2 pathway. *Biochemical Pharmacology*, *162*, 132-141.

Wang, X. Y., Yang, H., Wang, M. G., Yang, D. B., Wang, Z. Y., & Wang, L. (2017). Trehalose protects against cadmium-induced cytotoxicity in primary rat proximal tubular cells via inhibiting apoptosis and restoring autophagic flux. *Cell Death & Disease*, *8*(10), e3099-e3099.

WHO, (2000). World Health Organization. “Fifty-Third Report of The Joint Fao/Who Expert Committee on Food Additives”, Who Technical Report Series 896, Genova, Switzerland.

WHO, (2003). World Health Organization. Cadmium review. www.who.int/ifcs/documents/forums/forum5/nmr_cadmium. pdf, Last accessed on July 26, 2020.

WHO, (2019). World Health Organization. Preventing Disease through Healthy Environments: Exposure to Cadmium: A Major Public Health Concern. https://apps.who.int/iris/bitstream/handle/10665/329480/WHO-CED-PHE-EPE-19.4.3-eng.pdf, Last accessed on July 26, 2020.

Xu, X., Zhang, X., Carrillo, G., Zhong, Y., Kan, H., & Zhang, B. (2019). A systematic assessment of carcinogenicity of chemicals in hydraulic-fracturing fluids and flowback water. *Environmental Pollution*, *251*, 128-136.

Yalcin, I. E., Ozyigit, I. I., Dogan, I., Demir, G., & Yarci, C. (2020). Using the Turkish red pine tree to monitor heavy metal pollution. *Polish Journal of Environmental Studies*, *29*(5), 3881-3889.

Yamaguchi, C., Khamsalath, S., Takimoto, Y., Suyama, A., Mori, Y., Ohkama-Ohtsu, N., & Maruyama-Nakashita, A. (2020). SLIM1 transcription factor promotes sulfate uptake and distribution to shoot, along with phytochelatin accumulation, under cadmium stress in *Arabidopsis thaliana*. *Plants*, *9*(2), 163.

Yang, C. M., & Juang, K. W. (2015). Alleviation effects of calcium and potassium on cadmium rhizotoxicity and absorption by soybean and wheat roots. *Journal of Plant Nutrition and Soil Science*, *178*(5), 748-754.

Yang, Q., Li, Z., Lu, X., Duan, Q., Huang, L., & Bi, J. (2018). A review of soil heavy metal pollution from industrial and agricultural regions in China: Pollution and risk assessment. *Science of the total environment*, *642*, 690-700.

Yang, Q., Zhu, J., Luo, X., Li, F., Cong, L., Wang, Y., & Sun, Y. (2019). Melatonin attenuates cadmium-induced ovulatory dysfunction by suppressing endoplasmic reticulum stress and cell apoptosis. *Reproductive Biology and Endocrinology*, *17*(1), 61.

Yaseen, M. A. (2019). Effect of different cadmium levels on growth and biochemical parameters of *Cyprinus carpio* fingerlings reared in a close system. *Zanco Journal of Pure and Applied Sciences*, *31*(4), 139-152.

Yongming, S., Rongzhu, L., Jie, L., Yan, X., Zhu, Y., & Schweigert, M. (2011). The occupational disease prevention and control act of the people's republic of China: an awareness assessment among workers at foreign-invested enterprises. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, *21*(1), 103-116.

Zahra, S., Mahmood, S., Noreen, S., & Akrem, A. (2018). Independent and combined nickel and cadmium ınduced lipid peroxidation of biological membranes and its mitigation through antioxidant enzymes in *Grewia asiatica* L. *Pakistan Journal of Life & Social Sciences*, *16*(1), 48-54.

Zalups, R. K., & Ahmad, S. (2003). Molecular handling of cadmium in transporting epithelia. *Toxicology and Applied Pharmacology*, *186*(3), 163-188.

Zandonadi, D. B., Santos, M. P., Caixeta, L. S., Marinho, E. B., Peres, L. E. P., & Façanha, A. R. (2016). Plant proton pumps as markers of biostimulant action. *Scientia Agricola*, *73*(1), 24-28.

Zengin, F. K., & Munzuroglu, O. (2006). Effects of heavy metals (Pb^{++}, Cu^{++}, Cd^{++}, Hg^{++}) on total protein and abscisic acid content of bean (*Phaseolus vulgaris* L. cv. Strike) seedlings. *Fresenius Environmental Bulletin*, *15*(4), 277-282.

Zhang, T., Gao, X., Luo, X., Li, L., Ma, M., Zhu, Y., ... & Li, R. (2019a). The effects of long-term exposure to low doses of cadmium on the health of the next generation of mice. *Chemico-Biological Interactions*, *312*, 108792.

Zhang, Y., Li, S., & Li, S. (2019b). Relationship between cadmium content in semen and male infertility: a meta-analysis. *Environmental Science and Pollution Research*, *26*(2), 1947-1953.

Zhang, X., Xu, Z., Lin, F., Wang, F., Ye, D., & Huang, Y. (2016). Increased oxidative DNA damage in placenta contributes to cadmium-induced preeclamptic conditions in rat. *Biological Trace Element Research*, *170*(1), 119-127.

Ziller, A., Yadav, R. K., Capdevila, M., Reddy, M. S., Vallon, L., Marmeisse, R., ... & Fraissinet-Tachet, L. (2017). Metagenomics analysis reveals a new metallothionein family: sequence and metal-binding features of new environmental cysteine-rich proteins. *Journal of Inorganic Biochemistry*, *167*, 1-11.

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Research article

Quorum sensing inhibition properties of lichen forming fungi extracts from *Cetrelia* species against *Pseudomonas aeruginosa*

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Abstract

Pseudomonas aeruginosa is known to be responsible for many antibiotic resistant infections in hospitals. It can regulate its virulence gene expressions through its QS systems. It is now known that QS inhibition can make bacteria less violent and more vulnerable. Many natural sources such as bacteria, fungi and plants are known to produce QS inhibitor (QSI) metabolites. This study aims to investigate the QSI bioactivity of culture extracts obtained from lichen-forming fungi (LFF) of five different *Cetrelia* species against *P. aeruginosa.* Extracts were applied to monitor strains and all samples have shown varying amounts of QS inhibition activity. Our study demonstrates that LFF cultures can be utilized to produce QSI compounds instead of collecting slow growing natural lichen thalli. We believe that this research will cast a new light on identification and isolation of active compounds from the extracts and assessment of their compatibility for future drug research.

Keywords: *Quorum sensing; Pseudomonas aeruginosa; secondary metabolites; lichen forming fungi*

1. Introduction

Pseudomonas aeruginosa is a Gram negative, opportunistic nosocomial pathogen bacterium associated with multidrug resistant infections in immune compromised patients (Jones et al., 2009; Lambert et al., 2011; Pachori et al., 2019). *P. aeruginosa* is stated as the leading cause for high mortality rates in cystic fibrosis patients (Ciofu et al., 2015).

It can also survive in various environmental conditions due to its biofilm form, which provides a stable and secure environment to resist extreme conditions such as exposure to UV, antibiotics, pH changes or antimicrobial agents (Brackman and Coenye, 2015). Therefore, it is imperative to prevent the ability to develop biofilms, especially in antibiotic resistant strains in hospitals. *P. aeruginosa* employs cell-to-cell signaling mechanism called *quorum* sensing (QS) to regulate its physiological behaviors such as biofilm production, virulence and motility (Kostylev et al., 2019).

All bacteria communicate with each other via QS, utilizing small diffusible signaling molecules called autoinducers (AIs), leading to sporulation, conjugation, biofilm formation, bacteriocin production, bioluminescence, swarming etc. (Li et al., 2016). QS is mediated by AI molecules called N-acyl-homoserine lactones (AHLs) in Gram negative bacteria and by autoinducer peptides (AIP) in Gram positive bacteria (Jakobsen et al., 2013). Autoinducer-2 (AI-2) signal molecules have been detected in both Gram positive and negative bacteria. AHLs diffuse through the cell membrane and bind to regulatory proteins within the cell in Gram negative bacteria including *P. aeruginosa*.

The AHL-mediated QS system has been well characterized in *P. aeruginosa*, which has two main QS systems called LasIR

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and RhlIR. LasI produces *N*-(3-oxododecanoyl)-L-homoserine, lactone (3-oxo-C12-HSL) and RhlI produces *N*-butanoyl homoserine lactone (C4-HSL). These signal molecules accumulate in the surrounding milieu and activate transcriptional regulators LasR and RhlR. Pseudomonas quinolone signal (PQS) system is believed to act as a mediatory between LasIR and RhlIR QS systems (Diggle et al., 2003; McGrath et al., 2004).

The novel approach by employing quorum sensing inhibitors (QSIs) provides a fighting chance against bacteria before they develop antibiotic resistance (Hentzer et al., 2003). It is shown that inhibiting QS can leave bacteria vulnerable (Zeng et al., 2008). It is expected that natural metabolites can suppress QS systems of bacteria and thus they are a noteworthy source for drug materials (Paczkowski et al., 2017). In a recent study, Ahmed et al., (2019) have shown that *trans*-cinnamaldehyde and salicylic acid inhibit *P. aeruginosa* QS and thus reduce its virulence.

Lichens are complex organisms consisting of algae or cyanobacteria (photobiont) living together with fungi (mycobiont) in a symbiotic relationship. They are found in a wide range of habitats and synthesize chemically diverse organic compounds derived from primary or secondary metabolism (Molnar and Farkas, 2010). Secondary metabolites have importance in ethnobotany for their medicinal properties (Lal and Upreti, 1995; Malhotra et al., 2008). More than 1050 secondary metabolites are known, and their bioactivities such as antitumor, antibacterial, antifungal, antiviral, anti-inflammatory and antioxidant activities have been demonstrated (Molnar and Farkas, 2010; Shukla et al., 2010). It has been explained that lichens are promising candidates for discovering novel QSIs (Gokalsin and Sesal, 2016).

The lichen genus *Cetrelia* W.L. Culb. & C.F. Culb. belongs to lichenized fungi *Parmeliaceae* family. Like most secondary metabolites in lichens, the production of these compounds are regulated by polyketide synthase (PKS) of mycobiont counterpart. It is assumed that culturing the lichen forming fungi (LFF) has better potential for producing secondary metabolites in laboratory conditions than harvesting lichen thalli in nature. Therefore, for this study LFF cultures of five *Cetrelia* species were obtained from Korean Lichen & Allied Bioresource Center (KoLABIC), Sunchon National University, Korea, to investigate their QS inhibition potentials against *P. aeruginosa.* For this purpose, extracts were obtained from LFF cultures of *Cetrelia* species, and fluorescent monitor strains of *P. aeruginosa* were utilized for inhibition analyses.

2. Materials and Methods

2.1. Bacteria strains

P. aeruginosa lasB-gfp and *rhlA-gfp* biomonitor strains were employed to quantify QS inhibition (Hentzer et al., 2002; Yang et al., 2009). They contain promoters for two main QS systems that produce green fluorescent protein (GFP). The bacteria were grown in LB, and the QS inhibition assays were conducted with M9 minimal media (with 2.5 mg/l thiamine, 0.5% glucose, 0.5% casamino acids).

2.2. LFF isolation and cultures

Spore-discharge method (Yamamoto, 2002) was used to isolate the LFF from five *Cetrelia* species: *Cetrelia japonica, C. olivetorum, C. braunsiana, C. chicitae* and *C. delavayana.* All lichens were collected and the fungi were isolated by KOLABIC. Culture information is shown in Table 1.

Table 1
Information on lichen collections and their LFF cultures with the applied extract concentrations.

Lichen name	Collection No.	Country	KOLABIC No. (Lichen)	Extract concentrations (µg/ml)
Cetrelia japonica	30397	Korea	330	65
C. olivetorum	CH050076	China	3725	33.3
C. braunsiana	40425	Korea	1203	24.7
C. chicitae	TW090067	Taiwan	9612	16.7
C. delavayana	06-26823	China	8128	16

2.3. Preparation of LFF extracts

Approximately 1 g fresh weight mycelia were inoculated to malt-yeast agar plates. Grown LFF were then gently crushed and transferred into malt-yeast medium. All LFF samples were cultured at 18°C for 3 months (150 rpm shaking). Culture media were filtered and the filtrates were extracted by ethyl acetate 3 times. Solvents were removed using a rotary evaporator, and the powder extracts were weighed.

2.4. Pseudomonas aeruginosa QSI screens

QS inhibition assays were performed according to Bjarnsholt et al., (2010), with slight modifications. In short, M9 media (with 2.5 mg/l thiamine, 0.5% glucose, 0.5% casamino acids) were added to clear bottom black 96-well plates and two-fold serial dilutions of the extracts were prepared. Strains grown overnight were then added to obtain a final OD of 0.1 at 450 nm. Applied concentrations of the LFF extracts are shown in Table 1. Absorbance (450 and 600 nm) and fluorescence intensities (Ex: 485 nm, Em: 535 nm) were measured using a microplate reader (Cytation 3, Biotek), every 15 minutes, with constant shaking (180 rpm) at 36 ºC for 16 hours.

2.5. HPLC Analysis

Ethyl-acetate extracts were analyzed by HPLC (LC-10AT, Shimadzu, Japan) under following conditions: Acetonitrile (ACN) in 0.1% trifluoroacetic acid (TFA) gradient; solvent, Methanol:Chloroform (1:1, v:v); 1 ml/min flow rate; photodiode array detector (range 180-700 nm); detecting wavelength: 254 nm.

3. Results

3.1. QSI activity

LFF extracts obtained from five different *Cetrelia* species were applied to the monitor strains with the final concentrations as shown in Table 1. According to the results, all extracts have shown QSI properties on the monitor strain *lasB-gfp* and *rhlA-gfp* (Fig. 1-2).

The results are means of 3 individual experiments. Compared to untreated groups, the highest QS inhibition was observed in the LFF extract of *C. braunsiana* (approximately 63.8% for *las* and 52.6% for *rhl* system). Other samples also show similar inhibition percentages at different concentrations.

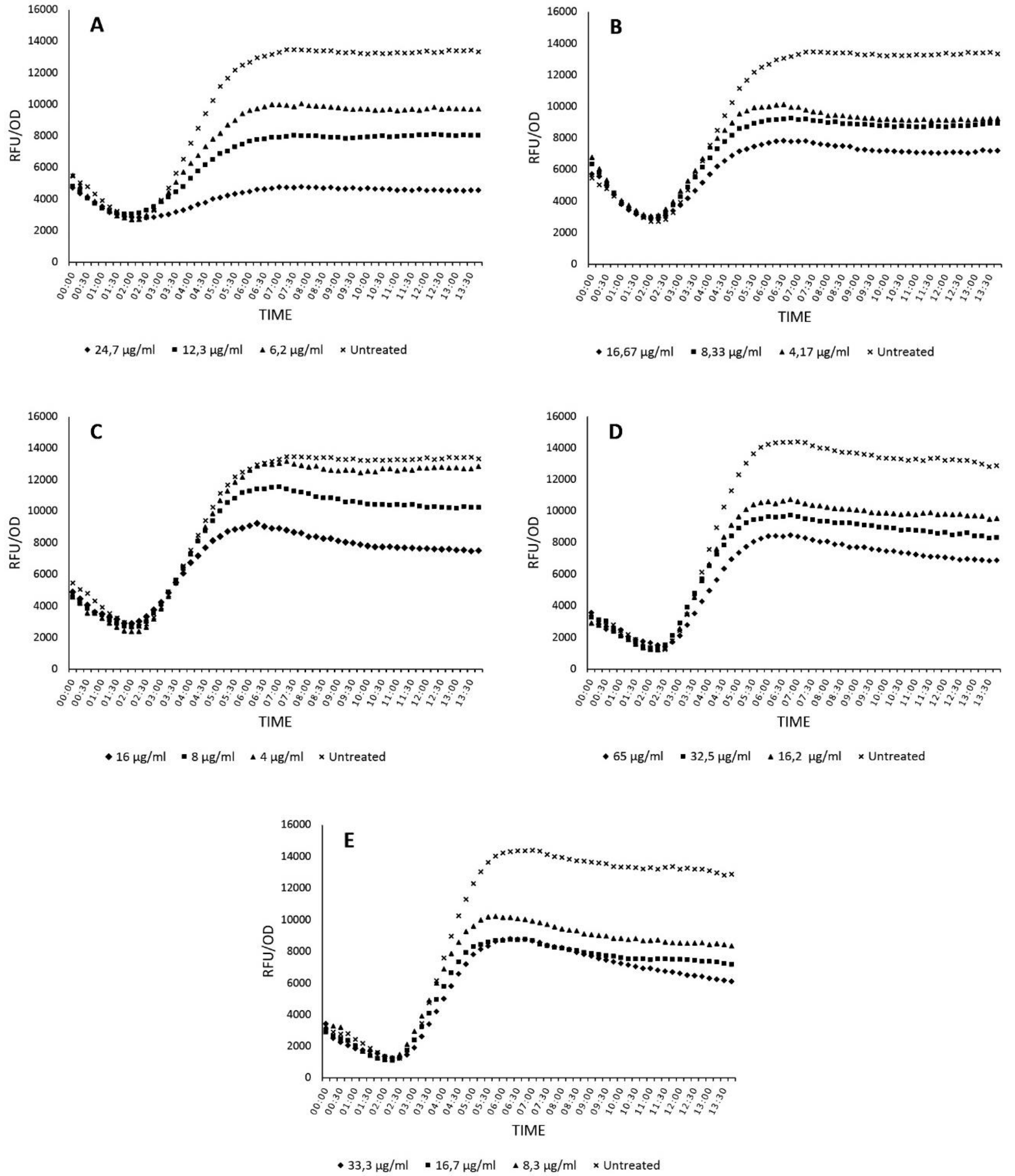

Fig. 1. Dose response curves of *lasB-gfp* monitor strain treated with LFF extracts obtained from different *Cetrelia* species. Data are shown as Relative Fluorescence Unit over Optical Density of 450nm. (A) *C. braunsiana*, (B) *C. chicitae*, (C) *C. delavayana*, (D) *C. japonica* and (E) *C. olivetorum*.

Results are presented as relative fluorescence unit (RFU) over absorbance to take minor growth inhibition rates into account. Descriptive statistics were used in this study.

2.3. HPLC Analysis

According to 16th minute retention time of HPLC, a common absorbance peak was detected in all extracts except *C. chicitae*. Results are shown in Fig. 3.

4. Discussion

P. aeruginosa continues to be a major cause of nosocomial infections in hospitals. It can detect its surrounding population using a signal system called QS and collectively res-pond to this information by regulating its virulence gene expressions (De Kievit, 2009). Employing QSIs proved that biofilm formation and virulence can be inhibited and provide a fighting chance against bacteria (Hancock and Speert, 2000).

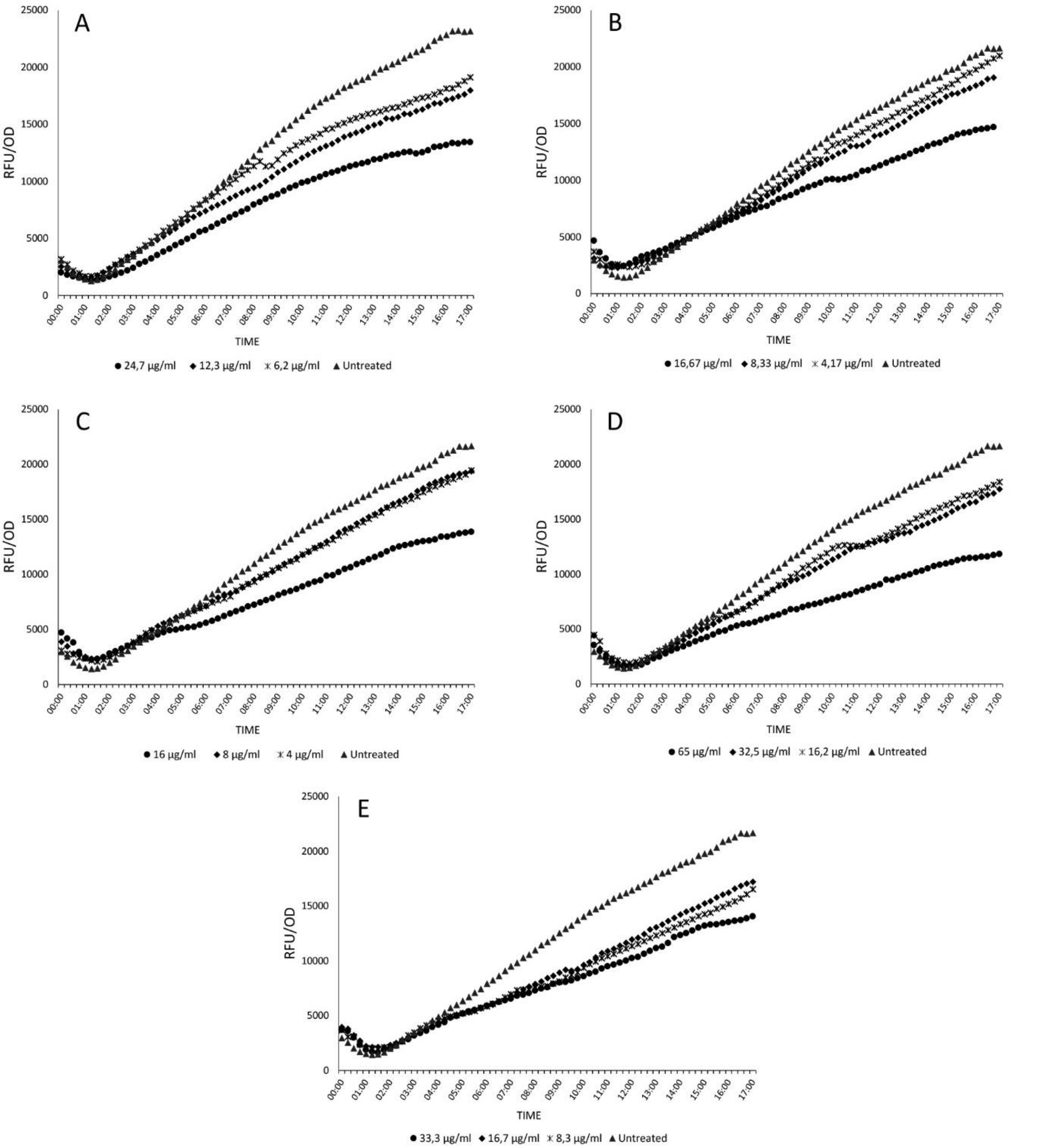

Fig. 2. Dose response curves of *rhlA-gfp* monitor strain treated with LFF extracts obtained from different *Cetrelia* species. Data are shown as Relative Fluorescence Unit over Optical Density of 450nm. (A) *C. braunsiana,* (B) *C. chicitae,* (C) *C. delavayana,* (D) *C. japonica* and (E) *C. olivetorum*.

Many effective QSIs have been discovered to this day (Azimi et al., 2012; Truchado et al., 2012; Al-Ani et al., 2015; Savo et al., 2015). New potential QSIs from lichen biosources would expectedly aid this possible alternative treatment method.

This study aims to investigate the QSI bioactivity of extracts obtained from LFF cultures of five *Cetrelia* species against *P. aeruginosa.* For this purpose, concentrations of ethyl-acetate extracts were applied to GFP producing monitor strains *lasB-gfp* and *rhlA-gfp* to observe QS inhibition. According to the results, all LFF isolates in this study have shown QSI properties with varying amounts. This means that every *Cetrelia* species in this study contains secondary metabolites that are biologically active against *P. aeruginosa* QS; although it is debatable if they're the same or similar compounds. According to HPLC analyses, a common compound exists in the LFF extracts of *C. japonica, C. olivetorum, C. braunsiana,* and *C. delavayana.* This unidentified compound might be the reason for QSI activity in these extracts. However, the amount of this compound in each species would most certainly change resulting in varying QS inhibition properties.

In a study, Savale et al., (2016) have shown that methanol extracts of C. *olvietorum* and its culture has antimicrobial pro-

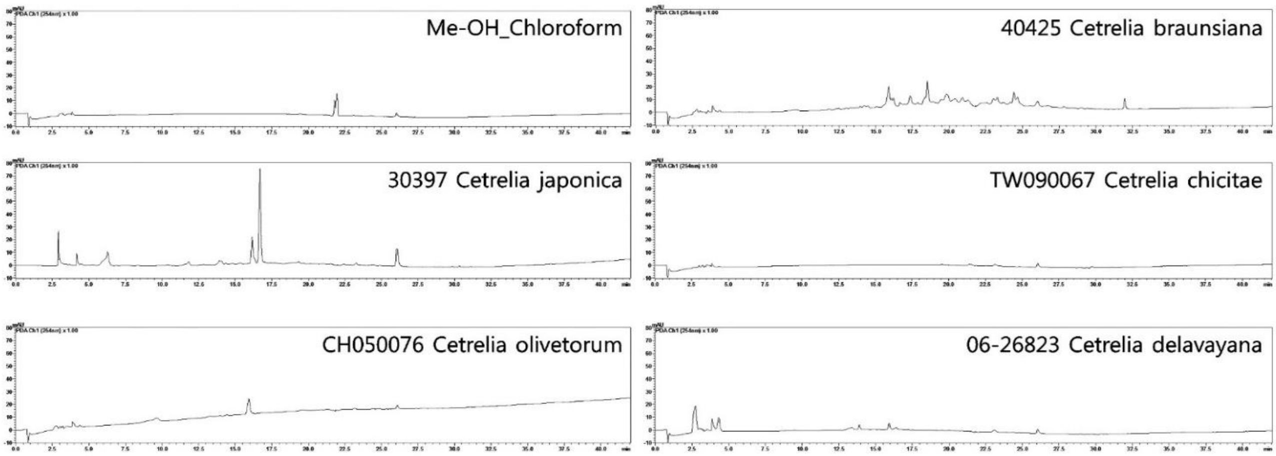

Fig. 3. HPLC chromatograms of ethyl-acetate extracts from *Cetrelia* LFF. A common absorbance peak was detected in all extracts except *Cetrelia chicitae* (RT = 16 min).

perties against *P. aeruginosa* at 103.44 µg/mL. In this study, applied concentrations of LFF extracts had no effect on bacterial growth. Furthermore, several studies demonstrate antioxidant and other biological activities of *Cetrelia* genus. However, the number of QS inhibition studies on lichen substances are limited (Fernández-Moriano et al., 2015; Shrestha, 2015; Yamamoto et al., 2015; Gokalsin et al., 2019). This study presents the QSI potential of lichen metabolites that *Cetrelia* LFF contain.

Industrial scale production of LFFs present a serious challenge for now. Therefore, the amount of extracts one can obtain may vary. Moreover, the solubility of the crude extracts also changes according to lichen species. Due to limited amount of extracts and their solubilities, concentrations of each sample are different in this study. However, the concentrations of bioactive metabolites that cause the QS inhibition in crude extracts can also vary due to multiple parameters such as species metabolism and environmental conditions. Therefore, isolation and analysis of pure compounds in future studies would highlight the QS inhibition properties of LFFs more efficiently. This study intends to show that LFF cultures can also be utilized to produce QSI compounds instead of collecting slow growing lichen thalli from nature. With further research, it is possible to identify and isolate active compounds from the extracts and assess their compatibility for drug research.

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References

Ahmed, S. A., Rudden, M., Smyth, T. J., Dooley, J. S., Marchant, R., & Banat, I. M. (2019). Natural quorum sensing inhibitors effectively downregulate gene expression of *Pseudomonas aeruginosa* virulence factors. *Applied Microbiology and Biotechnology*, *103*(8), 3521-3535.

Al-Ani, I., Zimmermann, S., Reichling, J., & Wink, M. (2015). Pharmacological synergism of bee venom and melittin with antibiotics and plant secondary metabolites against multi-drug resistant microbial pathogens. *Phytomedicine, 22*(2), 245-255. doi:10.1016/j.phymed.2014.11.019

Azimi, H., Khakshur, A. A., Aghdasi, I., Fallah-Tafti, M., & Abdollahi, M. (2012). A review of animal and human studies for management of benign prostatic hyperplasia with natural products: perspective of new pharmacological agents. *Inflamm Allergy Drug Targets, 11*(3), 207-221. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22512478

Bjarnsholt, T., van Gennip, M., Jakobsen, T. H., Christensen, L. D., Jensen, P. O., & Givskov, M. (2010). In vitro screens for quorum sensing inhibitors and in vivo confirmation of their effect. *Nature Protocols, 5*(2), 282-293. doi:10.1038/nprot.2009.205

Ciofu, O., Tolker-Nielsen, T., Jensen, P. O., Wang, H., & Hoiby, N. (2015). Antimicrobial resistance, respiratory tract infections and role of biofilms in lung infections in cystic fibrosis patients. *Advanced Drug Delivery Reviews, 85*, 7-23. doi:10.1016/j.addr.2014.11.017

De Kievit, T. (2009). Quorum sensing in *Pseudomonas aeruginosa* biofilms. *Environmental Microbiology, 11*(2), 279-288.

Diggle, S. P., Winzer, K., Chhabra, S. R., Chlshabra, S. R., Worrall, K. E., Camara, M., & Williams, P. (2003). The *Pseudomonas aeruginosa* quinolone signal molecule overcomes the cell density-dependency of the quorum sensing hierarchy, regulates rhl-dependent genes at the onset of stationary phase and can be produced in the absence of LasR. *Molecular Microbiology, 50*(1), 29-43. doi:10.1046/j.1365-2958.2003.03672.x

Fernández-Moriano, C., Divakar, P. K., Crespo, A., & Cuadrado, M. P. G.-S. (2015). Antioxidant and cytoprotective potentials of *Parmeliaceae* lichens and identification of active compounds. *Anales de la Real Academia Nacional de Farmacia*, *81*, 164-178.

Gokalsin, B., & Sesal, N. C. (2016). Lichen secondary metabolite evernic acid as potential quorum sensing inhibitor against *Pseudomonas aeruginosa*. *World Journal of Microbiology and Biotechnology, 32*(9), 150. doi:10.1007/s11274-016-2105-5

Gokalsin, B., Berber, D., Ozyigitoglu, G. C., Yesilada, E., & Sesal, N. C. (2019). Quorum sensing attenuation properties of ethnobotanically valuable lichens against *Pseudomonas aeruginosa*. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, 1-8.

Hancock, R. E., & Speert, D. P. (2000). Antibiotic resistance in *Pseudomonas aeruginosa*: mechanisms and impact on treatment. *Drug Resist Updat, 3*(4), 247-255. doi:10.1054/drup.2000.0152

Hentzer, M., Eberl, L., Nielsen, J., & Givskov, M. (2003). Quorum sensing - A novel target for the treatment of biofilm infections. *Biodrugs, 17*(4), 241-250. doi:Doi 10.2165/00063030-200317040-00003

Hentzer, M., Riedel, K., Rasmussen, T. B., Heydorn, A., Andersen, J. B., Parsek, M. R., . . . Givskov, M. (2002). Inhibition of quorum sensing in *Pseudomonas aeruginosa* biofilm bacteria by a halogenated furanone compound. *Microbiology-Sgm, 148*, 87-102.

Jakobsen, T. H., Bjarnsholt, T., Jensen, P. O., Givskov, M., & Hoiby, N. (2013). Targeting quorum sensing in *Pseudomonas aeruginosa* biofilms: current and emerging inhibitors. *Future Microbiology, 8*(7), 901-921. doi:10.2217/fmb.13.57

Jones, R. N., Stilwell, M. G., Rhomberg, P. R., & Sader, H. S. (2009). Anti pseudomonal activity of piperacillin/tazobactam: more than a decade of experience from the SENTRY Antimicrobial Surveillance Program

(1997-2007). *Diagnostic Microbiology and Infectious Disease, 65*(3), 331-334. doi:10.1016/j.diagmicrobio.2009.06.022

Kostylev, M., Kim, D. Y., Smalley, N. E., Salukhe, I., Greenberg, E. P., & Dandekar, A. A. (2019). Evolution of the *Pseudomonas aeruginosa* quorum-sensing hierarchy. *Proceedings of the National Academy of Sciences, 116*(14), 7027-7032.

Lal, B., & Upreti, D. K. (1995). Ethnobotanical Notes on Three Indian Lichens. *The Lichenologist, 27*(1), 77-79. doi:10.1006/lich.1995.0006

Lambert, M. L., Suetens, C., Savey, A., Palomar, M., Hiesmayr, M., Morales, I., . . . Wolkewitz, M. (2011). Clinical outcomes of health-care-associated infections and antimicrobial resistance in patients admitted to European intensive-care units: a cohort study. *Lancet Infect Dis, 11*(1), 30-38. doi:10.1016/S1473-3099(10)70258-9

Li, T., Cui, F., Bai, F., Zhao, G., & Li, J. (2016). Involvement of acylated homoserine lactones (AHLs) of Aeromonas sobria in spoilage of refrigerated turbot (*Scophthalmus maximus* L.). *Sensors, 16*(7), 1083.

Malhotra, S., Subban, R., & Singh, A. (2008). Lichens-role in traditional medicine and drug discovery. *The Internet Journal of Alternative Medicine, 5*(2), 151-170.

McGrath, S., Wade, D. S., & Pesci, E. C. (2004). Dueling quorum sensing systems in *Pseudomonas aeruginosa* control the production of the Pseudomonas quinolone signal (PQS). *Fems Microbiology Letters, 230*(1), 27-34. doi:10.1016/S0378-1097(03)00849-8

Molnar, K., & Farkas, E. (2010). Current results on biological activities of lichen secondary metabolites: a review. *Zeitschrift für Naturforschung C, 65*(3-4), 157-173. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20469633

Pachori, P., Gothalwal, R., & Gandhi, P. (2019). Emergence of antibiotic resistance *Pseudomonas aeruginosa* in intensive care unit; a critical review. *Genes & Diseases, 6*(2), 109-119.

Paczkowski, J. E., Mukherjee, S., McCready, A. R., Cong, J. P., Aquino, C. J., Kim, H., ... & Bassler, B. L. (2017). Flavonoids suppress *Pseudomonas aeruginosa* virulence through allosteric inhibition of quorum-sensing receptors. *Journal of Biological Chemistry, 292*(10), 4064-4076.

Savale, S. A., Pol, C. S., Khare, R., Verma, N., Gaikwad, S., Mandal, B., & Behera, B. C. (2016). Radical scavenging, prolyl endopeptidase inhibitory, and antimicrobial potential of a cultured Himalayan lichen *Cetrelia olivetorum*. *Pharmaceutical Biology, 54*(4), 692-700. doi:10.3109/13880209.2015.1072567

Savo, V., Joy, R., Caneva, G., & McClatchey, W. C. (2015). Plant selection for ethnobotanical uses on the Amalfi Coast (Southern Italy). *Journal of Ethnobiology and Ethnomedicine, 11*, 58. doi:10.1186/s13002-015-0038-y

Shrestha, G. (2015). Exploring the antibacterial, antioxidant, and anticancer properties of lichen metabolites, Doctoral Dissertation, (pp. 1-116). Brigham Young University, Provo, USA.

Shukla, V., Joshi, G. P., & Rawat, M. (2010). Lichens as a potential natural source of bioactive compounds: a review. *Phytochemistry Reviews, 9*(2), 303-314.

Truchado, P., Tomas-Barberan, F. A., Larrosa, M., & Allende, A. (2012). Food phytochemicals act as Quorum Sensing inhibitors reducing production and/or degrading autoinducers of *Yersinia enterocolitica* and *Erwinia carotovora*. *Food Control, 24*(1-2), 78-85. doi:10.1016/j.foodcont.2011.09.006

Yamamoto, Y. (2002). Discharge and germination of lichen ascospores in the laboratory. *Lichenology, 1*, 11-22.

Yamamoto, Y., Hara, K., Kawakami, H., & Komine, M. (2015). Lichen Substances and Their Biological Activities. In *Recent Advances in Lichenology* (pp. 181-199): Springer.

Yang, L., Rybtke, M. T., Jakobsen, T. H., Hentzer, M., Bjarnsholt, T., Givskov, M., & Tolker-Nielsen, T. (2009). Computer-Aided identification of recognized drugs as *Pseudomonas aeruginosa* quorum-sensing inhibitors. *Antimicrobial Agents and Chemotherapy, 53*(6), 2432-2443. doi:10.1128/Aac.01283-08

Zeng, Z., Qian, L., Cao, L., Tan, H., Huang, Y., Xue, X., . . . Zhou, S. (2008). Virtual screening for novel quorum sensing inhibitors to eradicate biofilm formation of *Pseudomonas aeruginosa*. *Applied Microbiology and Biotechnology, 79*(1), 119-126. doi:10.1007/s00253-008-1406-5

Cite as: Gokalsin, B., Berber, D., Hur, J. S., & Sesal, N. C. (2020). Quorum sensing inhibition properties of lichen forming fungi extracts from *Cetrelia* species against *Pseudomonas aeruginosa*. *Front Life Sci RT, 1*(1), 22-27.

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Research article

Investigation of hemeroby degree of vegetation in urban transport areas: the case of İzmit (Kocaeli)

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Abstract

One of today's main problems is the destruction of the ecosystems by human influence. In conjunction with the industrialization, increasing population and the number of factories has a negative impact on the natural vegetation of biotopes. To measure the intensity of this destruction, universally recognised hemeroby scale is used. İzmit, which is also an industrialized town and was reborn from its ashes after a major earthquake in 1999 has similar ecosystem problems. This study's primary aims are; (1) Identifying the biotope in İzmit's terrestrial (=railway and highway) transportation areas, (2) Comparing with the transportation areas of Anatolian side of İstanbul in A2 region, (3) Examining the causes of differences, (4) Additionally, revealing the floral structure of the city in transportation areas. According to the results of the study, the biotope type distributed in the terrestrial transportation areas of the city of İzmit is compared to the biotope type of the terrestrial transportation areas in the Anatolian side of Istanbul in A2 region. The causes of the differences observed are examined and the flora of the transportation areas of the city was revealed. According to our results, it's understood that these biotope types have different hemeroby degrees. Obtained results were compared with the results of similar studies from cities in Turkey as well as some European cities and the observed differences were evaluated. Additionally, flora of transportation areas of the city has been broadly revealed. Also, suggestions were made on the ecological basis of the city in the future, about the measures to be taken to protect the existing flora and the sustainability of the developing biotopes.

Keywords: *İzmit; urban; hemeroby; transportation areas; ecology; roads*

1. Introduction

Kocaeli, is an important city with numerous ships calling at its' harbours, smoking factory chimneys, rapidly increasing population where the distribution of goods were mainly made by sea and roads. Thus, the city showed a heterogeneous urban development. Turkey is the 18th most populous country in the World and Kocaeli is Turkey's 10th most populous city whereas it is ranked 1st as the most industrialized port city in Turkey. However, it shows both the positive and negative aspects of industrialization (Basaran et al., 2020; Governorship, 2020).

It is located in North western Turkey between 40°-41°N latitudes and 29°-31°E longitudes. Kocaeli is situated at the east end of Marmara Sea and Marmara Region. To the South it's neighbouring the İzmit Bay and to the North Black Sea coast with steep slopes (Fig. 1). Its neighbouring cities are Sakarya to the east, İstanbul to the West and Bursa and Yalova to the South (Mapsworld, 2020; Municipality, 2020).

Kocaeli has a population of 1.953.035 living within an area of 3.505,27 km^2. Population density is 588 people/km^2. 30° East longitude is considered as local time reference for Turkey. İzmit is the central district of Kocaeli province out of 12 total districts. İzmit's population is 363.416 living within an area of 480 km^2. The population proportion of İzmit to the population of Kocaeli province is 1/5.25 which means that there is a dense (clustering) urbanization in İzmit (Municipality, 2020; Nufusu, 2020).

The city named as Bithynia in ancient period (1200-800 BC) and was also known as Astakoz (712-711 BC), Olibia (326-

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279 BC, Nicomedia (named after king of Bithnia; Nicomedes) (280-94 BC), İznikomid, İznikmid (Ottoman), İzmid, İzmit, Kocaeli (1924-Today) respectively throughout the history (Erken, 2015; Municipality, 2020).

İzmit, like a phoenix reborn from its ashes managed great comebacks after mega earthquakes and city-wide devastating fires (24 August 358, December 362, 17 August 1999 earthquake). The plague of 1592 halted all the transportation activities in the city for over 6 months. The city will surely get over the Covid-19, 2020 pandemic like it did before. During the course of the pandemic, İzmit continued its transportation activities both in the sea and land routes. The social and commercial life started to get revived after the construction of Haydarpaşa-Ankara railroad in 1873 (Beyhan, 2007; Municipality, 2020).

Fig. 1. Study area İzmit's location within Kocaeli province.

When the landforms are considered, the highest point of Samanlı Mountains is Keltepe (Kartepe) with its height reaching 1601 metres. Other important mountains in the province are Dikmen Mountain (1387 m), Naldöken Mountain (1125 m), Naz Mountain (917 m) and Çene Mountain (646m). The prominent plains are the flatlands between İzmit city and Sapanca Lake, along with Dilovası. The parts of Kocaeli peninsula, which is a peneplain, within the borders of the province are composed of wavy flatlands (Semerci, 2003).

Some of the waters originating from the provincial lands flow into the Black Sea whereas some of them flows into the Sea of Marmara. Since the mountain ridges extending into Kocaeli Peninsula are closer to the Sea of Marmara, the rivers flowing into the Black Sea are longer (Beyhan, 2007).

The distribution of total land assets according to soil groups and consequently land use capability, top three spots are lime-free Brown forest soils (70.56%), rendzina soils (15.89%) and alluvial soils (4.65%) (Beyhan, 2007; Severoglu et al., 2011).

Kocaeli is a transition zone between Mediterranean climate with little rainfall and Oceanic climate. It's rainy in summer with high temperatures. Mean temperature of İzmit is around 14.4 ºC (30-year average). Rain can be seen in all months throughout the year in Kocaeli but January and December are generally rainy months. The precipitation regime type is W.A.S.S. (winter, autumn, spring, summer). The precipitation type falls into the category of Central Low Rainfall Mediterranean Precipitation Regime (Köppen and Geiger, 1954; Akman, 1990).

The mean temperature during the vegetation period in Kocaeli province (March 15-December 15) is 17.02 °C as seen in Table 1. Total mean rainfall of Kocaeli province is 62.25mm/year 35.74% of which falls during winter. Months with the most fruitful rains are December and January. 14.72% of the entire year's rainfall happens during the summer period. July and August have the least rainfalls with 9.1%. Spring precipitation is 22.08% whereas during the fall this increases to 27.44%. Snowfall is also but rarely seen.

According to the Turkish State Meteorological Service observation records of Kocaeli province, the monthly average relative humidity is at its lowest in June with 66.2% and highest in January with 75.8% and the annual mean relative humidity of Kocaeli province is 71.7%, number of mean yearly foggy days is 17.1, the annual average number of days with snow is 17.2, mean number of days with hailstorms is 0.8, mean number of days with frost is 14.1, annual average number of days with thunderstorms is 21 and the maximum snow cover thickness is 74 mm (Meteorology, 2020).

According to the Tubives (Turkish Plants Data Service) 2020 records, there are 344 taxa in Kocaeli province. Our province however, sees 950 species and subspecies spread across the province. 11.75% of these taxa belongs to *Asteraceae*, 8.94% to *Fabaceae*, 7.76% to *Poaceae*, 5.93% to *Lamiaceae*, 3.77% to *Scrophulariaceae*, and 3.77% to *Rosaceae* (Beyhan, 2007).

The number of vascular plants in Europe is 12500 and 28% of these plants are endemics. Turkey is one of the richest countries in terms of flora with 9996 plant species belonging to 1320 genus and 167 families. The diverse flora of Kocaeli was studied by many researchers. Evaluation of plants spreading in Kocaeli in terms of endemics and danger classes (Ozen and Acemi, 2011), Flora of Hereke, Kocaeli (Kose and Ozen, 2017) are two of these studies. Also numerous studies were carried out in urban and countrysides (Yarci and Ozcelik, 2002; Yarci et al., 2007; Altay et al., 2010a, 2010b; Osma et al., 2010; Severoglu et al., 2011; Eskin et al., 2012). Also, there are similar studies both in Turkey and Europe. Altay et al., (2015) studied railroads between Haydarpaşa and Gebze can be cited as an example. Similar studies in Europe were also carried out in North Germany (Brandes, 1984), Trento-Italy (Brandes, 2003a) and Strasburg-France (Brandes, 2003b).

Table 1
Temperature and precipitation values of Kocaeli province (Meteorology, 2020).

	January	February	March	April	May	June	July	August	September	October	November	December
Mean Temp. (˚C)	5.8	6.2	8	12.5	17.5	21.5	23.4	23.3	19.9	15.8	11.9	8.2
Min. Temp. (˚C)	2.7	2.9	4.1	7.7	11.9	15.6	17.9	18	14.6	1.4	8	4.9
Max. Temp. (˚C)	8.9	9.6	12.	17.4	22.6	26.9	28.9	28.7	25.3	20.2	15.8	11.5
Precipitation (mm)	90	69	65	53	47	42	31	37	54	70	81	108

Fig. 2. İstanbul-Adapazarı 2019 up-to-date routes of Turkish State Railways (TCDD, 2020).

Table 2
Hemeroby Scale (Jalas, 1955; Sukopp, 1976; Kowarik, 1988; Kowarik, 1990).

Hemeroby Step	Location /Vegetation
HO ahemerob	Practically non-existent in Europe (High mountains at the very most)
H1 oligohemerob	Flat or tall but dense forest without any affects. Swamps, rock and seaside vegetation.
H2 oligomesohemerob	Extensive, water-free wetlands. Areas with fever woody plants, some wet meadows.
H3 mesohemerob	Commonly used forests, undisturbed secondary forests, grasslands of anthropogenic regions, traditionally used meadows.
H4 mesoßeuhemerob	Culture woods comprising single tree species (eg.; memorial forests). Secondary forests, ruderalized dry meadows with sparse vegetation cover.
H5 ß-euhemerob	Young forests, dense grasslands and meadows, ruderal high shrubs vegetation's strongly ruderalized dry meadows in anthropogenic regions.
H6 ß-eu a-euhemerob	Traditional segetal vegetation comprising single tree species, trampled lawns, ruderal meadows.
H7 a-euhemerob	Fields and gardens worked intensely.
H8 a-eu polyhemerob	Field vegetations treated strongly with pesticides (eg; corn fields), ruderal primary vegetation, and trampled grasses.
H9 polyhemerob	Pioneer vegetation in railroads, garbage and slag dump sites, salt-spread roads

The expected hemeroby degree near railroads and land roads is H9 polyhemerob.

2. Materials and methods

This study was carried out in 2002-2006 vegetation period with plants collected from near İzmit's railroads and roads. Identifications and evaluations were made with known botanical methods according to Davis 1965-1985 and Davis et al., 1988.

Mapping was done according to Kunick (1987). Identification and classification studies of dried plant samples were carried out in MUFE (Marmara University, Faculty of Science and Arts Herbarium in Istanbul-Turkey) using "Flora of Turkey and the East Aegean Islands" with its supplements (Davis, 1965-1985; Davis et al., 1988; Guner et al., 2000). The flora is listed alphabetically by family, genus and species and given in Appendix.

Anthropocentrism (Angeles, 1981); the understanding that everything serves humanity, is dominant in societies raised with a human-centric environmental awareness. For this reason, as long as we continue exploiting the nature, environmental damage by the hands of humans will continue to increase. In our study, the degree of destruction caused by human effects in land transportation areas was evaluated according to the hemeroby scale (Jalas, 1955; Sukopp, 1976; Kowarik, 1988; Kowarik, 1990). Mapping works were carried out for the taxa located within 3 meters of transportation areas in İzmit (Kunnick, 1987).

2.1. Studying biotypes of terrestrial transportation areas in İzmit

Roads assume an important role in physical structure of cities by providing movement of people and any type of transportation used by people. Today, roads along with limited open and green areas, build up the breathing spaces in the city (Sayar, 1998). We will classify and examine the biotopes that we determined within İzmit as "Terrestrial Transportation Areas" as "railroads" and "motorways".

2.1.1. Railroads

Kocaeli province has 68 km of railroads as of today (Fig. 2). The new train station building of İzmit has opened to public in 29 July 1999 and the railroads started operating on this new route since then. The railroad mainlines which used to extend at a 90° angle to the motorway and shoreline, now runs along the shoreline parallel to the motorway (Fig. 3) (Municipality, 2020).

Fig. 3. Vegetation on and around the railroad in İzmit.

In İzmit, in the area called "(Demiryolu) Hürriyet Caddesi" old rails were removed, new cobblestones were laid, making walkways for pedestrians while large trees like sycamores were carefully preserved and labelled by "High Council of Monuments" (Fig. 4) (Beyhan, 2007).

Fig. 4. Old railway route, converted to pedestrian walkways by laying cobblestones in İzmit.

In İzmit, not all biotope types that we described as "Transportation Areas" have the same degree of hemeroby. Railways, being one of the main elements of transportation areas, represents hemeroby characteristics between Polyhemerob-Metahemerob (Beyhan, 2007; Altay et al., 2015).

2.1.2. Motorways

Within the borders of Kocaeli province, there are 249 km of state motorways; 180 km of which is asphalt and 69 km surface coated. 49 km are divided roads. Additionally, there is 207 km of provincial roads. The main arteries are TEM (Trans European Motorway) and D-100 (E-5) motorway.

The most common taxa in the vegetation on roadsides and refuges are *Nerium oleander* L., *Acer pseudoplatanus* L., *Platanus orientalis* L., *Cupressus sempervirens* L., *Hordeum murinum* L., *Raphanus raphanistrum* L.

Apart from this, planted woody taxa and the regions natural taxa are seen in Transportation Areas. "Motorways; Asphalt, Transit roads" which we have evaluated within the scope of Transportation Areas, on the other hand, shows Euhemerob characteristics. When analysed descriptively, the obtained results are better than the value shown on the hemeroby scale (Beyhan, 2007).

3. Results and discussion

In our study, conducted in İzmit region, naturally occurring 80 taxa, 32 families, 64 genera (60 species, 12 subspecies, and 8 varieties) that grows spontaneously around transportation areas, were identified. Among them, 70 species are dicots and two species are monocots (Table 3 and Supplement).

Table 3
Monocot (geophytes) and dicot ratios.

	Monocots		Dicots		
Taxon	Number	%	Number	%	Total
Family	1	3.12	30	93.75	32
Genus	1	1.56	56	87.5	64
Species	2	4	69	86.25	80

There are only two monocot species here, which are *Muscari commutatum* Guss. and *Muscari parviflorum* Desf. (*Asparagaceae*, belonged to *Liliaceae* previously) and constitutes 4% of total species. Dicots on the other hand, constitute 86.25% of total species. If we rank the families according to the number of species they contain; the ranking will be as, *Asteraceae* (13 species, 16.25%), *Poaceae* (9 species, 11.25%), *Brassicaceae* (8 species, 10%), *Fabaceae* (8 species, 10%), *Plantaginaceae* (3 species, 3.75%), and *Geraniaceae* (3 species, 3.75%) (Table 4).

Table 4
Ratios of richest families found in İzmit's transportation areas.

	Genera (64)		Species (80)		
Family	**Number**	**%**	**Number**	**%**	**Sp./Genus ratio**
Asteraceae	10	15.62	13	16.25	1.3
Poaceae	7	10.93	9	11.25	1.28
Plantaginaceae	1	1.56	3	3.75	3
Brassicaceae	8	12.5	8	10	1
Fabaceae	5	7.81	8	10	1.6
Geraniaceae	2	3.12	3	3.75	1.5

As can be seen from Fig. 5, families with higher number of taxa are determined as; *Asteraceae* (16.25%), *Brassicaceae* (12.5%), *Poaceae* (11.25 %), *Fabaceae* (7.81%), *Plantaginaceae* (3.12%), and *Geraniaceae* (3.12%). These values are proportionally accurate when the general vegetation and flora composition is taken into consideration.

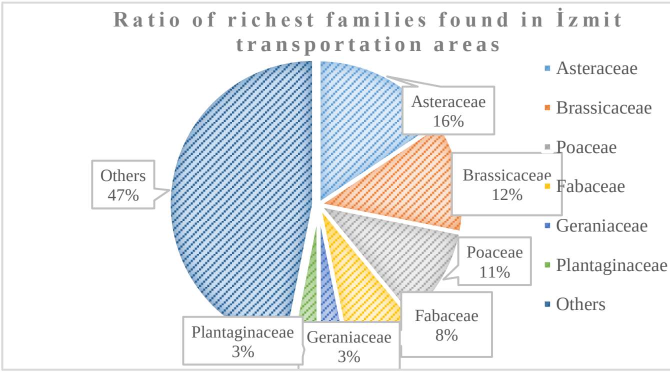


Fig. 5. Pie diagram of taxa distribution ratios of richest families in İzmit transportation areas.

Asteraceae has the highest number of species and a species/genera ratio of 1.3, whereas *Brassicaceae* has the lowest species/genus ratio of 1. This ratio is higher in other families. The ratios of other families are as follows; *Poaceae* (1.28), *Geraniaceae* (1.5), *Fabaceae* (1.6), *Plantaginaceae* (3). According to previous studies carried out in A2 region, *Asteraceae* family is the richest in terms of number of species when compared with other families (Altay et al., 2015). In one of studies regarding *Asteraceae*, Pietrzyk reported abundant *Asteraceae* species on the side of railroads and that they cause allergies (Pietrzyk et al., 2019). Another one from England studied railroad side habitats (Marshall, 2018). Borda-de-Ágalthough et al., (2017) suggested that the difference in the diversity of the species on left and right sides of the railways is due to *Asteraceae* members creating a barrier for other living things. It is kind of a transition zone since it prevents spreading (ecotone).

Pavlova and Tonkov (2005) mention that *Asteraceae* family is observed at a high rate in central Europe. This proves the success of the family in dispersal and survival. Yarci et al., (2007) recorded a similar distribution when he studied the vegetation of historical areas and buildings in Edirne. According to Davis, (1965-2000) *Asteraceae* family demonstrates success at similar levels all around Turkey.

When we examine the table, *Brassicaceae* family seems to be very rich in İzmit compared to other locations. The reason may be that our study comprises both railroads and motorways whereas other studies comprise railroads. Also, *Andrzeiowskia cardaminifolia* (DC.) Prantl., which is a very rare plant, was also detected in transportation areas. This taxon was normally registered in grids A2, A5, A6, C3 in İstanbul, Antalya and Samsun, and can be seen in Russia, Greece and W. Syria (Beyhan, 2007).

Table 5
Comparing percentages of richest families in İzmit with studies from Haydarpaşa-Gebze (Altay et al., 2015) and European cities. References: Northern Germany (Brandes, 1984), Trento-Italy (Brandes, 2003a), Strasburg-France (Brandes, 2003b).

Family	Haydarpaşa -Gebze	İzmit	Germany	Italy	France
Asteraceae	14.37	**16.25**	17.07	14.86	18.42
Poaceae	10.34	**11.25**	15.85	16.21	12.28
Brassicaceae	4.02	**10**	4.87	4.05	3.50
Fabaceae	12.64	**10**	1.21	5.40	3.50

Consequently, natural vegetation is desired to be kept under control by the use of herbicides near roads. However, if herbicides are used uncontrollably, they may cause damage to natural vegetation and we must protect our ecological treasures.

Highways, land roads and railroads act as ecological corridors. They form synthetic corridors. Bushy plants are tested to be helpful and successful in preventing events such as landslides and floods (Shi et al., 2018). Extensive use of concrete structures should be prevented, the natural vegetation should be preserved and allowed to spread. Thus, undesired events such as floods and landslides in cities can be reduced. Sides of highways and railroads can also assume the role of forming a green belt encompassing the city (Altay et al., 2015).

In order to create a solution here, younger generations should let go the human centric (Anthropocentrism) approach (Angeles, 1981) and start serving for the revitalization of the nature. The course of Covid-19 the humanity is enduring will likely help us understand the importance of balance in the nature. The consciousness for environmental protection, reduced consumption, reusing and recycling; and acknowledging the nature and developing empathy for nature should be popularized.

The future of humanity is entrusted to a sustainable environment, not an environment with all of its resources dried and drained.

Appendix

List of Flora (Taxa found in İzmit terrestrial transportation areas)

APIACEAE
Tordylium apulum L.

APOCYNACEAE
Nerium oleander L.

LILIACEAE
Muscari commutatum Guss. G.
Muscari parviflorum Desf.

ASTERACEAE
Bellis perennis L.
Calendula arvensis L. Th.
Circium creticum (Lam.) d'Urv. subsp. *creticum* H. E. Medit.
Cichorium inthybus L. Ch. E. Medit.
Crepis aurea (L.) Cass. subsp. *olympica* (C. Koch.) Lamond
Crepis armena DC.
Crepis reuterana Boiss. subsp. *reuterana*
Doronicum orientale Hoffm.
Pulicaria dysenterica (L.) Bernh.
Senecio taraxacifolius (Bieb.) DC. var. *taraxacifolius*
Senecio vulgaris L. Th.
Sonchus arvensis L. subsp. *uliginosus* (Bieb.)Beg.
Taraxacum officinale Wiggers Ch.

BETULACEAE
Carpinus betulus L.

BRASSICACEAE
Arabidopsis thaliana (L.) Heynhold
Arabis brachycarpa Rupr.
Capsella bursa- pastoris (L.) Medik. Th. Cos.
Calepina irregularis (Asso) Thellung
Cardaria draba (L.) Desv. subsp. *chalepensis* (L.) O.E.Schultz
Andrzeiowskia cardaminifolia (DC.) Prantl.
Neslia apiculata Fisch. Th. Wid.
Raphanus raphanistrum L.

BORAGINACEAE
Anchusa arvensis (L.) Bieb. subsp. *orientalis* (L.) Nordh
Echium plantagineum L.

CARYOPHYLLACEAE
Moenchia mantica (L.) Bartl. subsp. *mantica*
Stellaria media (L.) Vill. subsp. *pallida* (Dumort.) Aschers. & Graebn.
Cerastium glomeratum Thuill Th. Cos.

CONVOLVULACEAE
Convolvulus arvensis L. H. Cos.

CUCURBITACEAE
Ecballium elaterium (L.) A. Rich. H, Medit.

EUPHORBIACEAE
Euphorbia helioscopia L. Th.
Euphorbia exigua L. var. *retusa* L.
Euphorbia lathyris L.

FABACEAE
Hymenocarpus circinnatus (L) Savi.
Robinia pseudacacia L.
Trifolium stellatum L. var. *stellatum*
Trifolium striatum L.
Trifolium bocconei Savi
Medicago polymorpha L. var. *vulgaris* (Benth.) Shinners
Medicago marina L.
Vicia sativa L. var. *sativa*

GERANIACEAE
Geranium rotundifolium L.
Geranium lanuginosum Lam.
Erodium malacoides (L.) L'Herit.

HIPPOCASTANACEAE (SAPINDACEAE)
Aesculus hippocastanum L.

LAMIACEAE
Lamium amplexicaule L. T. Euro.- Sib.

LINACEAE
Linum austriacum L. subsp. *austriacum*

MALVACEAE
Malva sylvestris L. H.

MORACEAE
Ficus carica L. subsp. *carica* Ph, wid.
Morus alba L.

MYRTACEAE
Myrtus communis L. subsp. *communi*s

OLEACEAE
Ligustrum vulgare L. Ph, Euro.- Sib.
Phillyrea latifolia L. Ph, Medit.

OXALIDACEAE
Oxalis articulata Savigny

PAPAVERACEAE
Papaver macrostomum Boiss. & Huet.ex Boiss.

PLANTAGINACEAE
Veronica hederifolia L.
Veronica pectinata L. var. *pectinata*
Veronica polita Fries.

PLATANACEAE
Platanus orientalis L.

POACEAE
Hordeum murinum L. subsp. *leporinum* (Link) Arc. var. *simulans* Bowden
Hordeum distichon L.
Hordeum vulgare L.
Bromus diandrus Roth.
Agrostis stolonifera L.
Alopecurus vaginatus (Willd.) Boiss.
Lolium perenne L.
Melica ciliata L. subsp. *magnolii* (Gren & Godr) Husnot.
Phleum echinatum Host.

PORTULACACEAE
Portulaca oleracea L.

RANUNCULACEAE
Ranunculus marginatus d'Urv. var. *marginatu*s

ROSACEAE
Rubus sanctus Schreber.

RUBIACEAE
Galium tricornutum Dandy

SALICACEAE
Salix babylonica L.

SOLANACEAE
Solanum nigrum L.

URTICACEAE
Urtica dioica L.

VITACEAE
Vitis vinifera L.

Abbreviations: Ph=phanerophytes; Ch=chamaephytes; H=hemicryptophytes; Th=therophytes; G=geophytes; Euro.-Sib.=Euro-Siberian; Ir.-Tur.=Irano-Turanian; Medit.=Mediterranean; E. Medit.=East Mediterranean; cos.=cosmopolitan; wid.=widespread

References

Akman, Y. (1990). *İklim ve biyoiklim (climate and bioclimate)*. Palme Yayın-Dağıtım, Ankara.

Altay, V., Ozyigit, I. I., & Yarci, C. (2010a). Urban flora and ecological characteristics of the Kartal District (Istanbul): A contribution to urban ecology in Turkey. *Scientific Research and Essays*, *5*(2), 183-200.

Altay, V., Ozyigit, I. I., & Yarci, C. (2010b), Urban ecological characteristics and vascular wall flora on the Anatolian side of Istanbul, *Maejo International Journal of Science and Technology*, *4*(3), 483-495.

Altay, V., Ozyigit, I. I., Osma, E., Bakir, Y., Demir, G., Severoglu, Z., & Yarci, C. (2015). Environmental relationships of the vascular flora alongside the railway tracks between Haydarpaşa and Gebze (Istanbul-Kocaeli/Turkey). *Journal of Environmental Biology*, *36*(1 (Special Issue)), 153-162.

Angeles, P. A. (1981). "Antropocentrism" definition. *Dictionary of philosophy*. Maper & Row, London.

Basaran, B., Soylu, G. N., & Civan, M. Y. (2020). Concentration of phthalate esters in indoor and outdoor dust in Kocaeli, Turkey: implications for human exposure and risk. *Environmental Science and Pollution Research*, *27*(2), 1808-1824.

Beyhan, E. (2007). İzmit'in kent planlamasında ekolojik verilerin değerlendirilmesi, Doktora Tezi, (pp. 1-235). Marmara Üniversitesi, Fen Bilimleri Enstitüsü, Türkiye.

Borda-de-Água, L., Barrientos, R., Beja, P., & Miguel Pereira, H. (2017). *Railway ecology*. (pp. 1-320). Springer Nature.

Brandes, D. (1984). Flora und Vegetation von Bahnhöfen im nördlichen Deutschland. *Acta Botanica Slovaca Academiae Scientiarum Slovacae, Ser. A, Suppl*, *1*, 9-16.

Brandes, D. (2003a). Vascular flora of the Trento railway station (Italy)-some preliminary notes. *Working Group for Vegetation Ecology, Institute of Plant Biology, Technical University Braunschweig, Germany*. 1-8. http://www.ruderal-vegetation.de/epub/

Brandes, D. (2003b). Contributions to the urban flora and vegetation of Strasbourg (France). *Working Group for Vegetation Ecology, Institute of Plant Biology, Technical University Braunschweig, Germany*. 1-14. http://www.ruderal-vegetation.de/epub/

Davis, P. H. (1965-1985). Flora of Turkey and the East Aegean Islands. Vol. 1-9. Edinburg Univ. Press, Edinburg. UK.

Davis, P. H., Mill, R. R., Tan, K. (1988). Flora of Turkey and the East Aegean Islands (Supplement). Vol. 10. Edinburg Univ. Press, Edinburg. UK.

Erken, I. (2015). Tanzimat'tan Cumhuriyet'e Kocaeli sancağının idari yapısı. *Türkiyat Mecmuasi*, *25*(2). 193-236

Eskin, B., Altay, V., Ozyigit, I. I., & Serin, M. (2012). Urban vascular flora and ecological characteristics of the Pendik District, (Istanbul-Turkey), *African Journal of Agricultural Research*, *7*(4), 629-646.

Governorship, (2020). Official Website of Kocaeli Governorship, http://www.kocaeli.gov.tr/ilhk/iltan.php, Last Accessed on September, 2020.

Guner, A., Ozhatay, N., Ekim, T., Baser, K. H. C. (2000). Flora of Turkey and the East Aegean Islands (Supplement 2). Vol. 11. Edinburg Univ.

Press, Edinburg. UK.

Jalas, J. (1995). Hemeroby and hemerochore of plant species. *A terminologyical reform effort Actasoc. Faunaflora Fenn*, *72*, 1-15.

Kose, M., & Ozen, F. Fazıl, (2017). Flora of Hereke (Kocaeli). *Sakarya Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, *21*(6), 1165-1175.

Kowarik, I. (1988). Zum menschlichen Einfluβ auf Flora und Vegetation. Theoretische Konzepte und ein Quantifizierungsansatz am Beispiel von Berlin (West). *Landschaftsentwicklung und Umweltforschung*, *56*, 1-280.

Kowarik, I. (1990). Urban ecology: plants and plant communities in urban environments. *SPB Academica*, 99-103.

Köppen, W., & Geiger, R. (1954). Klima der erde (Climate of the earth). Wall Map 1:16 Mill. Klett-Perthes, Gotha. D. Brandes, "Flora und Veg etation von Stadtmauern", Tuexenia, 1992, 12, 315-319.

Kunick, W. (1987). Woody vegetation in settlements. *Landscape and Urban Planning*, *14*, 57-78.

Mapsworld, (2020). Official Website of Maps of World, https://www.mapsofworld.com/lat_long/turkey-lat-long.html, Last Accessed on September, 2020.

Marshall, B. R. (2018). "Railside habitat- Oxford ragwort flowering (*Senecio squalidus*), and ash saplings (*Fraxinus excelsior*) alongside a railway track. Mainline from Paddington to the west of England, Railways and roadsides (habitat); nr. Shrivenham, Oxfordshire, UK.

Meteorology, (2020). Official Website of State Meteorology Service, https://www.mgm.gov.tr/FILES/iklim/iklim_siniflandirmalari/koppen.pdf, Last Accessed on September, 2020.

Municipality, (2020), Official Website of Kocaeli Municipality, https://www.kocaeli.bel.tr/, Last Accessed on September, 2020.

Nufusu, (2020). Official Website of Turkey's Population Statistics, https://www.nufusu.com/ilce/izmit_kocaeli-nufusu, Last Accessed on September, 2020.

Osma, E., Ozyigit, I. I., Altay, V., & Serin, M. (2010). Urban vascular flora and ecological characteristics of Kadıköy district, Istanbul, Turkey. *Maejo International Journal of Science and Technology*, 4(1), 64-87.

Ozen F., & Acemi A. (2011). Kocaeli'de yayılış gösteren bitkilerin endemikler ve tehlike sınıfları yönünden değerlendirilmesi, *OT Sistematik Botanik*, *18*, 147-189.

Pavlova, D., & Tonkov, S. (2005). The wall flora of the Nebet Tepe Architectural Reserve in the city of Plovdiv (Bulgaria). *Acta Botanica Croatica*, *64*(2), 357-368.

Pietrzyk, M. D., Denisow, B., & Pietrzyk, L. (2019). Asteraceae species as potential environmental factors of allergy, *Environmental Science and Pollution Research 26*(1), 1-11

Sayar, A. (1998). Kent planlamasında ekolojik verilerin değerlendirilmesi-Muğla örneği, (Doktora Tezi), Ege Üniversitesi Fen Bilimleri Enstitüsü, İzmir, Türkiye.

Semerci, A. (2003). Kocaeli ekonomisinde tarım sektörünün yeri, genel yapısı, sorunları ve çözüm önerileri. *Türk-Koop Ekin Dergisi*, *Ankara*, *25*, 63-68.

Severoglu, Z., Altay, V., Keskin, M., Serin, M., & Yarci, C. (2011). Some ecological characteristics and the flora of Glck District and its environs (Kocaeli-Turkey). *Scientific Research and Essays*, *6*(4), 847-875.

Shi, H., Shi, T., Yang, Z., Wang, Z., Han, F., & Wang, C. (2018). Effect of roads on ecological corridors used for wildlife movement in a natural heritage site. *Sustainability*, *10*(8), 2725.

Sukopp, H. (1976). Dynamik und Konstanz in der Flora der Bundesrepublik Deutschland. *Schriftenreihe für Vegetationskunde*, 9-27.

TCDD, (2020). Official Website of Turkish State Railways, http://www.tcdd.gov.tr/, Last Accessed on September, 2020.

Tubives, (2020). Turkish Plants Data Service, http://194.27.225.161/yasin/tubives/index.php?sayfa=karsilastir, Last Accessed on September, 2020.

Yarci, C., & Ozcelik, H. (2002). Wall flora of Edirne (Thrace Region), *Ot Sistematik Botanik Dergisi*, *9*, 57-66.

Yarci, C., Serin, M., & Altay, V., (2007). The segetal vegetation of Kocaeli Province (Turkey), *Ekoloji*, *16*, 23-33.

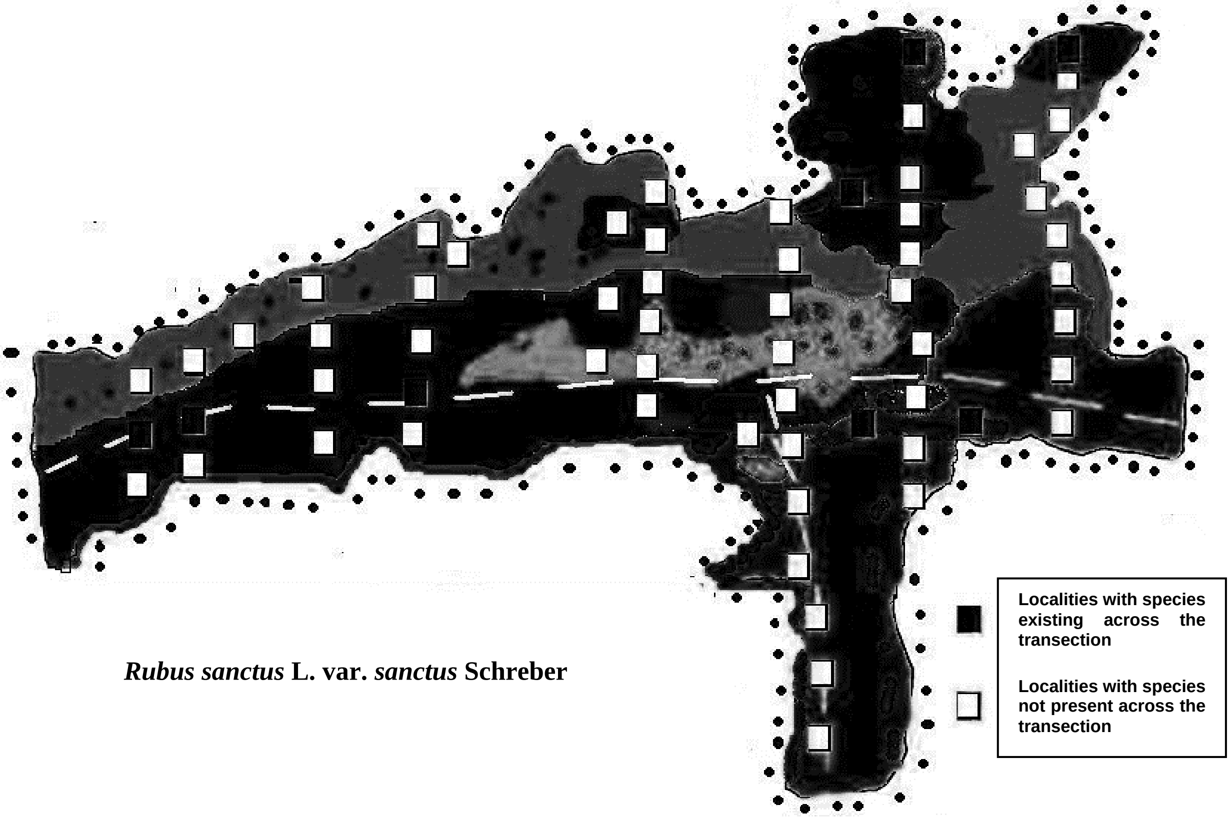
Cite as: Beyhan, E., Yarci, C. & Yilmaz, A. (2020). Investigation of hemeroby degree of vegetation in urban transport areas: the case of İzmit (Kocaeli). *Front Life Sci RT*, *1*(1), 28-34.

Supplementary

Display of taxa on the map, that are common on transects.

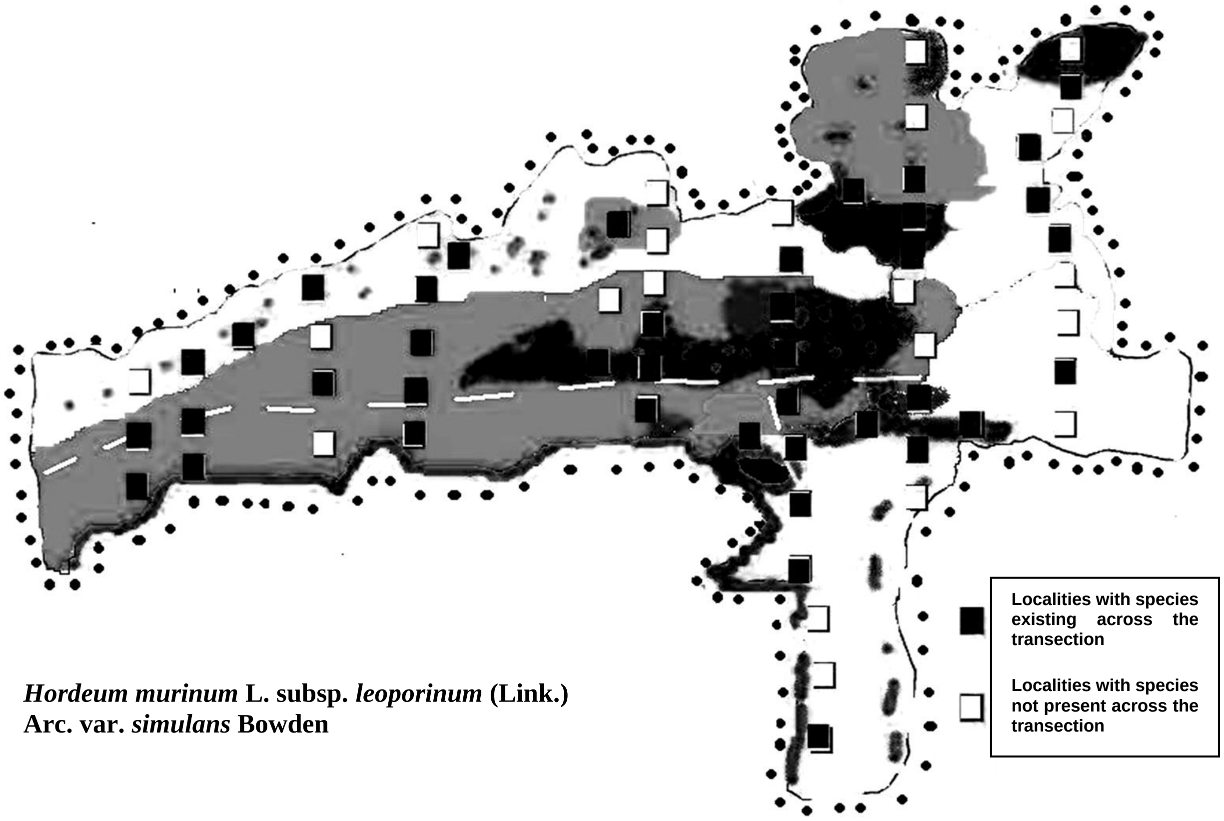
Suppl. Fig. 1. Distribution of *Platanus orientalis* L. in İzmit

Suppl. Fig. 2. *Platanus orientalis* L.



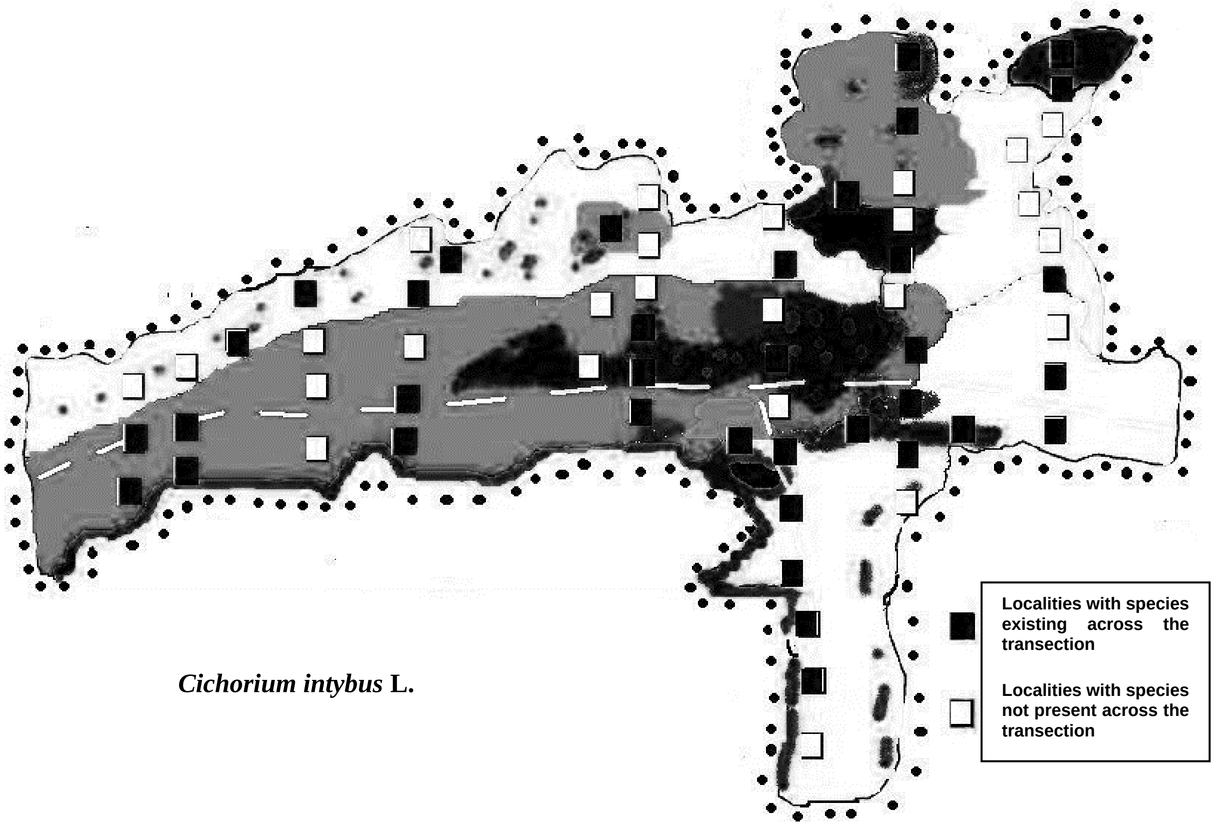
Suppl. Fig. 3. Distribution of *Rubus sanctus* L. var. *sanctus* Schreber in İzmit

Suppl. Fig. 4. *Rubus sanctus* L. var. *sanctus*



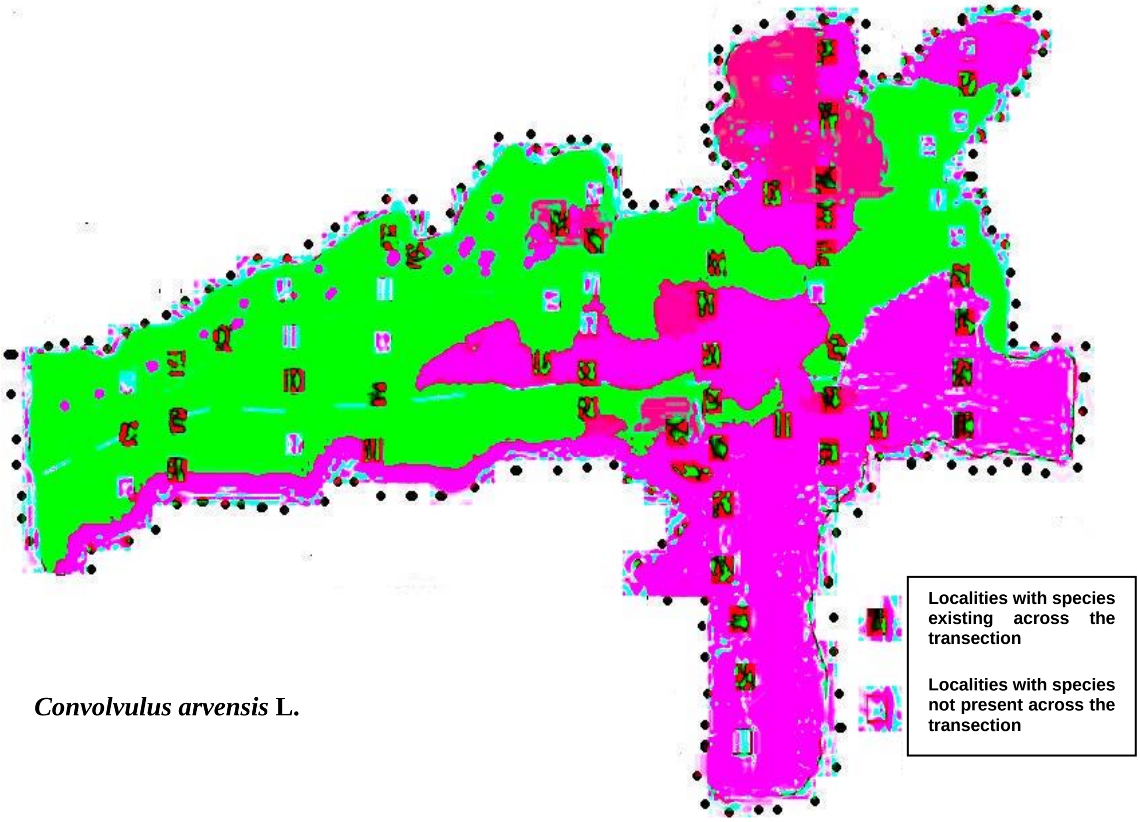
Suppl. Fig. 5. Distribution of *Hordeum murinum* L. subsp. *leoporinum* (Link.) Arc. var. *simulans* Bowden in İzmit

Suppl. Fig. 6. *Hordeum murinum* L. subsp. *leporinum* (Link.) Arc. var. *simulans* Bowden



Suppl. Fig. 7. Distribution of *Cichorium intybus* L. in İzmit

Suppl. Fig. 8. *Cichorium intybus* L.



Suppl. Fig. 9. Distribution of *Convolvulus arvensis* L. in İzmit

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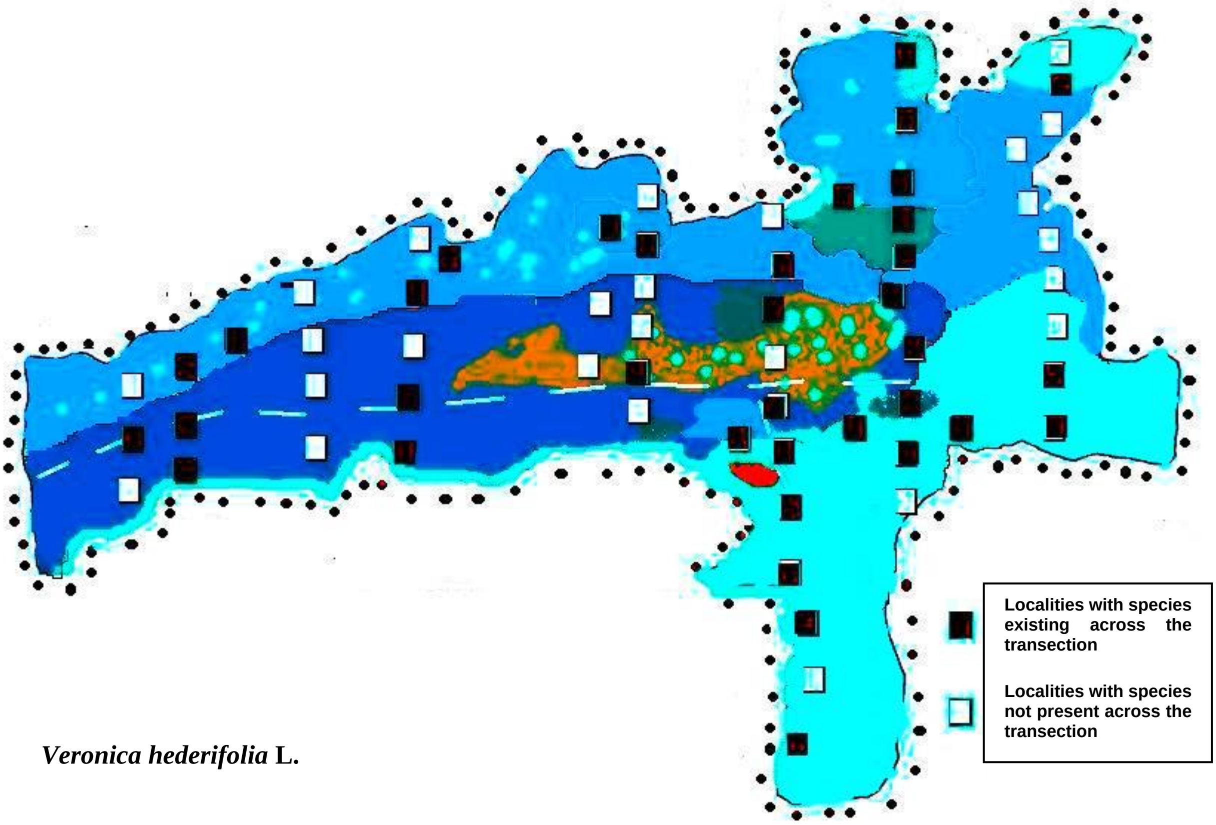
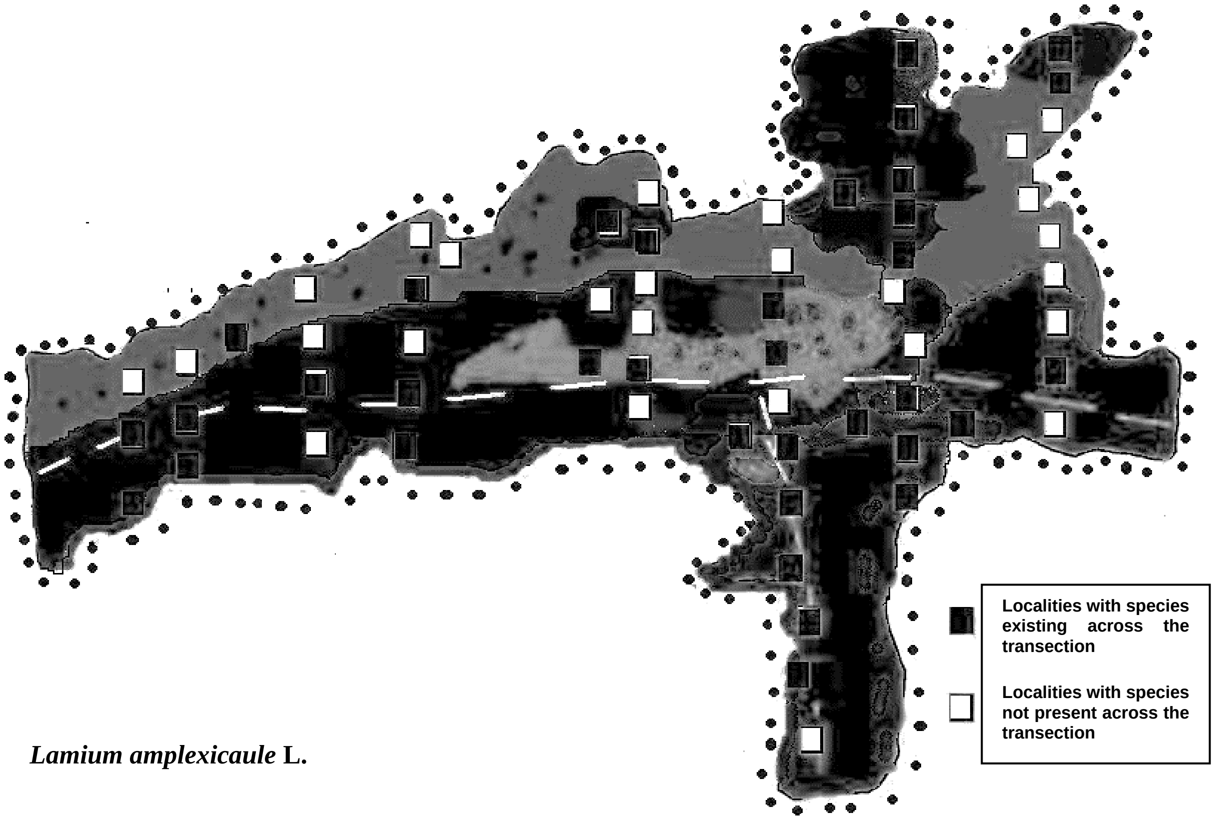
Suppl. Fig. 10. *Convolvulus arvensis* L.



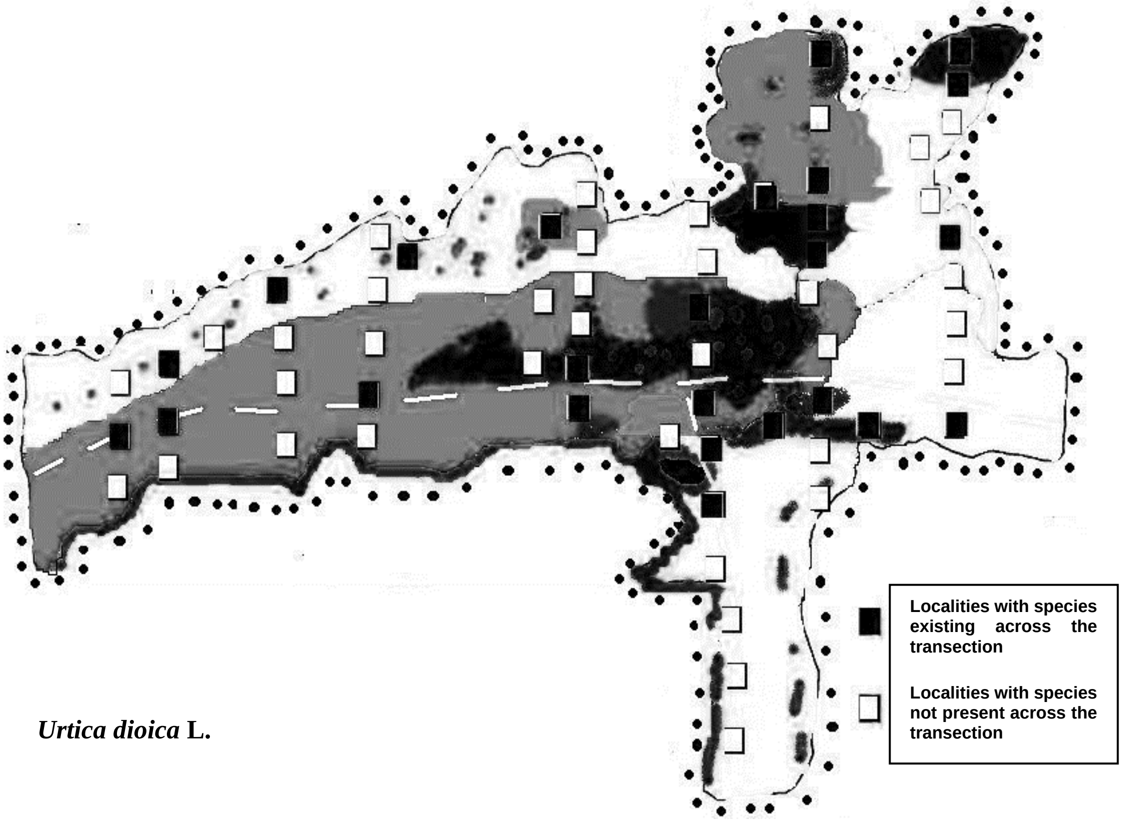
Suppl. Fig. 11. Distribution of *Veronica hederifolia* L. in İzmit

Suppl. Fig. 12. *Veronica hederifolia* L.



Suppl. Fig. 13. Distribution of *Lamium amplexicaule* L. in İzmit

Suppl. Fig. 14. *Lamium amplexicaule* L.



Suppl. Fig. 15. Distribution of *Urtica dioica* L. in İzmit

Suppl. Fig. 16. *Urtica dioica* L.

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Research article

Deposition of heavy metals on coniferous tree leaves and soils near heavy urban traffic

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Abstract

In this study, the heavy metal pollution and its accumulation effects in soil is the major cause. The magnitude and distribution of heavy metal pollution in Istanbul has been investigated by taking soil and plant samples from urban intersections and refuges defined as passive green areas in Ataşehir, Beykoz, Kadıköy, Kartal, Maltepe and Pendik, Sancaktepe, Sultanbeyli, Ümraniye and Üsküdar districts of Anatolian Side of Istanbul Province. Within this scope, 205 leaf samples (3 needle-leaved) and 170 soil samples were collected from 2 different depths (0-20 cm and 40 cm) and samples taked from 17 different passively green area locations. Concentrations of heavy metals such as cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn), which cause pollution in the samples were measured using the ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometer) instrument. The average Cd, Cr, Cu, Ni, Pb and Zn levels for 0-20 cm depth in soil samples were; 6.03, 55.72, 38.01, 48.59, 32.69, 90.30 mg kg^{-1}. For 20-40 cm deep soils, mean values were determined as 6.10, 55.66, 35.11, 49.75, 33.51, 83.85 mg kg^{-1}, respectively. Results show us more than one point samples in different depths and locations exceeded excepting limit values almost every heavy metal.

Keywords: *Soil pollution; roadside soils; roadside plants; Istanbul*

1. Introduction

Under the conditions of rapid urbanization and industrialization, heavy metals are being introduced into the soil environment via atmospheric and water pathways, which is causing an increase in soil heavy metal pollution (Agomuo and Amadi, 2017). Also, air pollution, one of the types of environmental pollution, is a serious problem all over the world threatening the health of all living things through the development of industrial activities. And from the 1900s onwards, heavy metal pollution especially from vehicle emissions seems to have increased significantly (Hawkins et al., 2020). In this context, air pollution can be defined as the presence of pollutants in various forms such as ash, dust, fog, soot, smoke, steam, gas and odor in quantities damaging all existences (Das et al., 2019; Karahan et al., 2020). Air, water and soil, there is a natural balance between them, are like rings of a chain intertwined with each other. For this reason air, water and soil pollution cannot be considered as independent phenomena. The pollution of any one of them means that a ring of the chain is broken which also affects others

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seriously, causing the ecosystem to deteriorate. The acid rains resulting from air pollution and the polluted water reaching the soil and causing soil pollution are examples that can be given in this respect. The pollution of soils, which is very difficult or even impossible to recover when they are lost, appears in a very long time compared to other types of pollution. For this reason, in order not to be late about soil pollution, it is firstly necessary to determine whether the soil in the vicinity is searched for dirt and pollution, if necessary, to take necessary preventive measures and to coordinate with related institutions and organizations (Keshavarzi et al., 2019). Moreover, related institutions should act in coordination with this issue.

The most important agent of air and soil pollution is heavy metals. The term of heavy metal is used for metals with a specific weight greater than 5 g cm^{-3} or for elements with a relatively large atomic number (Hogan, 2010; Ozdemir, 2019). Heavy metals include transition metals from elements that show metallic properties in the periodic system and some elements including a number of nonmetals, lanthanides and actinides (Bediako et al., 2015). Heavy metals are natural components of the environment. However, they have been mixed in soil, water and air as a result of rapid population growth, increased urbanization, industrial facilities, expansion of power plants, local heating systems and motor vehicles. The risk of these metals subjected to human health is very high because these metals have a tendency to be adsorbed, accumulated and biomagnified in the body that can be responsible for various diseases (Herojeet et al., 2015). This type of pollutions has adversely affected all the elements and the continuity of the ecosystem, causing environmental problems to be felt at a significant level (Karaca et al., 2005; Uyar et al., 2009; Dhakal and Kattel, 2019).

Heavy metals tend to accumulate in the soil. Unlike other toxic elements, they cannot be created or destroyed by living organisms (Ozyigit et al., 2019). The accumulation of metal quantities in the soil depends on the previous metal content of the soil, the emission levels, and the transport of metals gathered in the source of pollution to the relevant areas (Ronchi et al., 2019). Heavy metals are kept in the soil in consequence of the adsorption of the soil, chemical reactions and ion exchange (Li et al., 2020). Deposition of heavy metals depends on the amount of organic matter in the soil and on the type of clay minerals (Yin et al., 2020). Most of the metals, along with heavy and trace elements, are necessary for plant growth, but when they are present in high concentrations in the soil, they become harmful and toxic to living things (Ozyigit et al., 2018; Karahan et al., 2020). Especially in plants, the presence of excess amounts of Cd, Hg and Pb metals is seen as a sign of contamination (Hoang et al., 2020).

Plants are important ecosystem components that enable the transfer of substances within the ecosystem between biotic and abiotic environments (Martínez-López et al., 2014). The main source of trace elements in plants is the growth environment. Also, when we scope another harmful effects about heavy metals are, they has been found that there are positive relationships between atmospheric heavy metal accumulation and heavy metal concentrations in plants (Ugulu et al., 2012). Many plant species can accumulate potentially toxic substances in significant amounts (Piczak et al., 2003). *Pinus* sp., *Cedrus* sp. and *Juniperus* sp. were selected for this study because they meet most of the requirements of good bioindicators (Mingorance et al., 2007). The pine has needles with a thick epicutical wax layer that makes the most suitable biodegraders, especially those that are sensitive to environmental pollution (Mingorance et al., 2007; Serbula et al., 2012). Urban trees and shrubs are often used to provide biological isolation in industrial and urban areas, as they play an important role in filtering ambient air by absorbing particulate matter and removing heavy metals (McDonald et al., 2007; Dzierzanowski et al., 2011). To give information about short-term and long-term toxicity levels, plants with higher biological impressions, especially those plants that are green every season, are preferred.

In recent years, many studies have been carried out on determining the type, concentration and sources of heavy metals in roadside dust. For example, heavy metals such as Cd, Cu, Mn, Ni, Pb and Zn have been found to be an important contaminant on roadsides in Istanbul (Sezgin et al., 2004). In a study in Antalya, Cd, Cr, Cu, Pb and Zn and were investigated in coastal areas where marine and motor vehicles affected soil, soil samples taken from relatives of industrial zones and clean areas. Concentrations in the city were found to be quite high compared to clean areas (Guvenc et al., 2003).

Concentrations of Cd, Cu, Mn, Ni, Pb and Zn were investigated in Dhaka city of Bangladesh to determine heavy metal pollution in soil and plants. As a result, it has been understood that industrial solid wastes, wastewater and emissions cause heavy metal pollution around the city of Dhaka (Kashem and Singh, 1999). In Birmingham, UK, roadside heavy metal pollution has been identified in connection with intersections controlled by traffic lights that are likely to regularly stop vehicles (Charlesworth et al., 2003).

In Hong Kong and Jordan, a study has been conducted on some roadside parks and gardens in order to determine the heavy metal pollution in the soil. It is stated that the density of the metals is higher in the samples taken from the parks near the roadside, and there is a significant relation between traffic density and metal concentrations of leaves, soil and dust (Lee et al., 2006). In another study of heavy metal concentrations in plant, soil and air found at the roadside of Jordan, concentrations of Cu, Pb, Cd and Zn heavy metals were investigated. It has been found that automobiles make a great source of these elements around the roadside, so that roadside has a high content of heavy metals in the soil and plants (Jaradat and Momani, 1999).

Herewith, in this study, we aimed to use leaf samples from needle-leaved trees and various soil samples in different depths from passive green areas which may simply entail being open space in urban areas and not usually use for peoples to determine the current concentration of heavy metals in Anatolian Side of Istanbul Province.

2. Material and methods

2.1. Study area

Istanbul has a very important position between the Asia and Europe continents (Ozdemir et al., 2014). Its population is close to 15 million, the number of traffic-driven vehicles is 3 million 651 thousand 166, and this value is increasing day by day. For this reason, one of the biggest causes of environmental pollution in Istanbul is definitely traffic (Unal et al., 2020).

In this study, it is aimed to investigate the size and distribution of the pollution situation in the passive green areas of Istanbul Anatolian side. For this aim, 3 different kinds of plant leaf and 2 different depth soil samples were collected from 17 different locations in Istanbul Anatolia. The representation of these points on the map is given in Figure 1. Leaf samples were determined using available plants in the study areas. Also, soil samples were collected from the environment of all plant species.

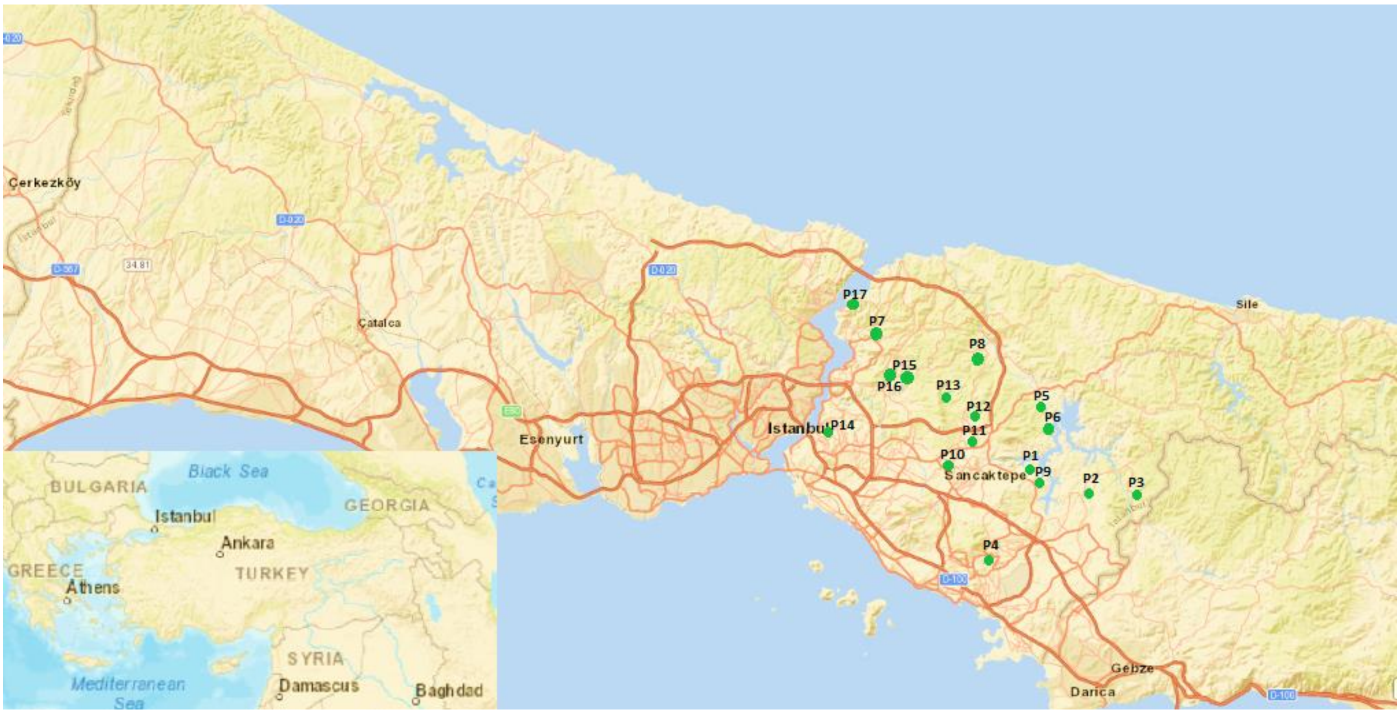

Fig. 1. Location of study areas in Istanbul Anatolian province (ESRİ, Arcgis).

2.2. Experimental study

A total of 28 soil samples were taken from 2 different depths, 0-20 cm and 20-40 cm by using drill tools. The soil study areas are divided into parcels by paying attention to differences such as soil color, area gradient, soil structure and at least one kilogram soil sample is taken to represent each parcel. A total of 51 leaf samples were taken from 3 different plants representing different layers of trees. Leaf samples were determined using available plants in the study areas. Plant species from which leaf samples are taken are as follows: Cedar (*Cedrus* sp.), Pine (*Pinus* sp.) and Juniper (*Juniperus* sp.). The coordinates of the study areas were given in Table 1.

Table 1
The coordinates of the study areas.

Location Code	Latitude	Longitude
P1	40.910219	29.183229
P2	40.924211	29.311629
P3	40.947897	29.310706
P4	40.861408	29.273036
P5	40.919180	29.278118
P6	40.942186	29.302335
P7	40.999386	29.073590
P8	40.979635	29.218200
P9	40.943105	29.216145
P10	40.940880	29.127078
P11	40.951061	29.161613
P12	40.968180	29.139885
P13	40.992566	29.127265
P14	40.987301	29.033883
P15	40.980263	29.077338
P16	41.005469	29.072423
P17	41.106940	29.084599

Taking of samples from the specified regions was carried out in April 2015. Concentrations of Cd, Cr, Cu, Ni, Pb, and Zn causing pollution were determined using ICP-OES instrument within the scope of heavy metal pollution in all samples.

The soil samples were subjected to an oven drying process at an average temperature of 35-40°C by laying them on a non-evaporating and non-hygroscopic tray with a thickness of not more than 15 mm. The soil samples to be analyzed were prepared by grinding with wooden and porcelain mortars and knurls in a such manner that they can pass through the sieve of 2 mm thickness to prevent metal contamination.

0.2-0.3 g of soil samples which are prepared for heavy metal analysis were weighed and transferred to pressure pots with Teflon material and 10 ml of aqua regia (1/3 HNO_3 / HCl) was added. Then, in the temperature-pressure controlled microwave device (BERGHOF Microwave Sting Unit) where the low temperature and high pressure disintegration processes can be performed, the disintegration process was carried out within the compass of the program that lasts one hour and provides gradual temperature increase. Then, the obtained solution was diluted with distilled water at the desired ratio, and the solution was ready for measurement. The solution obtained after the incineration process, after the method works in ICP-OES (Perkin Elmer Optima 2100 DV) instrument, was subjected to heavy metal detection by the method selected by choosing the wave lengths with low background (for Cd: 226.502, for Cr: 267.716, for Cu: 324.752, for Ni: 341.476, for Pb: 220.353 and for Zn: 213.857), low interference and least vibration. Leaf samples were washed with pure water and then dried in a fan-drying oven at a temperature of 65-70°C so that they can be passed through a 0.2 mm sieve. The heavy metal analysis method carried out in the soil samples was exactly applied to the prepared plant samples.

3. Results and discussion

In this study, it has been observed that the highest concentration of heavy metal was Zn (82.06 mg kg^{-1}) at the 10^{th} point, the lowest concentration of heavy metal was Pb (0 mg kg^{-1}) at 10^{th} point and Cd 0 mg kg^{-1}) at 8^{th} point. The highest value was found at the 8^{th} point for Zn (36.43 mg kg^{-1}) and the lowest value was found at the point P8/9 for Cd (0 mg kg^{-1}) and at the point of P8 for Cr (0 mg kg^{-1}) in the leaves of the pine plants. The

Table 2
The heavy metal concentrations of plant leaf samples (mg kg^{-1}).

		Cd	Cr	Cu	Ni	Pb	Zn
***Cedrus* sp.**	**Avg.**	0.16±0.07	16.38±19.57	18.35±10.09	10.49±15.92	5.75±6.89	44.60±22.00
	Min.	0.00 (P8)	3.00(P16)	8.95(P10)	1.73 (P3)	NA (P10)	21.80 (P10)
	Max.	0.38 (P6)	52.78 (P11)	38.88 (P6)	39.27 (P11)	19.33 (P6)	82.06 (P6)
***Pinus* sp.**	**Avg.**	0.11±0.06	9.17±8.21	8.41±3.97	4.06±6.34	2.14±1.40	26.25±6.13
	Min.	0.00 (P8&P9)	0.00 (P8&P9)	2.11(P10)	0.09 (P9)	0.68 (P15)	20.58 (P15)
	Max.	0.22 (P17)	25.71 (P14)	2.80(P9)	16.78 (P14)	4.06 (P29)	36.43 (P8)
***Juniperus* sp.**	**Avg.**	0.10±0.06	11.05±6.91	11.89±4.94	8.88±6.62	8.70±13.55	32.03±18.50
	Min.	0.00(P10)	2.11(P10)	5.79(P10)	1.55 (P1)	NA (P10)	13.69 (P10)
	Max.	0.14 (P4)	18.88 (P13)	18.12 (P15)	14.32 (P13)	29.70 (P5)	61.10 (P5)

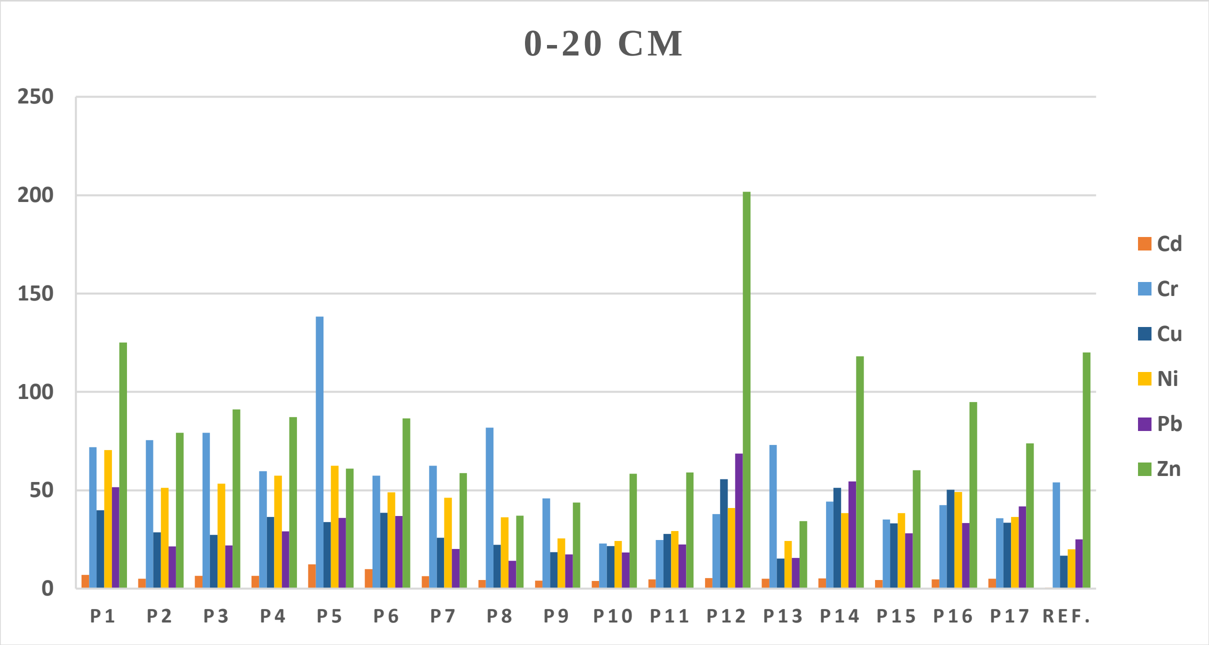

Fig. 2. The heavy metal concentrations of soil samples in the depth range of 0-20 cm (mg kg^{-1}) and compares according to references (Yalcin et al., 2020) values from previous studies.

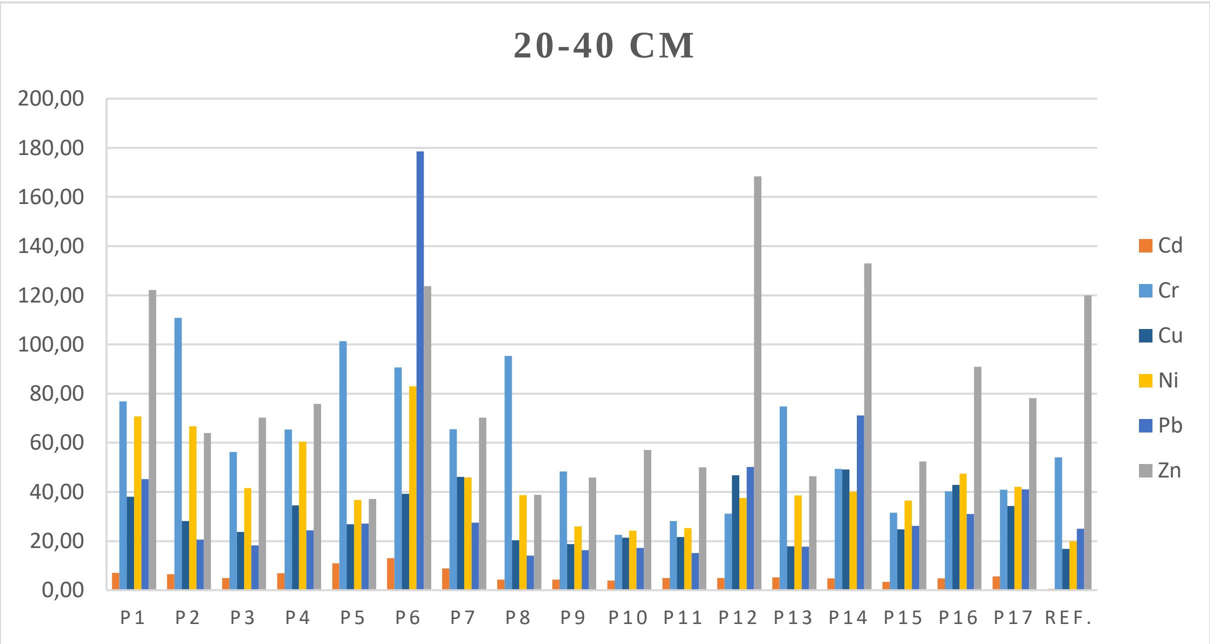

Fig. 3. The heavy metal concentrations of soil samples in the depth range of 20-40 cm (mg kg^{-1}) and compares according to references (Yalcin et al., 2020) values from previous studies.

Table 3
The heavy metal concentrations of soil samples in the depth range of 0-20 cm and 20-40 cm (mg kg^{-1}).

Notation	Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Ni	Pb	Zn
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
P1	6.99±0.6	7.00±1.0	71.82±15.9	76.84±17.9	39.86±6.0	38.05±9.0	70.45±7.6	70.71±8.1	51.52±30.0	45.22±25.0	125.08±20.7	122.15±19.1
P2	5.00±0.2	6.56±2.0	75.41±13.1	110.81±63.6	28.65±6.20	28.09±6.9	51.19±3.6	66.64±23.0	21.49±3.3	20.62±6.5	79.24±28.7	63.93±24.7
P3	6.50±2.2	4.99±1.0	79.22±17.9	56.27±18.5	27.33±6.8	23.75±11.9	53.27±11.0	41.50±14.9	21.99±2.4	18.28±5.5	91.08±5.5	70.24±37.2
P4	6.48±1.4	6.89±1.7	59.68±16.8	65.44±27.4	36.46±6.6	34.58±2.7	57.49±9.9	60.39±19.3	29.07±7.2	24.38±7.0	87.16±9.8	75.78±8.9
P5	12.32±6.4	10.92±2.8	138.30±98.6	101.28±26.7	33.75±8.3	26.80±8.3	62.48±25.2	36.75±10.1	35.88±7.11	27.04±3.5	60.96±9.4	37.11±4.8
P6	9.90±2.5	13.04±1.8	57.49±5.4	90.68±8.9	38.53±1.4	39.24±2.1	49.00±3.6	83.01±6.3	36.98±2.4	178.60±12.3	86.59±7.6	123.70±14.2
P7	6.35±1.2	8.91±2.8	62.53±14.2	65.50±26.5	25.86±12.0	46.15±8.5	46.15±13.4	45.80±21.6	20.23±3.3	27.46±5.6	58.65±29.3	70.26±51.3
P8	4.38±1.0	4.31±1.4	81.78±28.0	95.29±23.2	22.35±7.9	20.38±6.0	36.31±21.4	38.73±18.8	14.14±4.4	14.12±3.6	37.09±18.8	38.81±21.3
P9	3.99±1.4	4.29±1.3	45.80±14.3	48.27±9.5	18.59±10.7	18.77±11.9	25.53±11.4	25.89±15.1	17.31±7.1	16.27±7.2	43.71±24.3	45.82±40.4
P10	3.92±0.7	3.97±0.5	22.95±3.7	22.48±2.9	21.59±0.2	21.37±3.5	24.24±2.1	24.28±2.9	18.34±0.7	17.22±4.2	58.36±3.1	57.08±11.9
P11	4.76±0.1	5.00±0.5	24.73±1.5	28.18±8.9	27.77±1.4	21.59±7.7	29.27±1.0	25.23±5.6	22.40±6.3	15.08±3.3	59.11±0.2	50.02±11.12
P12	5.40±0.6	4.95±1.3	37.96±9.3	31.15±6.0	55.66±14.2	46.81±12.1	40.91±13.4	37.49±10.5	68.64±36.2	50.19±23.5	201.63±88.4	168.43±60.2
P13	4.98±1.1	5.20±1.0	72.99±46.1	74.72±54.8	15.20±3.1	17.80±5.4	24.28±14.8	38.61±24.7	15.67±2.9	17.76±3.6	34.31±2.5	46.43±14.1
P14	5.26±0.9	4.87±1.1	44.29±4.9	49.38±8.5	51.21±25.4	49.12±18.6	38.40±12.6	40.08±9.3	54.55±51.8	71.05±71.2	118.15±104.7	132.94±93.4
P15	4.42±0.8	3.35±0.3	35.14±3.2	31.51±2.0	33.15±3.0	24.75±0.9	38.38±8.8	36.52±4.7	28.10±12.6	26.13±9.2	60.12±10.5	52.40±14.9
P16	4.73±0.6	4.89±0.3	42.52±10.6	40.22±0.8	50.27±7.4	42.85±7.6	49.10±12.0	47.37±13.4	33.34±6.8	31.04±7.7	94.89±14.7	90.86±33.7
P17	5.10±0.3	5.59±0.3	35.74±3.1	40.85±9.6	33.47±3.8	34.27±2.2	36.43±4.3	42.01±13.0	41.72±3.3	40.98±3.8	73.81±4.2	78.09±8.5
Avg.	5.91±2.19	6.16±2.59	58.14±27.99	60.52±27.52	32.92±11.54	31.43±10.67	43.11±13.53	44.77±16.44	31.26±15.44	37.73±39.35	80.58±40.40	77.89±37.78
Min.	3.92	3.35	22.95	22.48	15.20	17.80	24.24	24.28	14.14	14.12	34.31	37.11
Max.	12.32	13.04	138.30	110.81	55.66	49.12	70.45	83.01	68.64	178.60	201.63	168.43

highest values of Zn (61.10 mg kg^{-1}) at the P5 point and the Pb and Cd values (0 mg kg^{-1}) at the P10 and P4 points, respectively, are the lowest values in the leaves of the juniper plants of the selected point. The result of leaf analysis of various plants collected from the study areas is shown in Table 2.

The normal worldwide distributions of the studied heavy metals in mg kg^{-1} in soils are 0.5 global average for Cd; 54 (global average) for Cr (Kabata-Pendias and Mukherjee, 2007; Yalcin et al., 2020). Ni is one of the micronutrients and also a heavy metal (Ozyigit et al., 2018), and it occurs in soils (in mg kg^{-1}) in the range of 0.2-450 with the average between 19-22. The natural Pb concentrations (in mg kg^{-1}) originated from the main rocks in regions between 10 and 40, with a grand average of 25 (Kabata-Pendias and Mukherjee, 2007; Yalcin et al., 2020). According to the literature, the normal limits for Cu (in mg kg^{-1} DW) the Cu contents (in mg kg^{-1} DW) in soils are found to be in ranges of 25-75 (Kabata-Pendias and Pendias, 2001; Dimitrijević et al., 2016).

In researches previously performed in Istanbul, the Zn concentrations (in mg kg^{-1} DW) in co-located soil samples for *Alcea pallida* (Yener and Yarci, 2010), *Hibiscus syriacus* (Yener, 2007), and *Celtis australis* (Ozturk et al., 2017) were found to be as 79.90, 62.53, and between 39.63-122.64, respectively.

In other studies done earlier in our country and abroad, the Zn levels (in mg kg^{-1} DW) in UW leaves and soils were reported as 7.42-19.53 and 35.55-217.00 for *Phoenix dactylifera* in Antalya-Turkey (Aksoy and Ozturk, 1996); 22.08-231.26 and 66.12-1215.25 for *Elaeagnus angustifolia* in Kayseri-Turkey (Aksoya and Sahin, 1999); 13.02-139.0 and 10.67-506.43 for *Robinia pseudoacacia* in Denizli-Turkey (Celik et al., 2005); and 50-151 and 173-576 for *Poa annua* in Bradford-England (Aksoy et al., 1999). According to the literature, the normal limits for Zn (in mg kg^{-1} DW) in plants are reported as 20-150 75 (Kabata-Pendias and Pendias, 2001; Dimitrijević et al., 2016) and the Zn contents (in mg kg^{-1} DW) in soils are found to be in ranges of 3-300 with a grand average of 65 (Kabata-Pendias and Pendias, 2001; Barker and Pilbeam, 2015; Yalcin et al., 2020).

As shown in Table 3, the highest concentrations of pollutants were found to be Zn (201.63 mg kg^{-1}) at the point P12 and Cd (3.92 mg kg^{-1}) at the point P10 when the concentrations of heavy metals in the 0-20 cm depth soil of the selected points were compared. For the depths of 20-40 cm, the highest concentration of heavy metal was found as Pb (178.6 mg kg^{-1}) at the point P6 and the lowest concentration of heavy metal was found as the Cd at the point P15 (3.35 mg kg^{-1}).

Cr, Cu, Ni, Pb, Zn heavy metal analyzes of 0-20 cm and 20-40 cm depth profiles of soil samples taken from 17 different points selected as research areas are shown in Table 3.

In terms of quantity, the heavy metals in the soil taken from the study areas are as follows; Zn> Cr> Ni> Cu> Pb> Cd (Table 3). According to the previous researches determined shown in Figure 2, soil measures shown us there is some important exceed values in the study. For 0-20 cm depth; For Cd, every study points exceed the reference (Barker and Pilbeam, 2015; Yalcin et al., 2020) value which is 0.5 mg kg^{-1}, the highest value was found at the point 5 for Cd (12.32±6.4 mg kg^{-1}) and the lowest value was found at the point 9 for Cd (3.92±0.7 mg kg^{-1}) and an average value for Cd is 5.91±2.19 mg kg^{-1}.

For measures of Cr, 9 study points exceed the reference (Kabata-Pendias and Mukherjee, 2007; Yalcin et al., 2020) value (P1, P2, P3, P4, P5, P6, P7, P8, P13), the highest value was found at the point 5 for Cr (138.30±98.6 mg kg^{-1}) and the lowest value was found at the point 10 for Cr (22.95±3.7 mg kg-

[1]) and average of Cr value is 58.14±27.99 mg kg^{-1}. For measures of Cu, all study points exceed the reference (Kabata-Pendias and Pendias, 2001; Dimitrijević et al., 2016) value except P13, the reference value for Cu is 16.78 mg kg^{-1} and the highest value was found at the point 12 for Cu (1 55.66±14.2 mg kg^{-1}) and the lowest value was found at the point 13 for Cu (15.20±3.1 mg kg^{-1}) and average of Cu value is 32.92±11.54 mg kg^{-1}. For Ni every study point exceeds the reference (Barker and Pilbeam, 2015; Yalcin et al., 2020) value which is 20 mg kg^{-1}, the highest value was found at point 1 for Ni (70.45±7.6 mg kg^{-1}) and the lowest value was found at the point 10 for Ni (24.24±2.1 mg kg^{-1}) and an average value for Ni is 43.11±13.53 mg kg^{-1}.

For Pb over half of the study points are exceed the reference (Kabata-Pendias and Mukherjee, 2007; Yalcin et al., 2020) value which is 25 mg kg^{-1} (P1, P4, P5, P6, P12, P14, P15, P16 and P17), the highest value was found at the point 12 for Pb (68.64±36.2 mg kg^{-1}) and the lowest value was found at the point 8 (14.14±4.4 mg kg^{-1}) and an average of Pb value is 31.26±15.44 mg kg^{-1}. For measures of Zn, only 2 points exceed the reference (Yener and Yarci, 2010) value which is 120.0 mg kg^{-1} (P1 and P12), the highest values was found at the point 12 for Zn (201.63±88.4 mg kg^{-1}) and the lowest value was found at the point 13 for Zn (34.31±2.5 mg kg^{-1}) and an average value for Zn is 80.58±40.40 mg kg^{-1}.

As shown in Figure 3, soil measures have shown us there is some important exceed values in the study. For 20-40 cm depth; For Cd, every study points exceed the reference (Kabata-Pendias and Mukherjee, 2007; Yalcin et al., 2020) value which is 0.5 mg kg^{-1}, the highest value was found at the point 6 for Cd (13.04±1.8 mg kg^{-1}) and the lowest value was found at the point 15 for Cd (3.35±0.3 mg kg^{-1}) and an average value for Cd is 6.16±2.59 mg kg^{-1}. For measures of Cr, 9 study points exceed the reference value (Barker and Pilbeam, 2015; Yalcin et al., 2020). The highest value was found at the point 2 for Cr (110.81±63.6 mg kg^{-1}) and the lowest value was found at the point 10 for Cr (22.48±2.9 mg kg^{-1}) and the average of Cr value is 60.52±27.52 mg kg^{-1}. For measures of Cu, all study points exceed the reference (Kabata-Pendias and Pendias, 2001; Dimitrijević et al., 2016) value, the reference value for Cu is 16.78 mg kg^{-1} and the highest value was found at the point 14 for Cu (49.12±18.6 mg kg^{-1}) and the lowest value was found at the point 13 for Cu (17.80±5.4 mg kg^{-1}) and average of Cu value is 31.43±10.67 mg kg^{-1}. For Ni every study point exceeds the reference (Barker and Pilbeam, 2015; Yalcin et al., 2020) value which is 20 mg kg^{-1}, the highest value was found at point 6 for Ni (83.01±6.3 mg kg^{-1}) and the lowest value was found at the point 10 for Ni (24.28±2.9 mg kg^{-1}) and an average value for Ni is 44.77±16.44 mg kg^{-1}. For Pb, over half of the study points exceed the reference (Kabata-Pendias and Mukherjee, 2007; Yalcin et al., 2020) value which is 25 mg kg^{-1}, the highest value was found at the point 6 for Pb (178.60±12.3 mg kg^{-1}) which is high values.

4. Conclusion

The intersections and the refuges where we are conducting our work are passively green and not actively used by people. Therefore, it is not possible to be directly affected by the pollution that occurs in such areas. However, the soil results show us that there is a very important and dangerous situation that may arise from time to time. The heavy metal values found at the study points are much higher than the exception we selected and at some points already affect heavy metals and some metals have already found all points such as Cd 10 times higher than the reference (Yalcin et al., 2020).

The important thing is that we have passive green areas, especially in cities such as Istanbul, due to the analyzes that have shown us that trees affected, urban life and increasing population every day. As previous studies have shown us that urban life is returning, like cars and factories and they increase the concentration of heavy metals over time.

This study is particularly important for some high heavy metal concentrations (such as P6 for Pb at 20-40 cm or P1 for Ni at 0-20 cm), considerations for subsequent studies. Anyway, as we know, soil deposits could be a thing of the past and could stabilize now, to be sure the analysis should continue at the same points with the methods.

Heavy metals accumulate in the soil causing irreversible soil pollution and affecting the health of all living things. For this reason, necessary precautions should be taken and such studies should be repeated at certain intervals to prevent and control soil pollution.

As a result, it is seen that heavy metal pollution is not in dangerous levels due to the heavy metal concentrations in the general soil of the Anatolian side of Istanbul except Southwest, North and northwest parts for now but the results of soils are threatening and must repeat and improve studies under future technologies and knowledge.

References

Agomuo, E. N., & Amadi, P. U. (2017). Accumulation and toxicological risk assessments of heavy metals of top soils from markets in Owerri, Imo state, Nigeria. *Environmental Nanotechnology, Monitoring & Management*, *8*, 121-126.

Aksoy, A., & Ozturk, M. (1996). *Phoenix dactylifera* L. as a biomonitor of heavy metal pollution in Turkey. *Journal of Trace and Microprobe Techniques*, *14*(3), 605-614.

Aksoy, A., & Sahin, U. (1999). *Elaeagnus angustifolia* L. as a biomonitor of heavy metal pollution. *Turkish Journal of Botany*, *23*(2), 83-88.

Aksoy, A., Hale, W. H., & Dixon, J. M. (1999). *Capsella bursa-pastoris* (L.) Medic. as a biomonitor of heavy metals. *Science of the Total Environment*, *226*(2-3), 177-186.

Barker, A. V., & Pilbeam, D. J. (2015). *Handbook of plant nutrition*. (pp. 1-773). CRC press.

Bediako, J. K., Wei, W., Kim, S., & Yun, Y. S. (2015). Removal of heavy metals from aqueous phases using chemically modified waste Lyocell fiber. *Journal of Hazardous Materials*, *299*, 550-561.

Celik, A., Kartal, A. A., Akdogan, A., & Kaska, Y. (2005). Determining the heavy metal pollution in Denizli (Turkey) by using *Robinio pseudoacacia* L. *Environment International*, *31*(1), 105-112.

Charlesworth, S., Everett, M., McCarthy, R., Ordonez, A., & De Miguel, E. (2003). A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK. *Environment International*, *29*(5), 563-573.

Das, S., Lee, S. H., Kumar, P., Kim, K. H., Lee, S. S., & Bhattacharya, S. S. (2019). Solid waste management: scope and the challenge of sustainability. *Journal of Cleaner Production*, *228*, 658-678.

Dhakal, B., & Kattel, R. R. (2019). Effects of global changes on ecosystems services of multiple natural resources in mountain agricultural landscapes. *Science of the Total Environment*, *676*, 665-682.

Dimitrijević, M. D., Nujkić, M. M., Alagić, S. Č., Milić, S. M., & Tošić, S. B. (2016). Heavy metal contamination of topsoil and parts of peach-tree growing at different distances from a smelting complex. *International Journal of Environmental Science and Technology*, *13*(2), 615-630.

Dzierzanowski, K., Popek, R., Gawrońska, H., Sæbø, A., & Gawroński, S. W. (2011). Deposition of particulate matter of different size fractions on leaf surfaces and in waxes of urban forest species. *International*

Journal of Phytoremediation, *13*(10), 1037-1046.
Guvenc, N., Alagha, O., & Tuncel, G. (2003). Investigation of soil multi-element composition in Antalya, Turkey. *Environment International*, *29*(5), 631-640.
Hawkins, S. J., O'Shaughnessy, K. A., Adams, L. A., Langston, W. J., Bray, S., Allen, J. R., & Firth, L. B. (2020). Recovery of an urbanised estuary: Clean-up, de-industrialisation and restoration of redundant dock-basins in the Mersey. *Marine Pollution Bulletin*, *156*, 111150.
Herojeet, R., Rishi, M. S., & Kishore, N. (2015). Integrated approach of heavy metal pollution indices and complexity quantification using chemometric models in the Sirsa Basin, Nalagarh valley, Himachal Pradesh, India. *Chinese Journal of Geochemistry*, *34*(4), 620-633.
Hoang, H. G., Lin, C., Tran, H. T., Chiang, C. F., Bui, X. T., Cheruiyot, N. K., & Lee, C. W. (2020). Heavy metal contamination trends in surface water and sediments of a river in a highly-industrialized region. *Environmental Technology & Innovation*, 101043.
Hogan, C. M. (2010). Heavy metal. Encyclopedia of Earth. National Council for Science and the Environment. Eds E. Monosson & C. Cleveland, Washington DC. https://editors.eol.org/eoearth/index.php?title=Special%3ASearch&profile=default&search=heavy+metal&fulltext=Search, Last accessed on September 2020.
Jaradat, Q. M., & Momani, K. A. (1999). Contamination of roadside soil, plants, and air with heavy metals in Jordan, a comparative study. *Turkish Journal of Chemistry*, *23*(2), 209-220.
Kabata-Pendias, A. & Pendias, H. (2001). *Trace elements in soils and plants*. 3rd ed., (pp. 1-432). CRC Press, Boca Raton New York, Washington, D.C.
Kabata-Pendias, A. & Mukherjee, A. B. (2007). *Trace elements from soil to human*. (pp. 1-550). Springer, Berlin Heidelberg, New York.
Karaca, F., Alagha, O., & Erturk, F. (2005). Statistical characterization of atmospheric PM_{10} and $PM_{2.5}$ concentrations at a non-impacted suburban site of Istanbul, Turkey. *Chemosphere*, *59*(8), 1183-1190.
Karahan, F., Ozyigit, I. I., Saracoglu, I. A., Yalcin, I. E., Hocaoglu-Ozyigit, A., & Ilcim, A. (2020). Heavy metal levels and mineral nutrient status in different parts of various medicinal plants collected from eastern Mediterranean region of Turkey. *Biological Trace Element Research*, *197*, 316-329.
Kashem, M. A., & Singh, B. R. (1999). Heavy metal contamination of soil and vegetation in the vicinity of industries in Bangladesh. *Water, Air, and Soil Pollution*, *115*(1-4), 347-361.
Keshavarzi, B., Najmeddin, A., Moore, F., & Moghaddam, P. A. (2019). Risk-based assessment of soil pollution by potentially toxic elements in the industrialized urban and peri-urban areas of Ahvaz metropolis, southwest of Iran. *Ecotoxicology and Environmental Safety*, *167*, 365-375.
Lee, C. S. L., Li, X., Shi, W., Cheung, S. C. N., & Thornton, I. (2006). Metal contamination in urban, suburban, and country park soils of Hong Kong: a study based on GIS and multivariate statistics. *Science of the Total Environment*, *356*(1-3), 45-61.
Li, B., Huang, H., Sun, Z., Zhao, N., Munir, T., Yu, W., & Young, B. (2020). Minimizing heavy metals in recovered struvite from swine wastewater after anaerobic biochemical treatment: reaction mechanisms and pilot test. *Journal of Cleaner Production*, 122649.
Martínez-López, J., Carreño, M. F., Palazón-Ferrando, J. A., Martínez-Fernández, J., & Esteve, M. A. (2014). Remote sensing of plant communities as a tool for assessing the condition of semiarid Mediterranean saline wetlands in agricultural catchments. *International Journal of Applied Earth Observation and Geoinformation*, *26*, 193-204.
McDonald, A. G., Bealey, W. J., Fowler, D., Dragosits, U., Skiba, U., Smith, R. I., & Nemitz, E. (2007). Quantifying the effect of urban tree planting on concentrations and depositions of PM_{10} in two UK conurbations. *Atmospheric Environment*, *41*(38), 8455-8467.
Mingorance, M. D., Valdes, B., & Oliva, S. R. (2007). Strategies of heavy metal uptake by plants growing under industrial emissions. *Environment International*, *33*(4), 514-520.
Ozdemir, H. (2019). Mitigation impact of roadside trees on fine particle pollution. *Science of the Total Environment*, *659*, 1176-1185.
Ozdemir, H., Pozzoli, L., Kindap, T., Demir, G., Mertoglu, B., Mihalopoulos, N., & Unal, A. (2014). Spatial and temporal analysis of black carbon aerosols in Istanbul megacity. *Science of the Total Environment*, *473*, 451-458.
Ozturk, A., Yarci, C., & Ozyigit, I. I. (2017). Assessment of heavy metal pollution in Istanbul using plant (*Celtis australis* L.) and soil assays. *Biotechnology & Biotechnological Equipment*, *31*(5), 948-954.
Ozyigit, I. I., Uras, M. E., Yalcin, I. E., Severoglu, Z., Demir, G., Borkoev, B., ... & Solak, A. O. (2019). Heavy metal levels and mineral nutrient status of natural walnut (*Juglans regia* L.) populations in Kyrgyzstan: nutritional values of kernels. *Biological Trace Element Research*, *189*(1), 277-290.
Ozyigit, I. I., Yalcin, B., Turan, S., Saracoglu, I. A., Karadeniz, S., Yalcin, I. E., & Demir, G. (2018). Investigation of heavy metal level and mineral nutrient status in widely used medicinal plants' leaves in Turkey: Insights into health implications. *Biological Trace Element Research*, *182*(2), 387-406.
Piczak, K., Leśniewicz, A., & Żyrnicki, W. (2003). Metal concentrations in deciduous tree leaves from urban areas in Poland. *Environmental Monitoring and Assessment*, *86*(3), 273-287.
Ronchi, S., Salata, S., Arcidiacono, A., Piroli, E., & Montanarella, L. (2019). Policy instruments for soil protection among the EU member states: A comparative analysis. *Land Use Policy*, *82*, 763-780.
Serbula, S. M., Kalinovic, T. S., Ilic, A. A., Kalinovic, J. V., & Steharnik, M. M. (2012). Assessment of airborne heavy metal pollution using *Pinus* spp. and *Tilia* spp. *Aerosol and Air Quality Research*, *13*(2), 563-573.
Sezgin, N., Ozcan, H. K., Demir, G., Nemlioglu, S., & Bayat, C. (2004). Determination of heavy metal concentrations in street dusts in Istanbul E-5 highway. *Environment International*, *29*(7), 979-985.
Ugulu, I., Dogan, Y., Baslar, S., & Varol, O. (2012). Biomonitoring of trace element accumulation in plants growing at Murat Mountain. *International Journal of Environmental Science and Technology*, *9*(3), 527-534.
Unal, Y. S., Sonuc, C. Y., Incecik, S., Topcu, H. S., Diren-Ustun, D. H., & Temizoz, H. P. (2020). Investigating urban heat island intensity in Istanbul. *Theoretical and Applied Climatology*, *139*(1-2), 175-190.
Uyar, G., Avcil, E., Oren, M., Karaca, F., & Oncel, M. S. (2009). Determination of heavy metal pollution in Zonguldak (Turkey) by moss analysis (*Hypnum cupressiforme*). *Environmental Engineering Science*, *26*(1), 183-194.
Yalcin, I. E., Ozyigit, I. I., Dogan, I., Demir, G., & Yarci, C. (2020). Using the Turkish red pine tree to monitor heavy metal pollution. *Polish Journal of Environmental Studies*, *29*(5), 3881-3889.
Yener, S. H. (2007). The biomonitor characteristics of *Alcea pallida* Waldst. et Kit and *Hibiscus syriacus* L. (Malvaceae), Ph.D. Dissertation. Marmara University, Institute of Sciences, Istanbul-Turkey.
Yener, S. H., & Yarci, C. (2010). *Alcea pallida* Waldst. & Kit.(Malvaceae) as a heavy metal biomonitor in Istanbul (Turkey). *Fresenius Environmental Bulletin*, *19*(5a), 1024-1030.
Yin, X., Zhang, L., Harigai, M., Wang, X., Ning, S., Nakase, M., & Takeshita, K. (2020). Hydrothermal-treatment desorption of cesium from clay minerals: the roles of organic acids and implications for soil decontamination. *Water Research*, 115804.

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